

ATTACHMENT E

White Paper: Pioneering MASH

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CHAPTER 4

PIONEERING MANUAL FOR THE ASSESSMENT OF SAFETY HARDWARE (MASH)

This chapter, named “Pioneering MASH,” is a stand-alone white paper which proposes a mini-plan in support of mission statement 2: *develop evaluation standards to support roadside safety innovation and decision making*. This white paper offers a mini-plan under the TCRS strategic plan frame work for achieving a MASH to foster innovation while ensuring changes are made when measurable gains are likely to result.

Crash testing standards have been regularly updated over the past 35 years. Each update resulted from a major research undertaking culminating in new test and evaluation procedures. While many concepts were re-used from the previous documents and some concepts were dismissed, the 2009 edition of MASH represents the most current research available. A major update to MASH is not proposed. It is proposed that MASH be implemented. Upon implementation, monitoring of necessary changes should be undertaken. It is proposed that future changes to MASH be motivated by field observations and the proposed changes to MASH be evaluated prior to implementation to assess the potential for improved safety. Finally, it is proposed that the hardware approval process be evaluated and documented within MASH.

The immediate implementation of MASH will remove the current ambiguity on the use of Report 350 or MASH hardware. Furthermore, it will allow for the evaluation of the current guidance within MASH as MASH compliant devices are deployed rather than considering new guidance before MASH is even fully implemented.

BACKGROUND

This section provides a summary of 2015 TCRS strategic plan, major updates to safety hardware evaluation standards, needed additional updates identified by the community and the 2009 MASH implementation agreement.

TCRS Strategic Plan

The TCRS vision, mission, and objectives, as outlined in the 2015 TCRS strategic plan are provide here for reference.

Vision: Lead roadside policy development, support safety innovations, and be an information resource to promote a decline in lane departure related deaths and serious injuries.

Mission In support of the AASHTO SCOH and SCOD Strategic Plans, (1) develop, implement, and maintain policies which reduce fatal and serious-injury lane departure crashes, (2) develop evaluation standards to support roadside safety innovation and decision making, and (3) monitor the effectiveness of implemented policies and testing standards to assess the progress being made and implement changes as needed to continue moving toward zero roadside fatal and serious-injury lane departure crashes.

Objectives proposed in support of the TCRS vision and three mission statements:

- A. Critique and improve the underlying assumptions within the RDG and MASH through the analysis of field performance and assessment of available data.

- B. Identify standards that are outdated, lacking, or not supported by current data analysis within the current RDG and MASH that should be addressed in upcoming revisions and conduct research to satisfy those needs.
- C. Keeping up with the dynamic changes in roadside policy can be costly (i.e., budget and schedule); make changes to the RDG and MASH when the change is likely to result in measurable gains.
- D. Provide tools which support making design and policy decisions.
- E. Determine the most effective means to communicate the MASH standards and RDG guidance to promote consistency in interpretation and implementation in the field.
- F. Develop and publish a RDG and MASH which are based on quantifiable performance measures and specific design goals.
- G. Identify and implement methods which will foster innovation in hardware development.

Major Updates to Safety Hardware Evaluation Standards

NCHRP Report 230 [Michie81] was published in 1981 to provide guidelines for performing and evaluating full-scale vehicle crash tests. Report 230 did not explicitly include multiple performance or test levels. The so-called “minimum” crash test matrix included small, medium and large passenger cars. Supplemental tests for heavier vehicles such as utility buses (i.e., school buses), small and large intercity buses, tractor trailer trucks and tanker trailer trucks were included.

Report 239 included four service levels for bridge railings and attempted to establish the service levels based on the capacity of the bridge railings based on the Report 230 supplemental tests.

1989 AASHTO Guide Specification for Bridge Railings [AASHTO89] recommended that all bridge railings should be evaluated in full-scale crash tests. A **major change** introduced was the concept of multiple performance levels. The three performance levels used for the first time in an AASHTO guide were:

- PL1 test conditions included the 5,400-lb pickup truck impacting at a speed of 45 mph and an angle of 20 degrees.
- PL2 test conditions increased the speed of the pickup truck test to 60 mph and a test with an 18,000 lb single unit truck impacting the barrier at a speed of 50 mph and an angle of 15 degrees was added to the test matrix.
- PL3 incorporated a test with a 50,000 lb van-type tractor trailer impacting the barrier at a speed of 50 mph and an angle of 15 degrees.
- Two passenger vehicles – a small 1800-lb passenger car and a 5400-lb pickup truck - were common to all three performance levels.

NCHRP Report 350 [Ross93] was published in 1993 with a **major change** of specifying six different test levels for roadside hardware, as follows:

- Test levels 1 through 3 are focused on the impact performance of passenger vehicles, with increasing impact speeds defined for increasing test levels.
- R350 TL3 test consists of a 2,000 kg (4,409 lb) pickup truck impacting a barrier at 100 km/h (62 mph) and 25 degrees, and an 820 kg (1807 lb) small car impacting a barrier at 100 km/hr (62 mph) and 20 degrees.
- R350 TL4 tests include the TL3 tests mentioned above plus an additional test involving an 8,000 kg (17,637 lb) single unit truck impacting the barrier at 80 km/h (50 mph) and

15 degrees. Note: These impact conditions are similar to those associated with PL2 in the 1989 GSBP.

- R350 TL5 tests include the TL3 tests mentioned above plus an additional test involving an 80,000-lb (36,000-kg) van-type tractor trailer impacting the barrier at a speed of 50 mph (80 km/hr) and an angle of 15 degrees.
- R350 TL6 uses the same impact conditions as TL5, but incorporates an 80,000-lb (36,000-kg) tractor-tank trailer.

The Manual for Assessing Safety Hardware (MASH) was published in 2009. [AASHTO09] Changes in vehicle fleet characteristics prompted NCHRP Project 22-14(02), "Improved Procedures for Safety-Performance Evaluation of Roadside Features." MASH includes essentially the same test level approach with some changes to vehicle type and impact conditions for test levels 1 – 4. The selection of test vehicles for test levels 1-3 (passenger vehicle tests) were based on sales data was a **major change**. Other changes included:

- The weight and body style of the small car test vehicle changed from a 820 kg (1807 lb) small car sedan to a 1100 kg (2425 lb) midsize sedan.
- The weight and body style of the pickup truck test vehicle changed from a 2,000 kg (4,409 lb), ¾-ton, standard cab pickup to a 2,270 kg (5,000 lb), ½-ton, 4-door pickup.
- The ballasted weight for the SUT test vehicle increased from 8,000 kg (17,636 lb) to 10,000 kg (22,046 lb).
- The impact angle for the small car was increased from 20 degrees to 25 degrees for test 10.
- The impact speed for the SUT was increased from 80 km/hr (49.7 mph) to 90 km/hr (56 mph).
- The resulting impact severity for TL3 increased by 13.6 percent, and the impact severity for TL4 increased 57 percent compared to Report 350.
- The changes to TL4 (i.e., SUT test) were made because without the change the impact severity for TL4 would be lower than that for TL3. It did not make sense for a higher level test to have the same or lower impact severity.
- The vehicle specifications and impact conditions for TL5 and TL6 have not changed.

Test Levels

FHWA established approximate equivalences between the Report 230 multiple service levels, the three AASHTO GSBP performance levels and the Report 350 test levels in a memorandum to FHWA Regional Administrators in 1997. [Horne97] While no official FHWA crash test equivalencies have been released to compare Report 350 and MASH test levels, Table 1 was developed under NCHRP 22-12(03) for the selection of bridge railings as a way to establish approximate correlations between the test levels used in the past.[Ray13]

Table 1. Approximate Crash Test Acceptance Equivalencies. [after Horne97]

Testing Criteria	Acceptance Equivalencies					
	TL1	TL2	TL3	TL4	TL5	TL6
MASH	TL1	TL2	TL3	TL4	TL5	TL6
Report 350	TL1	TL2	TL3	TL4	TL5	TL6
Report 230		MSL-1 MSL-2†				
AASHTO Guide Spec		PL1		PL2	PL3	

† This is the performance level usually cited when describing a barrier tested under NCHRP Report 230. It is close to TL3 but adequate TL3 performance cannot be assured without a pickup truck test.

Impact Conditions

The practical worst case impact conditions, have “been defined as the combination of the 5th percentile lightest and heaviest passenger vehicles impacting a safety feature at the 85th percentile highest speed and 85th percentile highest angle. This combination of nearly worst case weight, speed, and angle is believed to produce an extremely rare impact event. Nevertheless, these impacts do occur and have been designated as representative of the most severe impact conditions that can be practically accommodated. This definition of the worst practical impact condition was originally implemented for large passenger vehicles with the first set of evaluation guidelines presented in Highway Research Board Circular 482. [TRB62] The precedent established with the first set of guidelines for full-scale crash-testing has been extended through, Transportation Research Circular 191 [TRB78], and NCHRP 230 [Michie81] and 350 [Ross93].” [MASH09]

The base test level for longitudinal barriers, including bridge railings, to be used on the National Highway System (NHS) is Test Level 3 (TL3). Impact speeds and angles for TL3 have traditionally been selected to be equal to the presumed 85th percentile impact speed and 85th percentile impact angle from ran off road crashes. MASH impact speed and angle was found from [TBD]. Report 350 impact speed and angle was found from [TBD]. Report 230 impact speed and angle was found from [TBD]. AASHTO Guide Spec. impact speed and angle was found from [TBD]

Vehicle masses are normally selected to be equal to the 95th and 5th percentile values from the passenger car fleet. MASH reduced the light truck vehicle mass to the 90th percentile and the small car mass to the 2nd percentile of the 2002 new vehicle fleet. MASH notes this was done in recognition of the recent increase in the size of passenger vehicles and the expectation that high gasoline prices might push vehicle masses down,. The vehicle fleet was defined by vehicle sales. Report 350 vehicle fleet was defined from [TBD] data. Report 230 vehicle fleet was defined from [TBD] data. AASHTO Guide Spec. vehicle fleet was defined from [TBD] data.

May 2009 MASH Implementation Agreement

Upon completion of the draft MASH, the FHWA and AASHTO drafted and balloted alongside the 2009 MASH document an implementation agreement. This agreement included bulleted points which have been enumerated here for background information and reference later in this document:

1. The first bullet includes two statements:
 - a. “The AASHTO Technical Committee on Roadside Safety is responsible for developing and maintaining the evaluation criteria as adopted by AASHTO.”
 - b. “FHWA shall continue its role in the review and acceptance of highway safety hardware.”
2. “All highway safety hardware accepted prior to adoption of *MASH* using criteria contained in *NCHRP Report 350* may remain in place and may continue to be manufactured and installed.
3. Highway safety hardware accepted using *NCHRP Report 350* criteria is not required to be retested using *MASH* criteria.
4. If highway safety hardware that has been accepted by FHWA using criteria contained in *NCHRP Report 350* fails testing using *MASH* criteria, AASHTO and FHWA will jointly review the test results and determine a course of action.
5. Upon adoption of *MASH* by AASHTO, any new highway safety hardware not previously evaluated shall utilize *MASH* for evaluation and testing.
6. Any new or revised highway safety hardware under development at the time the *MASH* is adopted may continue to be tested using the criteria in *NCHRP Report 350*. However, FHWA will not issue acceptance letters for new or revised highway safety hardware tested using *NCHRP Report 350* criteria after January 1, 2011.
7. Highway safety hardware installed on new construction and reconstruction projects shall be those accepted under *NCHRP Report 350* or *MASH*.
8. Agencies are encouraged to upgrade existing highway safety hardware that has not been accepted under *NCHRP Report 350* or *MASH*:
 - a. during reconstruction projects,
 - b. during 3R projects, or
 - c. when the system is damaged beyond repair.
9. Highway safety hardware not accepted under *NCHRP Report 350* or *MASH* with no suitable alternatives available may remain in place and may continue to be installed.”
[MASH09]

Knowledge gaps within MASH

Knowledge gaps exist in *MASH* for which research is available. For example, the use of side-impact crash test evaluations was dismissed when *MASH* was published and the acceptance of computer modeling has advanced noticeably since *MASH*'s adoption in 2009.

Ray found that while side impact crashes account for only 9 percent of BCT terminal crashes they represent half of all severe and fatal crashes with BCTs. [Ray00] There are no side impact crash tests recommended in *MASH* for guardrail terminals, crash cushions or support structures. Citing considerable literature on the subjects of side impacts and non-tracking impacts with roadside features (see page 54) [Delays86; Mak92; Ross89; Ray00], *MASH* concedes that crash data analyses shows “...half of all run-off-the road crashes involve non-tracking vehicles in a yawing or sideslip motion at the time of impact. Furthermore, crash data studies also appear to indicate that the impact performance of roadside features can be adversely affected by non-tracking behavior.” [AASHTO09] While the importance of side impacts has been recognized in *MASH*, there are no recommendations that would lead to better roadside designs that include improved side impact protection.

With respect to Computer Modeling, MASH says “it is premature at this time to consider replacing the crash testing recommended herein with computer modeling to evaluate the impact performance of roadside safety features.” [AASHTO09] Computer modeling of crashes, however, has become a standard tool in the development and assessment of roadside safety hardware in recent years. While computer modeling will never “replace” crash testing, the FHWA in 2011 developed a procedure whereby computer modeling can be used to grant eligibility letters for modifications of already crash tested roadside hardware. The FHWA has issued a number of eligibility letters based solely on the results of computer modeling.

In summary, MASH dismisses side impact crash testing even though many of the fatal and severe injury crashes on some types of devices are associated with that crash mode and computer modeling was dismissed in MASH but since 2009 has become a standard method for designing and evaluating the safety performance of hardware. If the goal of MASH is innovative hardware development that improves the safety performance of roadside hardware some guidance ought to be provided for performing side impact crash tests and the appropriate use and role of computer modeling should be addressed in any update to MASH.

PROPOSED PIONEERING APPROACH TO THE SUPPORT OF SAFETY INNOVATION

The proposed approach to a pioneering MASH to support innovation in hardware development are discussed below. It is proposed that MASH be implemented immediately. It is further proposed that when implementing MASH: (1) the hardware assessment and approval process be clarified and documented; and (2) the verification and validation procedures documented in NCHRP Web-Only Report 179 be implemented within MASH as part of the hardware assessment process. It is proposed that the side-impact testing guidelines included in NCHRP 350, but excluded from MASH be updated and included a future update to MASH. While the number of crash tests necessary for hardware development may increase, it is suggested that this increase be offset through the use and acceptance of computer simulations in lieu of physical tests, when appropriate. Finally, it is suggested that to improve crash test quality and the ability of tests to simulate field observations, any future changes to the vehicles used or impact conditions be motivated by field observations.

Implement MASH

It is proposed that the MASH implementation agreement be updated at this time, particularly bullets seven and eight as listed in the background section. It is suggested that bullet nine remain as currently agreed upon. The following edits are suggested:

7. Highway safety hardware installed on new construction and reconstruction projects shall be those accepted under ~~NCHRP Report 350~~ *MASH*.
8. Agencies are encouraged to upgrade existing highway safety hardware that has not been accepted under ~~NCHRP Report 350~~ *MASH*:
 - d. during reconstruction projects,
 - e. during 3R projects, or
 - f. when the system is damaged beyond repair.
9. Highway safety hardware not accepted under *NCHRP Report 350* or *MASH* with no suitable alternatives available may remain in place and may continue to be installed.

Action: Update the MASH implementation agreement to remove the consideration of new installations of NCHRP Report 350 hardware.

Clarify hardware acceptance/approval/eligibility action items

The RDG currently discusses FHWA acceptance letters in section 5.1.1, stating the “longitudinal barriers used on the National Highway System (NHS) should be accepted as crashworthy by the Federal Highway Administration (FHWA).” [AASHTO11] The FHWA, however, states “eligibility letters are provided as a service to the States and are not a requirement for roadside safety hardware to be eligible for reimbursement on Federal-aid highway projects.” [FHWA14]. AASHTO and the FHWA appear to be assigning the responsibility for assessing crashworthiness to each other creating confusion over the role and use of MASH. Currently, it is unclear who is responsible for determining when hardware meets the crash test specification. It is critical that this issue be clarified to allow for that individual or agency to assume responsibility. Continued confusion will allow everybody to evade the responsibly, while clarity will sanction the intended individual/agency to behave dutifully. Three options are proposed for remedying this confusion:

- *Option 1:* States may individually accept as eligible hardware crash tested according to MASH as documented in a crash test report produced by a certified testing lab and stamped by a *Professional Engineer (PE)*. Recall that PEs subscribe to the following canons of ethics:
 - “Hold paramount the safety, health, and welfare of the public.
 - Perform services only in areas of their competence.
 - Issue public statements only in an objective and truthful manner.
 - Act for each employer or client as faithful agents or trustees.
 - Avoid deceptive acts.
 - Conduct themselves honorably, responsibly, ethically, and lawfully so as to enhance the honor, reputation, and usefulness of the profession.” [NSPE14]
- *Option 2:* Ask AASHTO National Transportation Product Evaluation Program to collectively review lab reports presented by certified testing labs stamped by a Professional Engineer (PE) to determine eligibility.
 - *National Transportation Product Evaluation Program (NTPEP)* is a national evaluation and auditing program for manufactured products that assists states with their evaluations of projects, including safety products. [NTPEP14]
 - State members pool resources and develop protocols for work plans.
 - NTPEP provides coordinated evaluations and has a guardrails technical committee. The guardrails committee currently only assesses manufacturing related items at this time.
- *Option 3:* FHWA continues to determine eligibility based on a crash test report submitted by a certified lab and stamped by a PE. AASHTO plays no role in accessing the crashworthiness of hardware or eligibility for federal-aid funding.

Under each of these options, the PE at the testing facility is certifying that the hardware has met the crash testing standard and the States and/or FHWA are reviewing the PE’s work.

Action: *Upon updating the MASH implementation agreement, choose a method to clarify the eligibility process and note the method in the implementation agreement or with a MASH errata.*

Implement the V&V procedures

MASH states that "...without extensive examination of a simulation program's input parameters, it is impossible for another party to critically evaluate the model's accuracy" on page 7. FHWA, however, currently uses the Verification and Validation (V&V) procedures developed under NCHRP 22-24 and published as NCHRP Web-Only Report 179 for assessing changes to hardware already approved.

It is unclear at this time who will determine when hardware has met the crash test specification, but it appears that the field has progressed enough to allow for the implementation of this alternative time and money saving evaluation standard to be implemented within MASH. Employing these procedures would allow the designer to generate a model, predict an outcome, conduct a physical test, and then apply V&V procedures. The model could then be extended to other tests not physically conducted possibly used in lieu of some physical tests or to determine the critical impact point/angle. For example, MASH requires guardrail terminal tests at either 5 or 15 degrees in tests 32 and 33 but provides little specific guidance on which angle should be used in which situation. Computer modeling could provide a way to demonstrate what the critical impact angle is such that a crash test is performed at the critical angle and other angles are assessed by computer modeling. Implementing the V&V procedures into MASH simply acknowledges the state of the practice as FHWA has already incorporated W-179 into its safety hardware evaluation procedures.

Action: *Upon updating the MASH implementation agreement, allow provisions for computer simulations to be used as surrogates for some tests and/or as a means of selecting the most critical tests, provided the V&V procedures are applied and stamped by a licensed professional engineer who is assuming responsibility for the analysis.*

Implement side impact and non-tracking event testing

MASH concedes that crash data analyses shows "...half of all run-off-the road crashes involve non-tracking vehicles in a yawing or sideslip motion at the time of impact. Furthermore, crash data studies also appear to indicate that the impact performance of roadside features can be adversely affected by non-tracking behavior." [AASHTO09] MASH goes on to dismiss this field-confirmed issue for which crash testing guidelines have previously been developed and implemented under NCHRP Report 350 [Ray99; Ray 93] by simply saying "[i]t is anticipated the most large structural supports and terminal and crash cushions would likely fail either of the side impact testing guidelines [developed by Ray and Carney or Ray, *et al.*]." It is illogical that devices being developed for the first time under MASH would not be subjected to side-impact or non-tracking events simply because hardware to satisfy the criteria could not be imagined by the authors at the time of publication. The state-of-the-art in roadside hardware technology will never advance if designers get a "free pass" on challenging impact conditions simply because an earlier generation of designers was unable to solve the problem. If a particular crash scenario is responsible for a large proportion of severe and fatal injuries it is irresponsible to ignore them simply because they are difficult.

It is proposed that the side-impact crash testing guidelines which were published as an appendix to NCHRP Report 350 be updated and published as part of a future update to MASH.

While it is proposed that side-impact and non-tracking events be considered, it is furthered proposed that higher reliance be placed on crash modeling with V&V where appropriate.

Research Needs Statement

- Update the side-impact guidelines and develop a MASH errata suitable for adoption by AASHTO.

Identify methods and procedures to improve the quality of crash tests

Crash tests are the roadside safety equivalent of “experiments” which are conducted to an established standard to ensure repeatability of the tests and comparability between tests. The purpose of the tests is to evaluate the crash-worthiness of the system. The purpose of these initial evaluations are not to capture all possible impact conditions and scenarios but to evaluate all devices under the same impact speeds and angles using the same vehicles. These conditions are presumed to be representative of the impact conditions in the field. Common installation/repair mistakes or maintenance issues are not observed by crash tests. Variability in occupants are not observed in crash tests. The range of vehicle size, impact speed, and angles are thought to be addressed by crash tests but this has not been verified. Each of these variability’s can be assessed through a review of available data.

While these impact conditions can be verified through field observations, it is also critical to review the perceived improvement to safety expected by implementing any changes. Perceived improvements should be documented and the changes justified by a measurable improvement.

Action: *Verify impact conditions with field observation. Justify changes to MASH with by measurable gains to safety.*

Research Needs Statement

- Verify impact conditions used in MASH with field observations.
- A study to verify the vehicle types has been funded. An RFP is anticipated within the 2015 fiscal year.

Summary

A major update to MASH is not proposed, however, it is proposed to update the implementation agreement. It is proposed that the hardware approval process be evaluated and documented within a future update to MASH. Upon implementation, monitoring of any necessary changes to vehicle types, impact angles or speeds should be undertaken. It is proposed that future changes to MASH be motivated by field observations and the proposed changes to MASH be evaluated prior to implementation to assess the potential for improved safety.

CONCLUSION

The proposed vision of the TCRS is to “Lead roadside policy development, support safety innovations, and be an information resource to promote a decline in lane departure related deaths and serious injuries.” The proposed second mission of the TCRS, in support of the vision,

is to “develop evaluation standards to support roadside safety innovation and decision making.” The TCRS strategic plan suggests seven objectives for achieving a pioneering MASH: (1) critique and improve the underlying assumptions within the RDG and MASH through the analysis of field performance and assessment of available data; (2) identify standards that are outdated, lacking, or not supported by current data analysis within the current RDG and MASH that should be addressed in upcoming revisions and conduct research to satisfy those needs; (3) keeping up with the dynamic changes in roadside policy can be costly (i.e., budget and schedule); make changes to the RDG and MASH when the change is likely to result in measurable gains; (4) provide tools which support making design and policy decisions; (5) determine the most effective means to communicate the MASH standards and RDG guidance to promote consistency in interpretation and implementation in the field; (6) develop and publish a RDG and MASH which are based on quantifiable performance measures and specific design goals; (7) identify and implement methods which will foster innovation in hardware development.

It is proposed that MASH be implemented; the hardware assessment and approval process be clarified and documented; and the V&V procedures documented in NCHRP Web-Only Report 179 be adopted into MASH. It is also proposed that the side-impact testing guidelines once included in NCHRP 350, but excluded from MASH, be updated and included as a future MASH errata. In conclusion, to improve the ability of crash tests to represent field situations, any future changes to the vehicles used or impact conditions should be motivated by field observations.

APPENDIX B: RESEARCH NEEDS STATEMENTS

Preliminary suggestions on RNS in support of Mission 2 are shown here.

Title: Update the side-impact guidelines and develop a MASH errata suitable for adoption by AASHTO.

Objective: Evaluate the side impact test and evaluation procedures included in Report 350 and determine if any changes or improvements are required. Document the side impact test and evaluation procedures such that they can be issued as an errata to MASH until MASH is revised at some point in the future.

Title: Verify impact conditions used in MASH with field observations.

Objective: Review available data to determine which/if impact conditions can be culled and make recommendations for improved testing. If available data is not sufficient, make recommendations to collect additional field observations for impact angles and speeds to improve MASH. The objective of this research will be to (1) evaluate available sources of data (2) collect new data only if necessary, and (3) make updated recommendations based on field observations.

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