A proposal to the
WyDOT Research Center

# WYDOT Research Center Proposal

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| **Project Title:** | Pooled Fund for the Development of Approach Guardrail Transitions for Box Beam and MGS (Wyoming, Montana) |
| **WyDOT Project Champion:** | William B. Wilson, P.E.<br>Architectural and Highway Standards Engineer<br>Wyoming Department of Transportation<br>5300 Bishop Blvd<br>Cheyenne, WY 82009-3340<br>(307) 777-4216 \| Email: bill.wilson@wyo.gov |
| **Principal Investigator:** | Roger Bligh, Ph.D., P.E.<br>Senior Research Engineer<br>Texas A&M Transportation Institute<br>Riverside 7091, 3100 State Highway 47<br>College Station, TX 77843<br>(979) 845-4377 \| Email: R-Bligh@tti.tamu.edu |
| **Proposal Date:** | October 5, 2018 |
| **Receiving Agency:** | Wyoming DOT Planning Division<br>Enid White, Research Center Manager<br>5300 Bishop Blvd<br>Cheyenne WY 82009<br>(307) 777-4182 |
| **Proposing Agency:** | Texas A&M Transportation Institute<br>The Texas A&M University System<br>400 Harvey Mitchell Parkway South, Suite 300<br>College Station, TX 77845-4375<br>(979) 862-6777 • (979) 862-3250 fax<br>REF: SRS #1901494 \| Email: awards@tamu.edu |

Texas A&M Transportation Institute

## 9.5 PROBLEM STATEMENT

Periodic changes in the guidelines and procedures for crash testing and evaluation of roadside safety features are necessary to keep current with improvements in technology and changes in the vehicle fleet, and to address issues gleaned from ran-off-road crash data. The American Association of State Highway and Transportation Officials (AASHTO) Manual for Assessing Safety Hardware (MASH) contains revised criteria for safety-performance evaluation of virtually all roadside safety devices.

It was recognized by the Federal Highway Administration (FHWA) and AASHTO that MASH represents an improvement in roadside safety design and that its implementation will result in safety improvements that will save lives. Consequently, a MASH implementation agreement was jointly developed and adopted by FHWA and AASHTO. The implementation agreement establishes compliance dates for use of MASH compliant hardware on the National Highway System (NHS).

Wyoming Department of Transportation (WYDOT) formulated a strategy for meeting the MASH compliance timeline and implementing standards and policies that offer to improve roadside safety in Wyoming. While many of WYDOT's roadside safety devices are considered MASH compliant, some barrier systems have yet to be updated to MASH. The compliance date for transitions, which is the roadside safety hardware category that is the focus of the proposed project, is December 31, 2019. This research is needed to provide crashworthy transitions systems for connection of common barrier types that are MASH compliant.

## 9.6 BACKGROUND STATEMENT

MASH guidelines contain recommended procedures for the testing and evaluation of roadside safety devices. Although significant progress has been made toward MASH implementation, many needs still remain unaddressed. Initial efforts at a national level focused on common types of longitudinal barrier systems such as solid concrete barrier systems and the Midwest Guardrail System (MGS). While WYDOT has benefited from these national efforts, there are some roadside safety systems that are specific to Wyoming or a smaller number of states. As an example, WYDOT uses a significant amount of box beam guardrail because its unique characteristics (e.g., narrow profile and larger ground clearance) help prevent snow drifting and facilitate snow clearing operations. For these same reasons, WYDOT has a need for open steel bridge rail systems instead of solid concrete bridge rail systems at some locations.

Several longitudinal barrier systems used by or of interest to WYDOT are MASH compliant. These include the MGS guardrail system and the Texas Department of Transportation (TxDOT) Type C2P bridge rail system. MASH evaluation of the box beam guardrail system will be completed soon under another WYDOT sponsored research project.

Having addressed WYDOT's guardrail and bridge rail needs, the next priority is to develop MASH compliant approach transitions between the guardrail and bridge rail systems. Properly designed transition systems are required to transition the stiffness from the more flexible guardrail systems to the more rigid bridge rail system in a manner that is crashworthy and provides continuity of protection along the roadside.

Due to their nature, transition systems are specific to the guardrail and bridge rail systems they connect. For example, a transition designed for use with an MGS guardrail has unique components and characteristics that prevent it from being used with a box beam guardrail system. The transition systems that have been evaluated to MASH to date almost exclusively involve a transition from a W-beam guardrail to a solid concrete bridge rail or parapet end. Information on these MASH transition systems can be found in a MASH Crash Test Database sponsored by the Roadside Safety Pooled Fund Program and maintained by Texas A&M Transportation Institute (TTI). Review of this database confirms that there are no systems available that transition an MGS or box beam guardrail directly to an open steel bridge rail system such as needed by WYDOT.

Previous research has developed a MASH compliant TL-3 transition from MGS guardrail to a thrie beam transition section using a non-symmetric W-beam to thrie beam connector section and appropriate post spacing to transition both the stiffness and geometry between the two different rail shapes. Details of this transition can be found in FHWA Eligibility Letter B231 and Research Report TRP-03-210-10. Since the upstream end of the MGS guardrail to thrie beam transition system is MASH compliant, not further research is needed if the tested details are acceptable to WYDOT. The proposed project will, therefore, focus on the downstream end of the transition where it attaches directly to the Type C2P bridge rail. Results from testing of the thrie beam transition attached to a solid concrete parapet (see Research Report TRP-03-175-06) will provide valuable information that can be utilized when developing transition details for attaching the thrie beam to the Type C2P bridge rail.

Currently there are no MASH compliant approach transition systems for box beam guardrail. A MASH TL-3 transition from box beam guardrail to Type C2P bridge rail will need to be developed and tested at both the upstream and downstream ends. The existing WYDOT box beam transition (ref. Standard Plan 606-6A) will be used as a starting point for the development of a MASH compliant box beam transition. The current box beam transition was tested under National Cooperative Highway Research Program (NCHRP) Report 350, which was the predecessor to MASH.

## 9.7 OBJECTIVES

The research objective is to develop two non-proprietary approach guardrail transition systems from box beam and MGS guardrail that are MASH Test Level 3 (TL-3) compliant. The transitions will be designed to connect the guardrail systems to the Texas Department of Transportation (TxDOT) Type C2P TL-4 bridge rail system. Direct connection between the transition section and bridge rail is desired to avoid use of a solid concrete parapet end that could hinder snow clearing operations.

## 9.8 BENEFITS

WYDOT's Mission Statement is to "provide a safe, high quality and efficient transportation system." One of the goals within the mission statement is to "improve safety on the state transportation system." Successful implementation of the transitions in WYDOT's standard plans will provide continuity for an improved level of safety offered by the MASH guardrail and bridge rail systems. Full implementation of MASH compliant roadside safety devices, including transition systems, will provide an enhanced level of safety that will help reduce the severity of lane departure crashes that represent over 75% of highway fatalities.

## 9.9 APPLICABLE QUESTION

The AASHTO/FHWA MASH Implementation Agreement requires state DOTs to provide MASH compliant roadside safety features to obtain federal funding reimbursement on projects let after the implementation date. The implementation date for transition sections is December 31, 2019. This research needs to proceed immediately in order to obtain results prior to the implementation date that can be used to update standard plans.

One of the uncontrollable factors that can affect the project schedule is inclement weather. Inclement weather can potentially delay completion of construction of the test installation or the testing once it has been initiated. If any tests are delayed or postponed due to rain, they will be rescheduled at the earliest available opportunity.

The project schedule includes a considerable amount of time for preparation and delivery of the final report. This is due in part to the requirement for Section 508 compliance and the WYDOT requirement that the final report be submitted at least 6 weeks prior to the project termination date. Upon completion of the full-scale crash testing, the TTI research team will assess the MASH compliance of the transition systems. The research team will transmit these conclusions to WYDOT while the documentation is being prepared. This will enable WYDOT to begin the process of updating the standard plans to incorporate the MASH transition systems.

The transition systems will be non-proprietary in nature. Consequently, none of the data, results, or report produced under the project will be considered confidential or sensitive, nor will it be copyrighted, patented, or trademarked.

## 9.10 STATEMENT OF WORK

### 9.10.1 Work Plan/Scope

The work plan for the proposed project consists of seven tasks that relate to the design, analysis, testing, evaluation, and documentation of two transition systems from approach guardrail to a bridge rail. Details of these tasks are described below.

***Task 1: Transition Design***

The scope of the project involves developing and testing two, non-proprietary, MASH TL-3 guardrail approach transitions to the TxDOT Type CP2 bridge rail. Under this task, the research team will develop initial designs for both transition systems. One system transitions from a box beam guardrail to the Type CP2 bridge rail and the other system transitions from an MGS W-beam guardrail to the same bridge rail. The Type CP2 bridge rail is a 42-inch tall system that has three steel longitudinal rail members attached to fabricated steel posts mounted on a concrete curb.

The purpose of the transition section is to transition the stiffness from the more flexible approach guardrail to the more rigid bridge rail. This creates two distinct transition points that need to be considered in the design process. The first is the transition from the approach guardrail to the upstream end of the transition section. The second is the transition from the downstream end of the transition section to the bridge rail.

The design of the downstream transition point involves connection to the bridge rail. The research team will design both transition systems to directly connect to the Type C2P bridge rail. The design of the connection details will include consideration of strength to resist impact loads and geometry to reduce vehicle snagging potential from both directions of travel (i.e., onto and off of the bridge structure). This will likely involve the use of connection plates with appropriate tapers. The termination of the upper bridge rail member will also need to be addressed to mitigate vehicle snagging potential.

Curbs can be a useful design element beneath the transition section in proximity to the bridge rail to help reduce potential for wheel snagging during an impact. However, the research team will design the transitions to function without a curb under the approach guardrail. Additionally, the 9-inch tall bridge rail curb onto which the steel rail is mounted will likely need to be tapered at the bridge end to further reduce vehicle snagging potential.

The research team will include consideration of post size, post spacing, and post embedment depth in the design of the transitions. The research team will assess the need for a lower rubrail element below the primary transition rail.

After completion of the engineering design, the research team will prepare and submit the detailed drawings of the recommended transition systems to WYDOT for review and approval.

***Task 2: Finite Element Modeling & Simulation***

The research team will model the approved transition designs for both the box beam and MGS guardrail systems for use in simulations to help assess impact performance and ability to meet MASH criteria. The finite element models will include detailed representation of the Type C2P bridge rail, transition section, approach guardrail, and terminal system. The soil will be explicity modeled to capture post-soil interaction. A concrete failure model will be incorporated at the end of the bridge rail curb to capture possible damage at the bridge rail post location from the impact loads. The TTI research team has developed material models for many common guardrail components such as W-beam, thrie beam, and W6x8.5 steel posts. Material properties for other components will be obtained through the literature.

Existing vehicle models representative of MASH design vehicles will be used in the simulations. These include models of a Chevrolet Silverado pickup truck and Toyota Yaris passenger car that were initially develop by the Federal Highway Administration (FHWA). These models have been modified by TTI researchers over the course of numerous simulation efforts to address identified issues (e.g., contact problems) and enhance reliability, robustness, and accuracy. Although the vehicle make and model of the available finite element vehicle models do not match what is used in full-scale crash testing, they do meet the MASH vehicle specifications.

A significant limitation that still exists with the vehicle models is the absence of validated suspension failure modes. Snagging contact on posts or other elements of a barrier system often result in failure of various components of the vehicle suspension and wheel assembly. Thus, predictive accuracy of simulations can be dependent on the severity of snagging that occurs during an impact. This becomes more of an issue as the stiffness of the barrier system increases. This limitation will be considered as results of the simulations are analyzed and assessed.

The impact simulations will be performed using LS-DYNA following MASH impact conditions. LS-DYNA is a commercially available, explicit finite element code developed and maintained by Livermore Software Technology Corporation (LSTC). LS-DYNA is well suited for performing dynamic impact analyses and has become the standard in the roadside safety design community. TTI researchers have decades of experience with this code and, more specifically, the modeling and simulation of impacts into roadside safety barriers.

The MASH test matrix for transitions includes two tests. Test 3-21 involves a 5,000-lb pickup impacting the transition at a speed of 62 mph and an angle of 25 degrees. Test 3-20 involves a 2,420-lb passenger car impacting the transition at a speed of 62 mph and an angle of 25 degrees. Impact simulations of both tests will be performed for both transition systems near the bridge end. Additional simulations of both tests will also be performed to evaluate the impact performance on the upstream end of the box beam transition. If a variation of a thrie beam transition system is used for the MGS guardrail as proposed, simulations at the upstream end will not be necessary due to availability of prior full-scale crash testing performed under previous research.

The results of the simulations will be analyzed to assess ability to comply with MASH criteria. Factors of interest include vehicle containment, vehicle stability, dynamic deflection, snagging occurrence and severity, and occupant risk.

The research team will recommend design modifications if needed to address any identified concerns or deficiencies. The research team will submit any recommended design changes to WYDOT for review and approval. Upon approval, the transition model will be modified and an impact simulation will be performed to reassess impact performance and determine the effectiveness of the design change.

### *Task 3: Test Installation Construction*

Once the details of the transition systems have been finalized through simulation and approved by WYDOT, the research team will develop and submit the detailed construction drawings for the test installations for review and approval. After approval of the test installation drawings, the test installation will be constructed at the TTI Proving Ground. The test installation will include at least 17 ft. of bridge rail per MASH Section 3.4.2.1. The bridge rail section will be anchored to a moment slab. A transition, approach guardrail, and terminal will be attached to each end of the bridge rail section. This will reduce repair requirements and help expedite execution of the testing matrix.

The research team proposes to construct the box beam transition first. As mentioned, a box beam transition will be constructed on each end of the bridge rail section with an appropriate length of approach guardrail attached. The guardrail will be anchored with a Type 1 end anchorage. After completion of the test installation, the box beam transition will be tested and evaluated under Task 4.

### *Task 4: Full-Scale Crash Testing – Box Beam Transition*

The full-scale crash testing will be performed at the Texas A&M Transportation Institute (TTI) Proving Ground facility, an International Standards Organization (ISO) 17025-accredited laboratory with American Association for Laboratory Accreditation (A2LA) Mechanical Testing Certificate 2821.01. The research team will perform the full-scale crash tests according to TTI Proving Ground quality procedures, and according to MASH guidelines and standards.

As previously discussed, the MASH test matrix for transitions includes two tests: Test 3-21 and Test 3-20, with the pickup truck and small passenger car, respectively. The research team will perform both tests at both the upstream and downstream ends of the transition for a total of four full-scale tests.

The crash tests on the box beam transition will be performed in the most critical order. Current thinking of the researchers is that Test 3-21 will be performed on the downstream end of the box beam transition (i.e., transition section to bridge rail section) on one side of the bridge rail section first. This will be followed by Test 3-20 on the downstream end of the transition on the opposite side of the bridge rail section.

After the tests on the downstream end have been completed, the bridge rail section and both box beam transition installations will be repaired. It is likely that the repair of the bridge rail section will include repair of the end of the concrete bridge rail curb from post-induced damage.

After repair of the test installation and curing of any concrete used in the repair, two full-scale crash tests will be performed on the upstream end of the box beam transition (i.e., approach guardrail to transition section). Test 3-21 will be performed on the upstream end of the box beam transition on one side of the bridge rail section, followed by Test 3-20 on the upstream end of the transition on the opposite side of the bridge rail section.

### *Task 5: Full-Scale Crash Testing – MGS Transition*

After completing the testing on the box beam transition, the bridge rail section will be repaired as needed and the box beam transitions, approach guardrail, and end anchorage sections will be removed. MGS transitions will be constructed on each end of the bridge rail section with an appropriate length of approach guardrail attached. The MGS guardrail will be anchored with a TxDOT Downstream Anchor Terminal (DAT).

Test 3-21 will be performed on the downstream end of the box beam transition (i.e., transition section to bridge rail section) on one side of the bridge rail section first. This will be followed by Test 3-20 on the downstream end of the transition on the opposite side of the bridge rail section.

If a variation of a thrie beam transition system is used for the MGS guardrail as proposed, full-scale crash testing at the upstream end will not be necessary if the details conform to those crash tested under previous research.

### *Task 6: Final Report*

At the conclusion of the full-scale crash testing, the research team will prepare and submit a final report to WYDOT. The final report will fully document the research effort, including transition design, transition modeling and simulation, full-scale crash testing, and assessment of MASH compliance.

The research team will submit the final report to WYDOT at least six weeks prior to the termination of the contract per WYDOT requirements. As required, the report will adhere to the standards for preparation and publication of scientific and technical reports as outlined in the FHWA *Communications Reference Guide (CRG)* updated February 24, 2017. In conformance with WYDOT policy, the final report will be written in compliance with Section 508 of the Rehabilitation Act of 1973 to make it accessible to persons with disabilities, including those persons with vision, hearing, cognitive, and mobility impairments. This will include development of Section 508 descriptions for all non-text elements, including but not limited to every photo, chart, graph, pie chart, flow chart, diagram, and equation.

### *Task 7: FHWA Eligibility Request*

Under this task, the research team will prepare a request for FHWA funding eligibility package for each transition system for submittal by WYDOT. In addition to the final report prepared under Task 6, the FHWA eligibility request package for each transition system will include FHWA Office of Safety *Form to Request Federal Aid Reimbursement Eligibility of Safety Hardware Devices (version 10.0)*, drawings of the test installation, high-speed and real-time video of the crash tests performed, and photographs of the test installation and test vehicle before and after each test.

The research team will submit a complete FHWA eligibility request package for each transition system to WYDOT for review and approval and subsequent submission to FHWA Office of Safety. It should be noted that the FHWA Office of Safety will only review eligibility requests for roadside safety devices that have been subjected to the full suite of MASH crash tests for that category of device. The proposed work plan, if successful, will satisfy this requirement for both the box beam and MGS transition systems.

## 9.10.2. Work Schedule

| | | | | | | | | | | | | | | | | **Budget** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Months** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | |
| Task 1: Transition Design | | | | | | | | | | | | | | | | | $26,799 |
| Task 2: Finite Element Modeling & Simulation | | | | | | | | | | | | | | | | | $61,385 |
| Task 3: Test Installation Construction | | | | | | | | | | | | | | | | | $53,132 |
| Task 4: Full-Scale Crash Testing – Box Beam Transition | | | | | | | | | | | | | | | | | $175,418 |
| Task 5: Full-Scale Crash Testing – MGS Transition | | | | | | | | | | | | | | | | | $88,417 |
| Task 6: Final Report | | | | | | | | | | | | | | | | | $35,151 |
| Task 7: FHWA Eligibility Request | | | | | | | | | | | | | | | | | $5,274 |
| | | | | | | | | | | | | | | | | **Total:** | **$445,576** |

### Key Milestones

| Tasks | Description | Timeline |
|---|---|---|
| Kick-Off Meeting | Web meeting to discuss project work plan and any design constraints to be considered under the project. | |
| Progress Reports | Progress Reports due to WYDOT's Research Manager electronically. Brief reports approximately 3-4 pages in length. | Due to RAC on or before the final calendar day in January, April, July, and September. |
| Task 1 | Transition Design | 1.5 months |
| Task 2 | Finite Element Modeling & Simulation | 5 months |
| Task 3 | Test Installation Construction | 2 months |
| Task 4 | Full-Scale Crash Testing – Box Beam Transition | 1 month |
| Task 5 | Full-Scale Crash Testing – MGS Transition | 1 month |
| Task 6 | Final Report<br>Due six weeks prior to contract term. Submit to Research Manager in electronic version (CD in PDF/Word format or electronically via e-mail, drop box or other document-sharing site). Written in compliance with Section 508 requirement. | 4.5 months |
| Task 7 | FHWA Eligibility Request | 0.5 month |
| | **Proposed Project Duration** | **15.5 months** |

*Timeline for Final Report includes six weeks review.

## *9.11. BUDGET*

| | Budgeted Amount by Tasks | | | | | | | Total Cost |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
| **Direct Cost** | | | | | | | | |
| Total Personnel Costs | | | | | | | | |
| Principal Investigator | 5,296 | 4,413 | - | 14,124 | 7,062 | 7,944 | 1,765 | **$40,604** |
| Other Personnel | 5,287 | 21,953 | - | 11,316 | 5,658 | 3,898 | - | **$48,112** |
| Fringe Benefits | 2,608 | 6,514 | - | 5,680 | 2,840 | 2,813 | 366 | **$20,821** |
| Research Travel | - | - | - | - | - | - | - | **$0** |
| Report Generation | - | - | - | 202 | 101 | - | - | **$303** |
| Other Direct Costs | - | - | 23,542 | 1,960 | 980 | - | - | **$26,482** |
| Other Direct Costs (non-idc) | 7,210 | 12,558 | 18,172 | 125,994 | 63,705 | 13,388 | 2,109 | **$243,136** |
| **Technical Transfer** | | | | | | | | **$0** |
| Conferences/Report | | | | | | | | **$0** |
| Presentation | | | | | | | | **$0** |
| Miscellaneous Travel | | | | | | | | **$0** |
| **Total Direct Costs** | **20,401** | **45,438** | **41,714** | **159,276** | **80,346** | **28,043** | **4,240** | **$379,458** |
| Modified Total Direct Cost (MTDC) | 13,191 | 32,880 | 23,542 | 33,282 | 16,641 | 14,655 | 2,131 | **$136,322** |
| IDC @ 48.5% of MTDC | 6,398 | 15,947 | 11,418 | 16,142 | 8,071 | 7,108 | 1,034 | **$66,118** |
| **TOTAL** | **26,799** | **61,385** | **53,132** | **175,418** | **88,417** | **35,151** | **5,274** | **$445,576** |

Because the Montana DOT is interested in adopting the same bridge rail as Wyoming, they also have a shared interest in developing approach guardrail transitions. They have proposed joining WYDOT in a pooled fund effort. Montana has already committed $250,000 of their SPR funds to this project, with the caveat that if we should experience a failing crash test or other setbacks which would result in increased costs to the project, WYDOT would provide the necessary supplemental funding, most likely through supplemental state funds.

TTI Costs = $ 445,576
Montana Contribution = - $ 250,000
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WYDOT Balance = $ 195,576
Travel for 1 to attend
crash tests = $ 1,500

**Total Request to WYDOT RAC = $ 197,076**
**=========**

**This project cannot be broken up into phases. The final deadline to begin using MASH hardware is December 31, 2019, so time is of the essence.**

## 9.12. IMPLEMENTATION

This research is a necessary step in WYDOT's efforts to implement the AASHTO Manual for Assessing Safety Hardware (MASH) to enhance roadside safety and reduce the severity of run-off-road crashes. AASHTO and FHWA have jointly adopted an implementation plan for MASH to continue to advance the performance of roadside safety devices.

This project addresses one important element of roadside safety – the transition from an approach roadside guardrail to a bridge rail. The guardrail, bridge rail, and the transitions between them must meet specific impact performance criteria. This research project will develop crashworthy, MASH compliant transition systems for two specific guardrail systems: box beam guardrail and MGS guardrail.

The results of the research can be implemented through the issuance of updated WYDOT standard plans through the . This will make the new MASH transition systems available for use in highway project plans and lettings. Specifically, the MASH box beam guardrail transition system will supersede Standard Plan 606-6A *Transitions A&B to TL-3 and TL-4 Steel Bridge Rails*. Similarly, the MASH MGS guardrail transition system will supersede Standard Plan 606-6A *Transition B to TL-4 Steel Bridge Rail*. Detailed drawings developed for each transition system under the research project will serve as the basis for updating the relevant standard plans.

## 9.13. TECHNOLOGY TRANSFER

As described in the implementation plan, the new MASH transition systems will be implemented through the issuance of updated standard plans. The information for updating the standard plans will be contained and transmitted in detailed drawings developed for each transition system. These detailed drawings will be incorporated into the final report and also electronically transferred to WYDOT in the preferred file format.

Additionally, the results of the testing of the transition systems will be included in a MASH Crash Test Database sponsored by the Roadside Safety Pooled Fund Program and maintained by TTI. This will help transfer the technology to other potential users. The results of the research will be further disseminated through presentations at key technical meetings such as Transportation Research Board (TRB) Committee AFB20 *Roadside Safety Design*.

## 9.14. DATA MANAGEMENT PLAN

Various data will be collected during the crash testing to assist with the assessment and documentation of the impact performance of the transition systems evaluated under the project. This data will include high-speed and real-time video, photographs of the vehicle and test article before and after each test, data sheets that document vehicle dimensions and record damage to the vehicle and test article after each test, and electronic data that includes acceleration time histories and angular velocity time histories measured for all three primary axes of the vehicle during each test. This data will be used to assess compliance with MASH evaluation criteria and document the results of the test in the final report.

The TTI Proving Ground will archive all data and information related to the tests. The data has redundant backup on offsite servers. This data and information will be retained indefinitely. WYDOT will be notified should there be a change in the TTI data retention policy that effects the storage of the data. If such a circumstance arises, WYDOT will be given the opportunity to obtain all test data.

**RESEARCH STAFF**

An exceptionally qualified research team has been assembled with the necessary experience and expertise to successfully perform the proposed project. The research team consists of Dr. Roger P. Bligh, Mr. Nauman Sheikh, Mr. Lance Bullard, Mr. Matt Robinson, Mr. James Kovar, and Mr. Nathan Schulz. These individuals are all well qualified for the work to be done, as demonstrated by their expertise and previous accomplishments in the areas of roadside safety design, simulation, testing, and evaluation. Members of the proposed research team are intimately familiar with the guidelines and procedures set forth in the AASHTO Manual for Assessing Safety Hardware (MASH), and recently were instrumental in the development of the 2nd edition of MASH that just recently published in December 2016. They have conducted numerous full-scale crash tests following MASH procedures and guidelines. A summary of their experience and their roles in the proposed project is provided below.

The project team will be supported by the TTI Proving Ground. The staff of the TTI Proving Ground has extensive expertise and experience in conducting full-scale crash tests. They will assist with construction and installation of test articles, preparation and instrumentation of the test vehicle, photographic documentation, data collection and analysis, and evaluation and reporting of test results. The TTI Proving Ground has conducted thousands of crash tests over the last 50 years and is one of the leading crash testing facilities in the world.

**Roger P. Bligh, Ph.D., P.E.**
Senior Research Engineer
Texas Transportation Institute, TAMUS 3135
Roadside Safety and Physical Security Division
College Station, TX 77843-3135
Phone: (979) 845-4377 E-mail: r-bligh@tti.tamu.edu

Dr. Bligh is a Senior Research Engineer and Manager of the Roadside Safety Program at TTI. He holds both a Master of Science and Ph.D. in Civil Engineering from Texas A&M University, and is a registered Professional Engineer in Texas. Dr. Bligh has 32 years of experience in the field of roadside safety. He has served as principal investigator or co-principle investigator on numerous studies sponsored by NCHRP, FHWA, various state agencies, and private concerns having a combined budget of over

$28 million. Dr. Bligh received the designation of Regents Fellow in 2009, which is the highest honor awarded by the Texas A&M University System based on exceptional contributions in scholarship, research, and service that have resulted in significant impact and lasting benefits to the state of Texas and beyond.

Dr. Bligh has extensive experience in applied research dealing with the design, analysis, testing, and evaluation of highway safety structures and the development of guidelines for the use, selection, and placement of these structures. He has co-authored more than 210 publications in this area. Dr. Bligh has made contributions to the design of numerous roadside safety devices including breakaway sign supports, work zone signs, work zone traffic control devices, guardrails, bridge rails, guardrail/bridge rail transitions, guardrail end treatments, median barriers, and portable concrete barriers. He is a three time recipient of the prestigious K.B. Woods Award, which is given annually by the Transportation Research Board (TRB) for the outstanding paper published in the field of design and construction of transportation facilities.

Dr. Bligh is chair of Transportation Research Board (TRB) Committee AFB20, "Roadside Safety Design." He just completed 15 years as co-chairman of the “Bridge Rail and Transitions” subcommittee of Task Force 13, “Standardization of Details for Bridge and Road Hardware.” Dr. Bligh is a member of American Traffic Safety Services Association’s (ATSSA’s) “Guardrail Committee,” “Education Task Force,” and “MASH Joint Task Force.” He is also a member of TRB Committee AFF10, “General Structures.”

Dr. Bligh is intimately familiar with the new AASHTO Manual for Assessing Safety Hardware (MASH) and has supervised many crash tests following MASH procedures. He recently worked on an update to MASH for the AASHTO Technical Committee on Roadside Safety (TCRS) to include test matrices for evaluating wire rope barrier systems in median ditches, and other changes to the test matrices, design vehicles, and evaluation criteria. The revised document published in December 2016 as MASH Second Edition, 2016.

Dr. Bligh also has a wide range of experience in the use and validation of computer simulation models for the development, analysis, and evaluation of highway safety appurtenances and roadside geometric features. He is currently serving as Director of the Center for Transportation Computational Mechanics (CeTCoM), which is a competitively procured center established by FHWA that focuses on the application of nonlinear, dynamic finite element analysis to roadside safety design. Dr. Bligh also served as chair of TRB Subcommittee AFB20(1), "Computational Mechanics" for 12 years.

Dr. Bligh will serve as Principal Investigator of the proposed project. As such, he will supervise and manage all aspects of the project.

**Nauman M. Sheikh, P.E.**
Associate Research Engineer
Texas Transportation Institute, TAMUS 3135
Roadside Safety and Physical Security Division
College Station, TX 77843-3135
Phone: (979) 845-8955 E-mail: nauman@tamu.edu

Mr. Sheikh is a licensed Professional Engineer with more than 13 years of experience in the field of roadside safety and computational mechanics. His primary area of expertise includes finite element modeling and simulation of full-scale vehicle impacts in support of the design and development of roadside safety and physical security devices such as concrete barriers, metal guardrails and end-terminals, crash cushions, security gates, anti-ram barriers and fences, etc. He has extensive experience in designing and conducting component-level and full-scale vehicle impact tests for validation of FE models.

Mr. Sheikh is an expert in using commercial analysis tools such as LS-DYNA, HyperMesh, LS-PrePost, HyperView, and SolidWorks. He is also well versed with the use of vehicle dynamics codes (Carsim and ADAMS) for simulating large numbers of roadway encroachment conditions for a variety of vehicle models, driver inputs, and terrain or slope conditions.

Mr. Sheikh has served as principal investigator and co-principal investigator on various research projects sponsored by the NCHRP and various DOTs and research agencies. He has successfully contributed to the design and analysis of several roadside safety appurtenances including concrete barrier systems, metal guardrails, bridge rails, work-zone barriers, guardrail end treatments, energy absorbing crash cushions, and anti-ram barriers. Mr. Sheikh has several peer-reviewed journal publications and has won various awards for his work, including twice being awarded the Transportation Research Board's prestigious K.B. Woods Award for outstanding research paper published on design and construction of transportation facilities (2012 and 2007).

Mr. Sheikh will serve as the lead simulation analyst for the proposed project. He will supervise and oversee the transition modeling and simulation analyses, and have direct responsibility for modeling and simulation of the MGS transition.

**D. Lance Bullard, Jr., P.E.**
Senior Research Engineer
Division Head, Roadside Safety & Physical Security Division
Texas Transportation Institute, TAMUS 3135
Roadside Safety and Physical Security Division
College Station, TX 77843-3135
Phone: (979) 845-6153 E-mail: l-bullard@tamu.edu

Mr. Bullard is the Division Head for the Safety and Structural Systems Division and a Senior Research Engineer for Texas A&M Transportation Institute. He has been employed with TTI a total of 21 years in various roles designing, developing, improving, analyzing, and full-scale crash testing highway safety appurtenances, such as guardrail terminals, crash cushions and breakaway sign supports, for both the U.S. and international markets. He is the Principal Investigator and Engineer for the Texas Department of Assistive and Rehabilitative Services Automotive Adaptive Equipment project that performs reviews and recommendations of vehicle modifications for driver adaptations for physically disabled persons and performs quality control and safety inspections of those modifications.

Mr. Bullard was employed as a private consultant to industry highway roadside safety hardware manufacturers for four years. During this time his consulting activities included much of the same work as his TTI activities, including setting up a private crash testing facility and conducting approximately 60 full-scale crash tests.

Mr. Bullard was previously associated with the Institute for approximately thirteen years prior to leaving. Mr. Bullard was an Engineering Research Associate and former Head of the Testing and Construction Section in the Engineering Factors Program at the Texas A&M Transportation Institute Proving Ground. Mr. Bullard has contributed to the conduct and/or analysis of more than 1000 full-scale vehicular crash tests. Mr. Bullard participated in the performance of motor vehicle defects analysis. He was Principal Investigator at TTI for the National Highway Traffic Safety Administration Office of Motor Vehicle Defects Investigation contract. Additionally, he participated in the conduct of numerous exhaust emissions and fuel economy tests for the various motor vehicle manufacturers, including Porsche, Peugeot, Ford, and General Motors. Mr. Bullard was also involved in the fabrication of a stationary parametric measurement device for the Federal Highway Administration, designed to measure vehicle mass moments of inertia.

Mr. Bullard has performed many accident investigations and reconstructions of passenger and commercial vehicle accidents. In addition, he has developed and taught courses in accident investigation and reconstruction and biomechanics of automobile accidents in the United States and the United Arab Emirates. He has authored and coauthored many technical reports relating to highway safety appurtenances. He has been active with the Society of Automotive Engineers Accident Investigation Practices Committee and several subcommittees thereof and a member of the National Research Council, Transportation Research Board committee for motorcycles and mopeds.

Mr. Bullard is active with the National Research Council Transportation Research Board - Committee AFB20 for Roadside Safety; a Research Affiliate of the American Association of State Highway Transportation Officials - Task Force 13 Committee for Highway Safety; a member of the National Mobility Equipment Dealers Association; a member of the Society of Automotive Engineers Adaptive Devices Standards Committee; Chairman for the American Society for Testing and Materials Development of a Standard Test Method for Boat Barriers; a committee member of the American Society for Testing and Materials for Security Systems and Equipment, Systems Products and Services; a member of the American Traffic Safety Services Association, Guardrail Committee; Chairman for the American Traffic Safety Services Association -

Safety Education Committee, and Task Force Leader for the American Traffic Safety Services Association - Guardrail Training Course.

Mr. Bullard is a licensed professional engineer in Texas, Louisiana, Georgia, and Washington. He holds fifteen U.S. patents for various highway safety devices and one patent in New Zealand.
Mr. Bullard received a Bachelor of Science degree in Mechanized Agriculture and a Bachelor of Science and a Master of Science degree in Civil Engineering from Texas A&M University. Prior to receiving his Bachelor degrees, he worked as an automobile mechanic and on a racing team.

Mr. Bullard will provide overall supervision of the crash tests performed under the proposed project.

**Matthew Robinson**
Research Specialist V
Texas Transportation Institute, TAMUS 3135
Roadside Safety and Physical Security Division
College Station, TX 77843-3135
Phone: (979) 458-3541 E-mail: m-robinson@tamu.edu

Mr. Robinson is a Senior Research Specialist and manager of the TTI Proving Grounds. He has been employed with TTI since 2012. He holds a B.S. in Electronics Engineering Technology from Texas A&M University. Mr. Robinson has over 20 years of experience in the automotive and electronics industry. His specialty is data acquisition, wireless communications, and native vehicular electronic systems.

Mr. Robinson's primary role at TTI is to ensure that crash tests are performed to the quality prescribed by TTI's approved laboratory procedures. TTI is an A2LA accredited laboratory and operates independently of the design teams to ensure impartial evaluation of crash tests. Mr. Robinson ensures that TTI's Proving Ground produces consistent, high-quality results in the performance and evaluation of crash tests.

Mr. Robinson will serve as test conductor for the full-scale crash tests performed under the project. As such, he will be responsible for coordinating preparation for the tests.

**James C. Kovar**
Associate Transportation Researcher
Texas Transportation Institute, TAMUS 3135
Roadside Safety and Physical Security Division
College Station, TX 77843-3135
Phone: (979) 458-3874 E-mail: j-kovar@tti.tamu.edu

Mr. Kovar is an Associate Transportation Researcher in the Roadside Safety and Physical Security Division at the Texas A&M Transportation Institute. He holds a B.S. in Civil Engineering with a specialty in Structural Engineering and is currently pursuing a

Ph.D in the same field. Mr. Kovar is a registered Engineer-in-Training in the state of Texas. He has been working at TTI for 5 years and has experience in designing and analyzing various types of crashworthy devices. Mr. Kovar is also active in the TRB AFB20 committee.

Over the years, he has analyzed and designed steel guardrail systems, concrete median barriers, bridge rails, and wire cable median barriers. On the physical security side, Mr. Kovar has analyzed and designed structures ranging from low speed ASTM F3016 bollards to high speed ASTM F2656 security barriers. Mr. Kovar has experience performing structural analyses, finite element analyses, and 3D modeling using programs including LS-DYNA, HyperMesh, LS-PrePost, SAP, and SolidWorks.

Mr. Kovar will perform structural engineering analyses in support of the design of the transition systems. This will include the design of connection plates and hardware for attachment of the transition rail elements to the bridge rail system.

**Nathan Schulz**
Associate Transportation Researcher
Texas Transportation Institute, TAMUS 3135
Roadside Safety and Physical Security Division
College Station, TX 77843-3135
Phone: (979) 845-4368 E-mail: n-schulz@tti.tamu.edu

Mr. Schulz is an Associate Transportation Researcher at TTI in the Infrastructure Protection Program. He holds a Master of Science degree in Civil Engineering from Texas A&M University and is currently pursuing a Ph.D. in Civil Engineering at Texas A&M University. Mr. Schulz is a registered Engineer-in-Training in the state of Texas. In his time with TTI, he has been involved in research with various State Departments of Transportation (DOTs), Federal Highway Administration (FHWA), National Cooperation Highway Research Program (NCHRP), and several private industry sponsors. In these various projects, he has worked to design and evaluate bridge rails, guardrail systems, concrete median barriers, and roadway gates to mitigate injury to occupants in passenger vehicles, heavy truck vehicles, and motorcycles.

Mr. Schulz also has a wide range of experience in the use and validation of computer simulation models for the development, analysis, and evaluation of highway safety appurtenances and roadside geometric features. He is experienced with LS-DYNA, HyperMesh, and LS-PrePost in the analysis and design of roadside safety and perimeter security devices. He also has taken several classes studying Computational Fluid Dynamics (CFD) and applied it to various problems in the civil engineering field.

Mr. Schulz will serve as a simulation analyst under the proposed project. He will lead the modeling and simulation of the box beam transition system.

## RESEARCH FACILITIES

The Texas A&M Transportation Institute (TTI), established in 1950 and a member of The Texas A&M University System, seeks solutions to the problems and challenges facing all modes of transportation. The Institute conducts about 600 research projects annually with over 200 sponsors at all levels of government and the private sector.

Through strategies and products developed through its research program, TTI has saved Texas and the United States billions of dollars. The Institute has made significant advancements in transportation safety, mobility, planning, systems, infrastructure, the environment and other areas vital to an efficient transportation system and good quality of life.

At any one time, TTI has research sponsors in about 30 states and has conducted research for sponsors in all 50 states and 20 foreign countries. In the laboratory and the classroom, through the Dwight Look College of Engineering and other colleges at Texas A&M University, TTI researchers help prepare students for transportation careers.

TTI's 10 state and national research centers illustrate the breadth and significance of the Institute's research program. Center research emphasis areas range from computational mechanics and simulation to railway, border mobility, and ports and waterways research.

With headquarters and laboratories on the Texas A&M University campus in College Station, TTI also operates several facilities in Bryan, including roadside safety, visibility, pavements, environmental and emissions testing facilities at the university's RELLIS Campus.

TTI has offices in Arlington, Austin, Dallas, El Paso, Galveston, Houston and San Antonio. Internationally, TTI has locations at the Texas A&M University Center in Mexico City and in Doha, Qatar, on the campus of Texas A&M University at Qatar.

A research program with breadth and depth requires the availability of extensive state-of-the-art laboratories. TTI has these facilities. The labs and equipment available to researchers are vital to the Institute's ability to successfully undertake critically needed research.

TTI's expansive field-testing facilities are essential in providing real-world findings to state, national and international sponsors. Located 10 miles from the main campus of Texas A&M University, TTI's RELLIS Campus is home to many testing facilities. The campus provides the realistic conditions needed for crash testing; pavement friction and smoothness testing; erosion and sediment control product testing; environmental and emissions testing; and traffic engineering studies. These comprehensive facilities contribute to TTI's ability to provide full-service transportation research solutions.

The Roadside Safety Program is part of the Roadside Safety & Physical Security Division of TTI. Research in the Roadside Safety Program involves identifying, analyzing, and developing solutions for roadside safety problems with the goal of reducing the tremendous loss of life that occurs on our nation's highways each year as a result of roadside accidents. Specific research activities include the design, analysis, testing, and evaluation roadside safety structures, and the development of guidelines for the use, selection, and placement of these structures. Innovative safety devices designed by TTI researchers are in use worldwide and are saving lives on a daily basis. Roadside safety structures addressed by the Program include guardrails, bridge rails, median barriers, transitions, end treatments, crash cushions, breakaway support structures, and work zone traffic control devices.

Crash tests are often conducted in support of the development and evaluation of these safety devices. Such tests are conducted with the support of the TTI Proving Ground located at Texas A&M University's RELLIS Campus. The Proving Ground Program is staffed by highly skilled personnel who fabricate and construct test articles, conduct crash tests, and process, analyze, and report crash test data. These crash tests are used to demonstrate design viability and safe impact performance before a system is implemented on the roadside.

Today's simulation technology now permits accurate modeling of vehicle interactions with roadside safety devices on the computer. The Roadside Safety Program works closely with the Center for Transportation Computational Mechanics in applying state-of-the-art analytical tools such as LS-DYNA to roadside safety problems. Researchers have access to vast array of high-speed computing facilities which enable large, detailed simulations to be run in a short time period. Sophisticated finite element models of vehicles and roadside safety hardware are used to conduct virtual crash tests to evaluate impact performance, assess design alternatives, and perform design optimization in a predictive manner. Use of these sophisticated analysis tools provides an enhanced understanding of crash dynamics that enables researchers to design better, more cost-effective safety hardware at a lower cost to the sponsor.

Research within the Roadside Safety Program also addresses the influence of roadside geometric features such as driveways, slopes, ditches, shoulders, and medians on the safety of vehicles encroaching into the roadside environment. Researchers perform clinical analysis of real-world crash data and use sophisticated computer simulation codes to better understand the nature and severity of roadside crashes, evaluate countermeasures, and develop design guidelines. Researchers have drafted or are currently developing safety guidelines for roads in such areas as median barrier warrants, clear zones, slope rounding, and driveway slopes and spacing. Benefit/cost analysis is used to evaluate the cost effectiveness of safety alternatives with consideration given to various traffic, roadway, roadside, and vehicle characteristics.

Researchers in the Roadside Safety Program partner with federal and state agencies, other universities and research institutes, and industry on research and development projects. These agencies include the Federal Highway Administration (FHWA), the

American Association of State Highway and Transportation Officials (AASHTO), the National Cooperative Highway Research Program (NCHRP), the Texas Department of Transportation (TxDOT), and other state departments of transportation. In addition, the Program's researchers have affiliations with a number of national and international organizations. These affiliations have enabled the researchers to develop strong working relationships and provides for the exchange of ideas and information with professionals throughout the world.

The Proving Grounds Research Facility, a 2,000-acre complex, enables researchers to conduct experiments and testing with the ultimate goal of improving transportation safety. This facility is one of only two university-based centers of its kind in the United States where researchers perform product testing for clients from across the country, as well as test new TTI-developed roadside safety devices. An expanse of paved runways is ideally suited to perform full-scale testing of safety designs. Roadside devices, crash cushions, and barrier systems undergo the substantial testing that is required before field installations. The size of the facility provides realistic conditions for crash testing and friction pavement testing. Crash tests are conducted using a wide spectrum of vehicles, from subcompacts and three-quarter-ton trucks to 80,000-pound tractor-trailer rigs. Other proving ground facilities include:

The TTI Proving Ground is an International Standards Organization (ISO) 17025-accredited laboratory with American Association for Laboratory Accreditation (A2LA) Mechanical Testing certificate 2821.01. The TTI Proving Ground is located at a 2000-acre complex of research and training facilities located 10 miles northwest of the main campus of Texas A&M University. The site, formerly a United States Army Air Corps base, has large expanses of concrete runways and parking aprons that are well-suited for experimental research and testing in the areas of vehicle performance and handling, vehicle-roadway interaction, durability and efficacy of highway pavements, and evaluation of roadside safety hardware. The TTI Proving Ground consists of four technical sections that perform and evaluate full-scale crash tests of roadside safety and physical security systems. Details of these technical sections are described below.

The Construction Section fabricates prototype devices and constructs full-scale test installations. Most sponsors provide detailed drawings or pre-fabricated components for their roadside safety test appurtenances. The Construction Section works closely with the engineers and sponsors to assure proper installation. The section is staffed with six full-time experienced individuals and equipped with extensive industrial equipment.

The Electro-Mechanical Research Instrumentation group designs, fabricates, calibrates and maintains measurement and control systems for a variety of transportation research projects. Although a large number of instrumentation system components are available commercially, many unique components and systems must be designed and fabricated using electronic and automotive laboratory facilities. The electronic research instrumentation laboratory is often called upon to provide instrumentation for highly specialized experiments where appropriate systems are not available. The capability of the electronic instrumentation group to design and fabricate nonstandard measurement equipment allows quick development of instrumentation systems necessary for the solution of transportation research problems. Typical of such nonstandard systems are: (1) crash test data acquisition systems using a combination of telemetry, high speed, on-board data collection and analog to digital data processing hardware; (2) dynamic structural analysis of roadside barriers during a crash event, through the use of strain gages and high speed digital data recording; (3) radio control systems for remotely driving 80,000 pound, 18 wheeler trucks up to 50 mph for crash testing; (4) state-of-the-art system for determining the location of portable traffic message signs using global positioning system, imbedded microprocessor, cell phone and digital mapping technology.

The Photographic Research Instrumentation section is responsible for the documentation and data acquisition from crash tests or any other related highway safety research. The photo-instrumentation group uses photography as a technique for the collection and storage of data captured during the dynamic events that occur during crash tests, or events that occur too rapidly for human observation. With the provisions of frame accurate time references in the high speed camera equipment, the analysis of physical events in terms of time and displacement are captured on film for a later means of quantitative analysis of the event or action.

The photo-instrumentation group has an extensive inventory of high speed video cameras for the documentation of high speed events at speeds up to 2000 frames per second. These include two Kodak Imager cameras and one HG model camera for use in on-board or high acceleration applications. Once the event is captured on high speed video, the photo-instrumentation group uses motion analysis software to analyze details of the crash test. A mini-digital video camera and still cameras recorded and documented conditions of each test vehicle and the installation before and after the test.

The Evaluation and Reporting Section provides an interdisciplinary approach to experiment planning, testing, data reduction and analysis, and report writing. The section staff includes individuals with backgrounds in mathematics, engineering and physics. They are well-versed in the analysis of electronic data. Computer aided drafting is also accomplished by this section.

This section is responsible for analyzing and evaluating data collected in various test programs and preparing test reports summarizing the test results. The analysis and evaluation functions are highly automated and computerized. This group occupies a central position in the pursuit of research objectives and has provided the essential elements for many technical reports covering a wide spectrum of highway safety research.