Form ProjAgre
(Rev. 1/2018)
(RTI)

RTI
PROJECT AGREEMENT
Between the
TEXAS DEPARTMENT OF TRANSPORTATION (TxDOT)
(RECEIVING AGENCY)
AND
Texas A&M Transportation Institute (TTI)
of The Texas A&M University System
(PERFORMING AGENCY/S)

Fiscal Year **2019**

☒ **Research Project**
☐ **Implementation Project**

Project Number: **19-203**

Document Date: 4/12/18

Project Title: Traffic Safety Improvements at Low Water Crossings

For TxDOT Purposes Only:

Performing Agency/ Subrecipient:		Federal Awarding Agency: Federal Highway Administration	
DUNS #	93-848-5539	CFDA #	20.205
Indirect Cost Rate	48.5%	CFDA Name	Highway Planning and Construction
FAIN #			
Federal Award Date			
Amount of Federal Funds Obligated to Performing Agency/ Subrecipient		Amount of Federal Funds Obligated	
Contact Information	TxDOT's Research Technology and Implementation Division	Phone: (512) 416.4730	Email: RTIMain@txdot.gov

THIS PROJECT AGREEMENT is made pursuant to the terms and conditions of a Cooperative Research and Implementation Agreement(s) (CRIA) entered into by and between the Texas Department of Transportation (TxDOT) and The Texas A&M University System, Texas A&M Transportation Institute.

This project agreement is under the terms of:
☒ CRIA Article 9A and is considered a part of the Annual Program.
☐ CRIA Article 9B and is considered an independent project.

PART I. Project Description. The Performing Agency(s) shall undertake and complete the project named above and as further described in Exhibit B, attached hereto and made a part of this Project Agreement. Exhibit B must comply with the requirements of the most recent Research Manual.

PART II. Period of Performance Start and End Date. Continuation of the project beyond August 31 each year is subject to authorization by TxDOT and the availability of funds. TxDOT will notify the Performing Agency(s) of initial project approval and annual continuation approvals by Activation Letters. The Activation Letter will signify final approval and authorization to the Performing Agency(s) to initiate the work for a fiscal year. Each Activation Letter shall include the project activation date and shall be attached hereto and made a part of this agreement as if it had been attached at the time this Project Agreement is signed. The Activation Letters will specify the remaining project duration unless terminated in accordance with Article 29 of the CRIA.

May 31, 2020
Project Termination Date

PART III. Project Budget. The total estimated project cost, which includes all authorized direct and indirect costs which may be incurred by the Performing Agency(s), is shown below along with a breakdown by fiscal year and agency. Attached hereto as Itemized Budget - Exhibit A and made a part of this agreement is an annual Itemized Budget for each Performing Agency which details approved project costs for each fiscal year of this project.

Budget Breakdown
(Attach an itemized budget
for each fiscal year
for each Performing Agency.)

FY	Agency	Budget	FY	Agency	Budget
19	TTI	$216,844			
20	TTI	$221,837			

Total Project Budget: $438,681

PART IV. Project Supervision. The Performing Agency Project Supervisor, whose agency shall be the lead agency, and other primary research staff are named below.

	Name	Title	Agency	Phone No.	Email
Project Supervisor	Chiara Silvestri Dobrovolny	Associate Research Scientist	TTI	979-845-8971	c-silvestri@tti.tamu.edu
Researcher or PI	Kevin Balke	Senior Research Engineer	TTI	979-845-9899	k-balke@tti.tamu.edu
Researcher or PI	Subasish Das	Assoc. Transp. Researcher	TTI	979-845-9958	subaishsn@gmail.com
Researcher or PI	Roger Bligh	Senior Research Engineer	TTI	979-845-4377	r-bligh@tti.tamu.edu
Researcher or PI	Adam Pike	Assoc. Research Engineer	TTI	979-862-4591	a-pike@tti.tamu.edu
Researcher or PI	Timothy P. Barrette	Assoc. Transp. Researcher	TTI	979-845-6174	t-barrette@tti.tamu.edu
Researcher or PI	Hasan H. Charara	Software Applic. Dev. III	TTI	979-845-1908	h-charara@tti.tamu.edu
Researcher or PI	David Florence	Assoc. Transp. Researcher	TTI	979-845-9898	d-florence@tti.tamu.edu
Researcher or PI	Geza Pesti	Research Engineer	TTI	979-845-9878	g-pesti@tti.tamu.edu
Researcher or PI	Stefan Hurlebaus	Research Scientist	TTI	979-845-9570	shurlebaus@civil.tamu.edu
Researcher or PI	Richard A. Zimmer	Senior Research Specialist	TTI	979-845-6388	d-zimmer@tti.tamu.edu

PART V. No Waiver. This Project Agreement does not waive the rights, responsibilities, and obligations provided each party under the CRIA and incorporates all the provisions of the CRIA as if set forth herein.

IN WITNESS WHEREOF, this Project Agreement is hereby accepted and executed.

Approved and Accepted by the Performing Agency:

_______________________________ Date: _______________

William R. Stockton, Ph.D., P.E.
Executive Associate Director
Texas A&M Transportation Institute
The Texas A&M University System

Approved and Accepted by the Receiving Agency:

_______________________________ Date: _______________

Kenneth Stewart
Director of Contract Services

Exhibit A - Itemized Budget

Project No: 19-203 Created Date: 4/12/18 Form ExhA_DB
Agency: TTI Revision #: (Rev.3/2018)
Primary Agency X Revision Date: (RTI)

Direct Costs

Salaries & Fringe				
Role	**Fringe**	**FY19**	**FY20**	**Total Costs**
Research Supervisor	16.8	18,538.00	7,254.00	25,792.00
Professional	16.8	96,121.00	106,929.00	203,050.00
Sub professional / Technical	16.8	6,051.00	-	6,051.00
Administrative or Clerical ^	16.8	1,322.00	1,163.00	2,485.00
Student	2.4	9,549.00	5,639.00	15,188.00
	Total Salaries and Wages	131,581.00	120,985.00	$ 252,566.00

Subcontractors				
Sub #	**Description of Duties**	**FY19**	**FY20**	**Total**
1	Install guardrail system and repair the system in between tests	25,000.00	55,000.00	80,000.00
	Total Subcontracts	25,000.00	55,000.00	$ 80,000.00

Equipment (items over $5,000; list each item separately)				
Deliverable #	**Description of Equipment ^^**	**FY19**	**FY20**	**Total**
	Total Equipment	-	-	$ -

Travel				
City, State	**Purpose**	**FY19**	**FY20**	**Total**
Austin, TX	Attend project meetings	244.00	244.00	488.00
Bryan, TX	Trips to RELLIS Campus to conduct testing	160.00	160.00	320.00
	In-State & Out-of-State Travel Total	404.00	404.00	$ 808.00

Operating, Supplies and Other Expenses				
In/Excluded MTDC	**Description ^^^**	**FY19**	**FY20**	**Total**
Excluded from MTDC	Computer Operations	2,562.00	1,846.00	4,408.00
Excluded from MTDC	Specialized Service Center - Photometric Field Equipment @ $150/day	900.00	-	900.00
Excluded from MTDC	Specialized Service Center - Erosion Function Apparatus Testing @ $1,200/test	8,400.00	-	8,400.00
Excluded from MTDC	Specialized Service Center - Editing Services @ $54/hour	-	2,160.00	2,160.00
Excluded from MTDC	Specialized Service Center - Construction Section Services @$41/hour	-	6,724.00	6,724.00
Excluded from MTDC	Specialized Service Center - Evaluation/Reporting & Photographic Res. @ $72/hour	-	1,152.00	1,152.00
Excluded from MTDC	Specialized Service Center - Construction Section Services for DEMO @ $41/hour	-	1,968.00	1,968.00
Included in MTDC	Research Supplies (sensors - $2,390; Brackets - $300; guide wires - $300; signs - $300; base materials - $1,500; asphalt - $750; roller - $1,020; track steer - $840; concrete disposal - $300; misc. items for testing $300)	7,000.00	1,000.00	8,000.00
	Total Expendable Operating and Other Expenses	18,862.00	14,850.00	$ 33,712.00

Total Direct Costs	FY19	FY20	Total
	175,847.00	191,239.00	$ 367,086.00

Indirect Costs						
				FY19	**FY20**	**Total**
$ MTDC * =	286,374.00	**Indirect Cost Rate**	48.50%	79,533.00	59,359.00	138,892.00
Less University's Contribution		**% MTDC *** =**	23.50%	38,536.00	28,761.00	67,297.00
			Indirect Cost Total	40,997.00	30,598.00	$ 71,595.00

Total Project Costs by Fiscal Year (Direct Costs Plus Indirect Costs)	FY19	FY20	Total
Total Project Costs	216,844.00	221,837.00	$ 438,681.00

Comments: The fringe rate excludes medical for staff and eligible students. For budgeting purposes, medical is calculated per the Performing Agency's Fringe Benefit Memorandum and is included in the FY Salaries & Fringe amount(s).

MTDC Notes:

* Calculate Modified Total Direct Costs (MTDC) based on the University's negotiated (federal) F&A agreement. Per 2 CFR 200 Rule, Uniform Administrative Requirements, Cost Principles, and Audit Requirements for Federal Awards, MTDC should never include, equipment, tuition remission, rental costs, scholarships and fellowships, and the portion of each subcontract over $25,000.

** Enter the University's federally approved indirect cost rate % or 10% de minimis. Form will calculate total, based on MTDC.

*** The Performing Agency will share in the cost of the project by making the above University Contribution.

Notes:

Amounts on Exhibit A are estimates of the project tasks and deliverables.

This electronic form contains formulas that may be corrupted when adding or deleting rows, or by conversion of the spreadsheet. The university is responsible for the calculations of the budget.

^ Must include documentation to support the charges.

^^ Include equipment specifications and application of equipment within the workplan task(s) for which it is being purchased.

^^^ For Supplies that have an aggregate amount of $5,000 or more, provide line item details.

Components which constitute a larger system, costing over $5,000 in the current project should be listed under Equipment.

19-203, TRAFFIC SAFETY IMPROVEMENTS AT LOW WATER CROSSINGS

PROJECT ABSTRACT

Texas has been reported to lead the nation in flood-related deaths, with the majority of deaths caused by motorists attempting to drive through moving water. Motorists might attempt to cross a flooded roadway not realizing its depth or, especially at nighttime during heavy storms that make it difficult to see that flooded road. The report established that it only takes 18-24 inches of moving water to sweep away a truck, and 6 inches to carry away a small car. Many accidents, rescues, and deaths occur at low water crossings, and most accidents occur at night. While it may be impractical to raise or remove all low water crossings across the state, there are low-cost means to better alert the driving public to the risks of low water crossings.

The Performing Agency shall investigate low-cost approaches to improve low water crossings, with a focus on easy to install and maintain features, such as:

- Reflective pavement markings and markers,
- Flood-detection sensors,
- Active/passive warning devices, and
- Infrastructure-to-Infrastructure (I2I) and Infrastructure-to-Vehicle (I2V) technologies.

IMPLEMENTATION

The Performing Agency shall investigate and document the Receiving Agency's current practices with respect to management of low water crossings.

The Performing Agency shall compile findings on low-cost approaches to improve low water crossings statewide, with a focus on easy to install and maintain features, such as: reflective pavement markings and markers, flood-detection sensors, and active/passive warning devices.

The Performing Agency shall provide adequate recommendations for improvement at low water crossing locations based on the testing program outcomes conducted to evaluate the accuracy of the detection/warning systems.

WORK PLAN

Almost every year Texas leads the Nation in flood-related deaths and property damage. The geography of the State makes it a unique position to receive both frontal tropical hurricanes and large air masses that can bring in air moistures in almost any direction and drop rain with world class intensity. Texas holds half of the 12 world records of rainfall in 48 hours or less, which are mainly distributed on the Golf Coast area and the Balcones Escarpment in Central Texas, also known as the Flash Flood Alley due to its typical flash storm producing extreme rainfall. Almost all Texas major cities lie in the paths of these storms, and since Texas has a predominant climate with long dry periods between storms, it is easy to forget the common cycle and become victim of Texas flash floods.

In fact, for the cities of Austin and San Antonio, flash flooding is the number one natural disaster threat. Although both cities manage programs to help prevent and/or reduce flooding problems, within the past three decades Texas has done little to secure its floodplains against torrential downpours.

Texas has been reported to lead the nation in flood-related deaths, with the majority of deaths caused by motorists attempting to drive through moving waters. Flash flooding is most severe in urban areas since urbanization increases runoff by 2 to 6 times over what would occur in natural terrain. Flood waters can fill streets, freeway underpasses, and parking lots and can sweep away cars. Motorists might attempt to cross a flooded roadway not realizing its depth or, especially at nighttime during heavy storms that makes it difficult to spot a flooded roadway. The report established that it only takes 18-24 inches of moving water to sweep away a truck, and 6 inches to carry away a small car. With flash flooding typically lasting on the order of 6 hours or less, less warning lead time is provided which requires quicker action on the part of the motorists.

In 2015-2016, Texas lead the nation in flood related fatalities and the majority of those fatalities were vehicle-involved. Table 1 shows flood involved fatalities in the U.S. and Texas. In Texas, about 50% of the flood involved fatalities are vehicle-involved. Many accidents, rescues, and deaths occur at low water crossings, and most occur at night. While it may be impractical to raise or remove all low water crossings across the state, there are low-cost means to better alert the driving public to the risks of low water crossings. The installment of permanent signs or gates can often be costly and difficult to maintain. Placing temporary signs and barricades requires significant field crew effort who cannot be everywhere at once. These facts present a need for a research project to investigate low water crossings locations and recommend adequate improvements to address motorists' safety at the flooded locations.

Table 1. Flood Related Fatalities in the U.S. and Texas.

Year	Total Fatalities	U.S. Vehicle involved Fatalities	Percentage	Total Fatalities	Texas Vehicle involved Fatalities	Percentage
2012	29	10	34.5%	5	3	60.0%
2013	82	37	45.1%	12	7	58.3%
2014	40	18	45.0%	6	3	50.0%
2015	176	112	63.6%	48	25	52.1%
2016	126	58	46.0%	38	18	47.4%

Source: http://www.nws.noaa.gov/om/hazstats/

The Performing Agency's work plan shall consist of eight tasks, which shall be accomplished as follows.

Task 1. Project Management and Research Coordination

The Performing Agency shall conduct project management activities and coordinate research activities including, but not limited to, project meetings between the Performing Agency and the Receiving Agency, preparation of meeting notes, and documenting work efforts into monthly progress reports (MPRs).

The Performing Agency shall conduct the following activities:

- Kick-off meeting. The Performing Agency shall schedule a kick-off meeting with the Project Team.
- Progress meetings. Throughout the project, the Performing Agency shall schedule meetings with the Project Team to discuss topics such as the status of the research, research results from the work plan, future activities, and issues that might have emerged since the last progress meeting.
- Close-out meeting. The Performing Agency shall schedule a close-out meeting with the Project Team approximately one month before the end of the research to discuss the final deliverables with Project Team members. The close-out meeting shall discuss the findings of all tasks in the study effort.
- MPRs. The Performing Agency shall submit monthly progress reports to summarize activities completed during the previous month and highlight issues that might have emerged during the previous month.

Working in conjunction with the Project Team, the Performing Agency shall conduct a Value of Research (VoR) assessment. In developing the VoR, the Performing Agency shall identify sources for both qualitative and economic data, such as Receiving Agency construction bids (economic), material price lists from vendors (economic), pavement performance data (economic), and district personnel (qualitative). Table 2 illustrates the qualitative and economic benefit areas designated by the Receiving Agency for this project.

The Performing Agency shall complete the VoR Template, including the economic based calculations, the description of economic variables used within the calculations, and the qualitative values of the selected benefit areas.

The Performing Agency shall evaluate the initial submission of the VoR Template and revise, if needed.

The Performing Agency shall continue to identify qualitative and economic VoR data during the course of the research project. The Performing Agency shall include this information within the resubmittal of the VoR Template at the end of the project within the Project Summary Report (PSR) and Research Report (R1).

Table 2. Qualitative and Economic Benefit Areas Designated by Receiving Agency.

Selected	Functional Area	QUAL	ECON	Both	TxDOT	State	Both
X	System Reliability		X		X		
X	Intelligent Transportation Systems		X				X
X	Engineering Design Improvement			X			X
X	Safety			X			X

Figure 1 summarizes the work plan developed to address the required technical objectives listed below:

1. Investigate each of the Receiving Agency Area Office's current inventory and management approach of low water crossings.
2. Conduct a survey of other state Department of Transportations (DOTs), American Association of State Highway Transportation Officials (AASHTO), Federal Highway Administration (FHWA), and other agencies on low water crossing management techniques.
3. Determine which reflective pavement markings and striping can show the most contrast when submerged and not submerged in water.
4. Evaluate flood sensor and flood warning devices for roadways, and assess their cost/benefit, including maintenance and applicability in urban and rural and high-volume and low-volume traffic settings.
5. Conduct controlled environment testing for appropriate I2I and I2V technologies, and verify the accuracy of the system function.
6. Conduct developmental testing to verify the accuracy of the water level sensors and the functionality of the developed and applied technologies. A final set of tests shall be needed to validate the accuracy of the overall connected system for different scenarios.

Deliverables: The Performing Agency shall submit the following deliverables to the RTI Project Manager at RTIMAIN@txdot.gov, per the attached Project Deliverables Table:

- Monthly Progress Reports (MPRs) that summarize the progress of tasks and roadside safety device test results.
- Value of Research (VoR) baseline data that includes both qualitative and economic benefits.
- Research Report R1 that document work performed, findings, and recommendations.
- PSR summarizing all activities and findings.

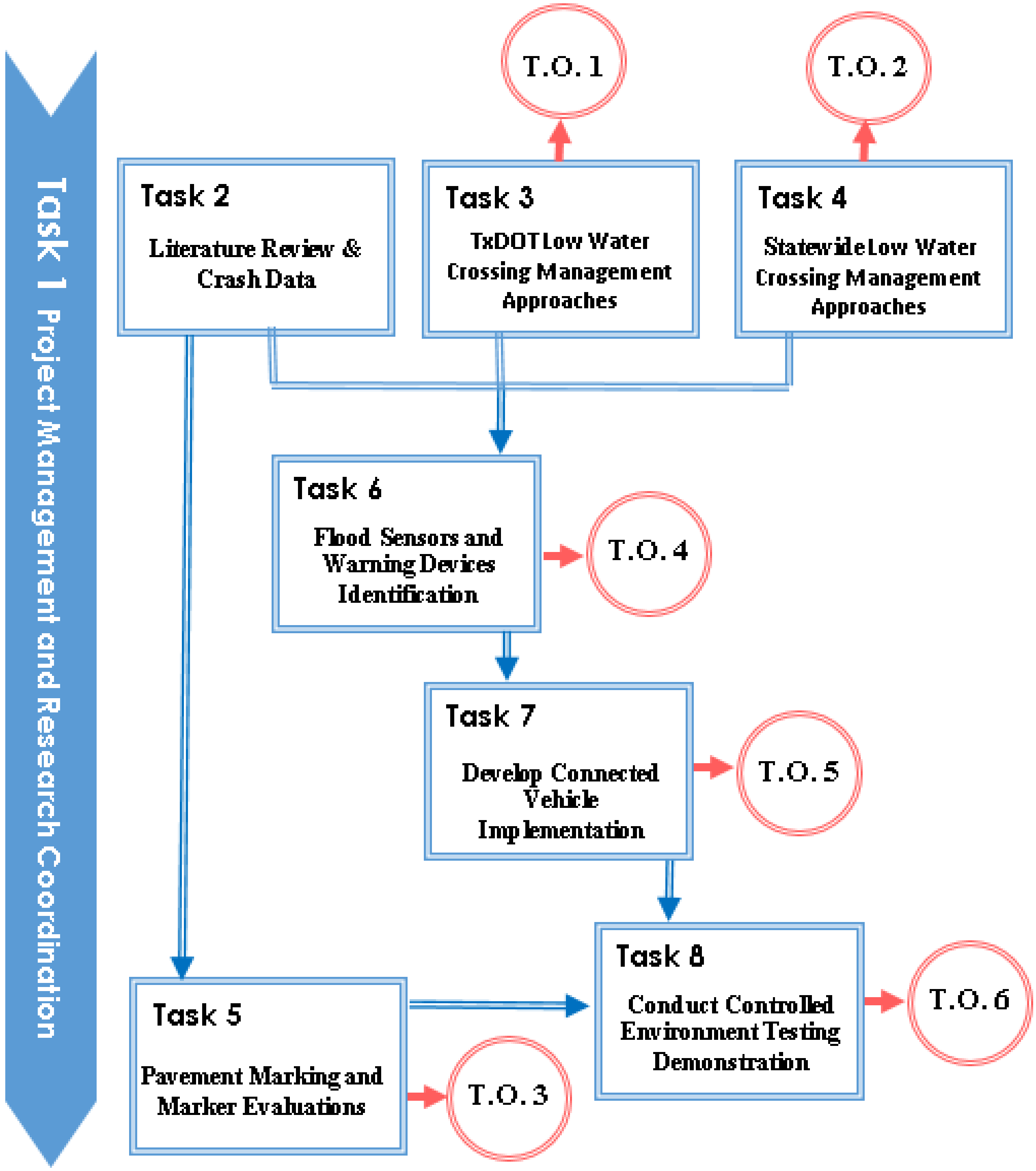

Figure 1. Work Plan Flowchart.

Task 2. Literature Review and Crash Data Analysis

The Performing Agency shall develop a synthesis of relevant information in the research literature and state policy documents regarding low water crossing related issues. The synthesis will consist of a literature review to obtain the best available knowledge on the following topics:

- Low water crossing related crash and incident trends, focusing on the effects of the following variables on crash frequency and severity:
    - Roadway geometry (e.g. lane width, pavement marking, and shoulder type).
    - Traffic control devices (e.g. low water crossing signs, and warning devices).
    - Weather (e.g. precipitation, and extreme weather event).
- Effectiveness of different low water crossing countermeasures (e.g., signs, warning devices).
- State agency practices, including:
    - Low water crossing design and countermeasure implementation warrants.
    - Criteria and methods for diagnosing problems and choosing advanced alternatives.
    - Low water crossing inventory and management approaches.
- Other relevant issues, possibly including design considerations, the needs of connected vehicle technologies, cyber-physical infrastructure, and smartphone app for flood hazard warning.

Upon completion of this Task, the Performing Agency shall:

- Categorize locations/scenarios for consideration of the testing demonstration in Task 8;
- Prioritize characteristics of locations where future device deployment is most needed;
- Provide information to assist for cost-benefit assessment of flood sensors and warning devices in Task 6.

The Performing Agency shall conduct the literature search using both manual and computerized methods. Computerized searches shall be conducted in the Transportation Research Information Service (TRIS) and Transportation databases. TRIS includes the capability to search several databases including the Highway Research Information Service database for domestic literature, the Highway Research in Progress database for ongoing research studies, and the International Road Research Database for relevant foreign literature. The literature review shall include state policy documents, national guidance documents (e.g., Highway Safety Manual), technical reports/journals, and informational documents published by agencies such as FHWA and AASHTO.

Deliverables: The Performing Agency shall submit Technical Memorandum TM-2 to RTIMain@txdot.gov, copying the RTI Project Manager, per the attached Project Deliverables Table. TM-2 shall document the work performed within this Task, including findings, and recommendations.

Task 3. Receiving Agency Low Water Crossing Management Approach

The Performing Agency shall investigate each Receiving Agency Area Office's current inventory and management approach of low water crossings. Texas Natural Resources Information System (TNRIS) maintains a location database of low water crossings in Texas. The purpose of this database is to locate all existing low water crossings locations. This database provides locations of 8,339 low water crossings in Texas (as shown in Figure 2).

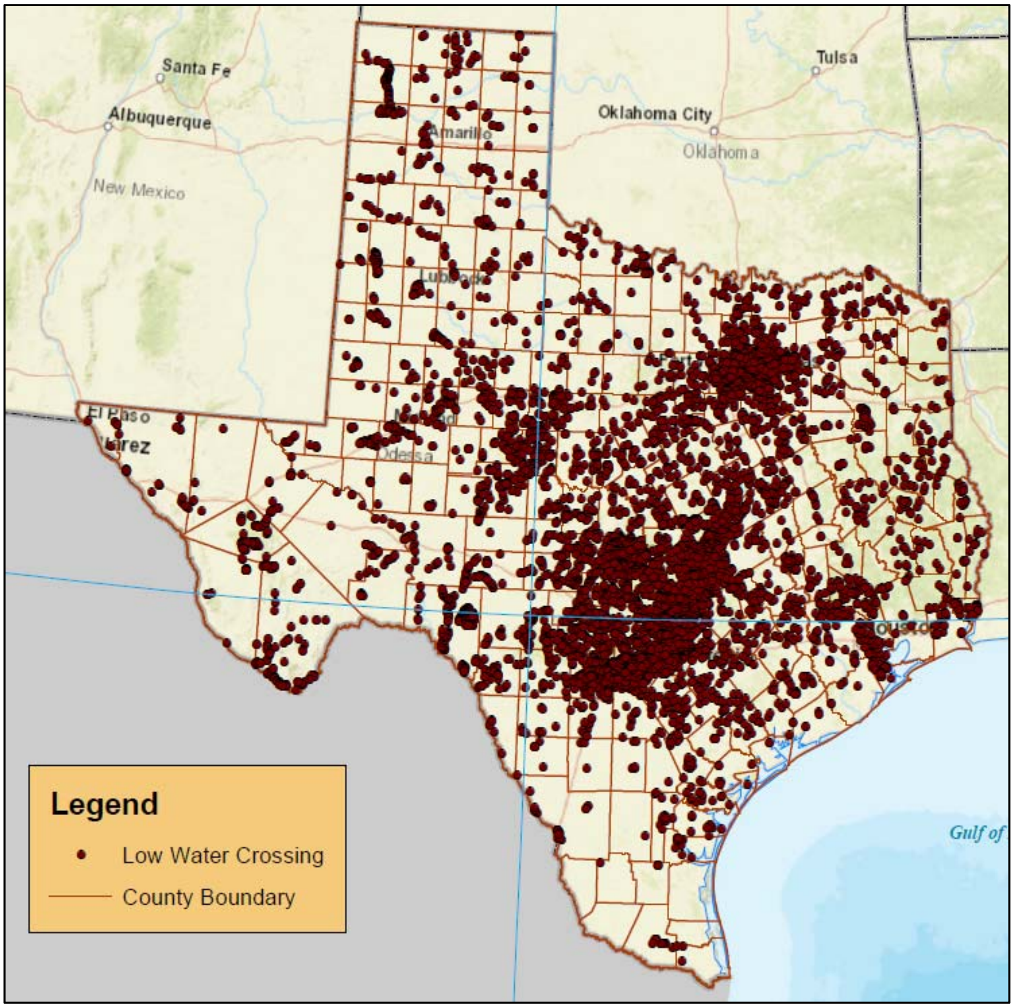

Figure 2. Low Water Crossings in Texas (Source:
https://tnris.org/data-catalog/entry/low-water-crossings/)

The Performing Agency envisions using this comprehensive list as a starting point to identify low water crossing related traffic crashes during flood events. This will help to generate a comprehensive database on the low water crossing related traffic crashes. The Performing Agency shall review the most recent available five years from the Crash Record Information System (CRIS) database to identify the extent of the low water crossing traffic incidents and extrapolate useful available information regarding those locations.

To accomplish the research objective, the Performing Agency shall access additional datasets to incorporate additional needed data types (listed in the first column of Table 2). For each data type, the Performing Agency identified available Receiving Agency data sources containing pertinent information and data (second column in Table 3).

Table 3. Required Data Types and Existing Receiving Agency Data Sources.

Data Type	Receiving Agency Data Source
Crash	• Crash Record Information System (CRIS)
Roadway	• Road-Highway Inventory Network Offload (RHiNO) • Google earth aerial and street views
Weather	• National Climatic Data Center
Traffic	• RHiNO
Low Crossing related sign and countermeasure location	• Other District data
Construction dates	• Other District data
Project cost	• Other District data

When available, the Performing Agency shall work closely with the Receiving Agency Districts to identify and categorize types of both passive and active devices utilized by the Districts to improve conspicuity and alert motorists of flooding events at low water crossings.

Deliverables: The Performing Agency shall submit Technical Memorandum TM-3 to RTIMain@txdot.gov, copying the RTI Project Manager, per the attached Project Deliverables Table. TM-3 shall document work performed within this Task, including findings, and recommendations.

Task 4. Statewide Low Water Crossing Management Approaches

The Performing Agency shall conduct a survey of other DOTs, AASHTO, FHWA, and other Agencies on low water crossing management techniques. The Performing Agency shall design the survey with the additional intent to identify and categorize types of both passive and active devices utilized by the surveyed Agencies to improve conspicuity and alert motorists of flooding events at low water crossings.

The Performing Agency shall acquire the Receiving Agency's for review and approval of the survey before distributing to the other entities.

Deliverables: The Performing Agency shall submit Technical Memorandum TM-4 to RTIMain@txdot.gov, copying the RTI Project Manager, per the attached Project Deliverables Table. TM-4 shall document work performed within this Task, including findings, and recommendations.

Task 5. Pavement Marking and Marker Evaluations for Low Water Crossings

The task 5 objective is to evaluate the visibility performance of pavement markings and markers when utilized in low water crossing areas. To meet this objective, the Performing Agency shall evaluate the contrast of the markings and markers compared to the road surface when submerged and not submerged in water during both day and night conditions. The Performing Agency describes the anticipated methodology to define and acquire treatments for evaluation, to determine the experimental design for evaluation of the treatments visibility, to analyze the collected data, and to develop the task's deliverable in the descriptions below.

Definition and Acquisition of Existing or Potential Marking and Marker Treatments for Evaluation

The Performing Agency shall contact marking and marker treatments manufacturers to identify existing marking or marker products that would be beneficial at low water crossings, serving as either a warning to drivers or to aid in delineating the roadway. The Performing Agency shall consider available potential possibilities such as markings with wet-reflective optics, raised retroreflective pavement markers (RRPMs), internally illuminated markers, and contrast markings. The Performing Agency shall conduct this search with the goal to acquire and test a selection of treatments to determine their capability of providing delineation or warning at low water crossing when submerged and not submerged in water. The Performing Agency shall select marking and marker types for further evaluation through testing.

Finalize Experimental Design and Conduct Testing

The Performing Agency shall prepare an experimental design for appropriate testing of selected markings and markers. The Receiving Agency will review and provide feedback on the experimental design. Upon receiving approval of the test design, the Performing Agency shall proceed with testing. The experimental design and subsequent testing shall be setup to yield a dataset suitable for assessing the visibility performance of the selected markings and markers in both dry and wet conditions, during both day and night conditions.

The Performing Agency shall conduct the approved testing in a controlled testing environment due to the unpredictable nature of water flowing across low water crossings. The Performing Agency shall modify the existing facilities typically used for water runoff, soil erosion, and sediment retention for the purposes of conducting this research. The wet conditions will consist of varying levels of water that will submerge the treatments. The water used to submerge the treatments shall be of varying clarity (evaluated with a turbidity sensor) to simulate different flooding conditions. The Performing Agency shall use the sediment retention channel (Figure 3) to hold water at varying depths while the treatments are placed along the modified bottom, which will simulate a typical low water crossing road surface. The Performing Agency shall use the facility equipped with a large water holding tank with an agitator to suspend solids in the water to produce varying levels of water clarity and shall evaluate a single treatment at a time. During daytime testing, the sun will be the only illumination source. The Performing Agency shall use a vehicle headlamp at the appropriate geometry to provide illumination during the nighttime testing. The Performing Agency shall use a calibrated imaging spectroradiometer to capture images of the treatment in the various test conditions. The spectroradiometer captures accurate color and luminance levels for every pixel in the scene. The Performing Agency shall setup the spectroradiometer to represent a typical driver viewing position of the treatments.

Figure 3. Sediment Retention Device.

Analysis of Collected Data

The Performing Agency shall analyze and quantify the visibility performance of the marking and marker treatments. Performance metrics will include luminance, color, and their associated contrast with the surrounding simulated road surface. The contrast is a comparison of the treatment value to that of the surrounding surface. The Performing Agency shall collect data using the imaging spectroradiometer and analyze the data with the associated software. The software allows the user to select areas of the image to include in the analysis. Figure 4 provides an example of a marking that was captured during a wet-night test. The left image is the captured luminance of the marking and surrounding road surface. The right image is a false color version of the same image. The Performing Agency shall include color images in the analysis. These images allow the user to select specific areas to analyze for luminance or color.

For each of the test conditions, the Performing Agency shall develop a database of the results for each treatment. For each metric, the Performing Agency shall first characterize its performance using descriptive statistics and graphical plots to describe its range and variability across different materials and testing conditions. The goal of the analysis is to determine the contrast levels of the markings and markers when submerged and not submerged in water.

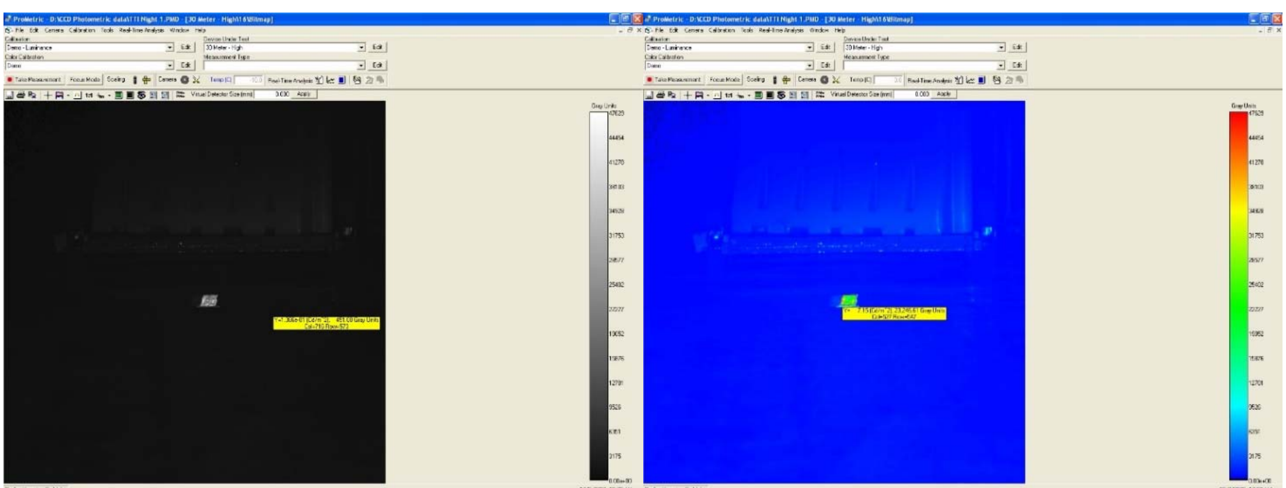

Figure 4. CCD Imaging Spectroradiometer Luminance and Color Analysis [Grey Scale (Left), False Color (Right)].

Deliverables: The Performing Agency shall submit Technical Memorandum TM-5 to RTIMain@txdot.gov, copying the RTI Project Manager, per the attached Project Deliverables Table. TM-5 shall document work performed within this Task, including material selection, test conduction, findings, and recommendations.

Task 6. Flood Sensors and Warning Devices Identification

The objective of Task 6 is to evaluate flood sensors and flood warning devices for roadways, and assess their cost/benefit. To meet this objective, the Performing Agency shall conduct a review of existing sensors and devices that are currently on the market including existing countermeasures utilized by the Receiving Agency and other off-the-shelf flood sensors and warning devises available. The Performing Agency shall assess their cost/benefit, including maintenance and applicability in urban and rural and high-volume and low-volume traffic settings.

The Performing Agency shall develop a metric to evaluate up to five flood sensors and warning device combinations. For the flood sensors, the Performing Agency shall develop a weighting system to judge the priority of incorporating the sensors in Tasks 7 and 8. The Performing Agency shall review the information for the flood sensors and agree on a single set of weighting factors for the following attributes:

- Applicability (in urban and rural and high volume and low-volume traffic settings),
- Robustness (e.g. ability to handle freezing),
- Durability (e.g. long term reliability),
- Accuracy (e.g. performance during fluctuating air/water temperature, dirty water, foam penetration, debris),
- Precision,
- Repeatability (linearity and hysteresis, output stability),
- Ease of use (ease of installation, ease of calibration, power requirements), and
- Cost.

Table 4 shows an example of how to acquire the rating of different flood sensors and warning device combinations. In the event that certain information is unavailable, the Performing Agency shall work with the Receiving Agency to modify the approach. For example, there may not be quantifiable information concerning a flood sensor or warning device concerning ease of use or cost. In this case, the Performing Agency shall give an overall score of 1 to 10 for those sensors based on their own judgment. The Performing Agency shall review and recommend to the Receiving Agency viable flood sensor and warning device options. Based on the recommended viable flood sensor options, the Receiving Agency will prioritize up to three flood sensors for conduction of laboratory testing to assess their capabilities and robustness.

If no other currently available off-the-shelf sensor can serve the purpose of this research, the Performing Agency shall develop and evaluate a new flood sensor.

Deliverables: The Performing Agency shall submit Technical Memorandum TM-6 to RTIMain@txdot.gov, copying the RTI Project Manager, per the attached Project Deliverables Table. TM-6 shall document work performed, findings, and recommendations.

Table 4. Evaluation Metric for Evaluating Flood Sensor Technologies.

	Applicability	Robustness	Durability	Accuracy	Precision	Repeatability	Ease of Use	Cost	Rating
Weighting Factor in %	20	10	10	10	10	10	20	10	
Ultrasonic Distance Sensor									
Laser Distance Sensor									
Submersible Pressure Transducers									
High Accuracy Pressure Transducers									
Bubbler Sensor									
Radar Level Sensor									
Float and Pulley Shaft Encoders									
Combination of Ultrasonic and Bubbler									
Combination of Bubbler and Pressure									
…..									

The Performing Agency shall conduct laboratory testing to assess the capabilities and robustness of up to three flood sensors and combination of sensors identified in Task 6. The experimental setup consists of a test tank, rugged staff gauge (as reference), flood sensors, water pump, temperature sensor, humidity sensor and the data acquisition system. The Performing Agency shall install the flood sensors, humidity sensor and temperature sensor and connect it to the data acquisition system. The Performing Agency shall use the water pump to change the water level in the test tank. The Performing Agency shall test the air temperature effect, water temperature effect, foam effect, debris effect, wave effects as well as the linearity, hysteresis, drying effects, and output stability on the output of the flood sensor.

Task 7. Develop Connected Vehicle Implementation

The Performing Agency shall design, build, and test a prototype system for providing alerts and warnings at low-water crossings using connected vehicle technology. The system shall use appropriate I2I and I2V technologies for providing flood conditions reports at low water crossing in a connected vehicle environment. The Performing Agency shall consider two different architectures: one integrating with the Receiving Agency's Lone Star Traffic Management System software and another as a standalone system for deployment at an isolated low-water crossing. The Performing Agency shall follow systems engineering principles to design, build and test the system. The Performing Agency budgeted a subcontractor who will assist with the following:

- Develop new use cases for providing connected vehicle alerts at low water grade crossings.
- Develop the system architecture and system requirements installing and integrating with flood monitoring equipment with the Receiving Agency's Lone Star Traffic Management System software.
- Develop interfaces for integrating flood-monitoring sensors with Roadside Unit (RSU) devices.
- Develop logic for using basic safety messages for issuing alerts traffic management centers (TMCs) of vehicle entering flooded crossings.

- Develop Traveler Information Message (TIM) sets for providing traveler alerts at low water and flood prone crossings.
- Develop prototype interface for displaying TIM alerts of flooded conditions in connected vehicles.
- Develop interfaces and logic for activating external communication devices (such as Dynamic Message Signs (DMS), flasher assemblies, etc.) to alert travelers to flooded road conditions.

To the extent reasonable, coordination between other CV projects will be considered, including but not limited to the Texas Connected Freight Corridor Advanced Transportation and Congestion Management Technologies Deployment (ATCMTD) program and the Safety through Disruption (SAFE-D) University Transportation Center (UTC) smart connected corridor.

The Performing Agency shall fund the construction of a prototype system for testing in their close-course environment facility. The purpose of the prototype is to demonstrate the functionality of the system using real systems typically deployed by the Receiving Agency. The Performing Agency shall obtain a traditional real flood detection and warning assembly typically used by the Receiving Agency to achieve this purpose.

The Performing Agency shall use the constructed equipment/instrumentation to conduct the research testing.

Deliverables: The Performing Agency shall submit Technical Memorandum TM-7 to RTIMain@txdot.gov, copying the RTI Project Manager, per the attached Project Deliverables Table. TM-7 shall document work performed, findings, and recommendations.

Task 8. Conduct Controlled Environment Testing Demonstration

The Performing Agency shall install and conduct demonstration testing of the prototype system developed in Task 7 during a simulated flood event. The Performing Agency shall complete developmental testing to verify the accuracy of the water level sensors and the functionality of the developed and applied technologies. The Performing Agency shall conduct a final set of tests to validate the accuracy of the overall connected system for those prioritized scenarios identified in Task 3.

To conduct the demonstration, the Performing Agency shall install the system in its test facility where flooding conditions can be simulated on a roadway. The Performing Agency shall use its controlled environmental test facility for conduction of the developmental testing. This environmental test facility is best suited to meet the needs to conduct the research test plan, only requiring minimal adaptation for testing completion (Figure 5). The concrete ditch is a recessed trench, 12.5 ft. wide, 400 ft. long, and 30 inches deep. A reinforced concrete liner was constructed on the bottom and both sides. Utilization of this existing concrete ditch equates to considerable cost saving for the Receiving Agency, rather than acquire the construction of the test site from an outside source.

Figure 5. Proposed Demonstration Site.

In conducting the demonstration testing, the Performing Agency shall equip at least two vehicles with connected vehicle technologies, including an in-vehicle system processing and displaying incoming flood conditions alerts and warning, dedicated short-range communication (DSRC) radios for providing two-way communications between the infrastructure and the vehicle, and appropriate software from processing alerts broadcast from the infrastructure. In this test, the Performing Agency shall drive the equipped vehicles, at highway speeds, towards a simulated low-water crossing and demonstrate the different types of messages that can be sent to the vehicle, based on the water levels and flood conditions at the low water crossing. The Performing Agency shall test the system under various water clarity and water depth conditions. The Performing Agency shall conduct this testing in close-course test environment.

As part of this task, the Performing Agency budgeted the subcontractor to assist in accomplishing the following:

- Develop a test plan for conducting the demonstration testing that matches the use cases identified in Task 7.
- Install and operate a complete prototype system at a simulated low-water crossing.
- Temporarily equip a least two passenger vehicles with connected vehicle test equipment.
- Conduct the demonstration testing according to the test plan.

Deliverables: The Performing Agency shall submit Technical Memorandum TM-8 to RTIMain@txdot.gov, copying the RTI Project Manager, per the attached Project Deliverables Table. TM-8 shall document work performed, findings, and recommendations.

ASSISTANCE OR INVOLVEMENT BY THE RECEIVING AGENCY

Throughout the course of this project, the Performing Agency shall rely on guidance and input from the Receiving Agency Project Team for identification of specific requirements and constraints; provide VoR baseline data; provide assistance in identifying and contacting the Receiving Agency districts for information on inventory and management approach of low water crossings; review and provide feedback on survey structure; review test scenarios; provide assistance in reviewing and approving work plan. Details of the requested assistance are provided below by task.

Task 1 – Provide VoR baseline data.

Task 2 – None.

Task 3 – Provide assistance in identifying and contacting the Receiving Agency districts for information on inventory and management approach of low water crossings.

Task 4 – Review and provide feedback on survey structure for investigation of Statewide management approaches of low water crossings.

Task 5 – Review and provide feedback on the research experimental design for marking and marker's evaluation.

Task 6 – Provide recommendation and feedback to the research approach for ranking identified flood sensors.

Task 7 – Provide an off-line, test version of Lone Star system where integration testing can be performed.

Task 8 – Review and approve test plan.

Project Deliverables
(Rev. 2/2018)
(RTI)

Project Deliverables Table

Project #	19-203	Project Name:	Traffic Safety Improvements at Low Water Crossings					Original	X	Created Date:	4/12/18
Primary 1:	TTI	FY '19	216,844.00	FY '20	221,837.00	Total	$ 438,681.00	Revised	R	Revision #	
Agency 2:		FY '19	-	FY '20	-	Total	$ -	Completed		Revision Date:	

Task	Agency #	Deliverables*	Task Start Date	Due Date (Budgeted Month End Date)	Monthly Budget Forecast **,*** Primary 1	Comments
1	1	Project Management and Research Coordination	9/1/2018	5/31/2020		
2	1	Literature Review and Crash Data Analysis	9/1/2018	2/28/2019		
3	1	Receiving Agency Low Water Crossing Management Approach	9/1/2018	1/31/2019		
4	1	Statewide Low Water Crossing Management Approaches	9/1/2018	2/28/2019		
5	1	Pavement Marking and Marker Evaluations for Low Water Crossing	9/1/2018	6/30/2019		
6	1	Flood Sensors and Warning Devices Identification	10/1/2018	8/31/2019		
7	1	Develop Connected Vehicle Implementation	4/1/2019	11/30/2019		
8	1	Conduct Controlled Environment Testing Demonstration	8/1/2019	3/31/2020		
1.1	1	MPR	9/1/2018	9/30/2018	2,602.00	
1.2	1	MPR	10/1/2018	10/31/2018	3,903.00	
1.3	1	MPR	11/1/2018	11/30/2018	5,204.00	
1.4	1	MPR	12/1/2018	12/31/2018	6,505.00	
1.5	1	MPR	1/1/2019	1/31/2019	7,806.00	
1.6	1	MPR	2/1/2019	2/28/2019	10,408.00	
1.7	1	MPR	3/1/2019	3/31/2019	11,710.00	
1.8	1	MPR	4/1/2019	4/30/2019	13,011.00	
1.9	1	MPR	5/1/2019	5/31/2019	14,312.00	
1.10	1	MPR	6/1/2019	6/30/2019	15,613.00	
1.11	1	MPR	7/1/2019	7/31/2019	18,215.00	
1.12	1	MPR	8/1/2019	8/31/2019	20,817.00	
				Total	130,106.00	
1.13	1	MPR	9/1/2019	9/30/2019	5,326.00	
1.14	1	MPR	10/1/2019	10/31/2019	7,986.00	
1.15	1	MPR	11/1/2019	11/30/2019	10,648.00	
1.16	1	MPR	12/1/2019	12/31/2019	13,310.00	
1.17	1	MPR	1/1/2020	1/31/2020	14,641.00	
1.18	1	MPR	2/1/2020	2/29/2020	15,972.00	
1.19	1	MPR	3/1/2020	3/31/2020	18,634.00	
1.20	1	MPR	4/1/2020	4/30/2020	21,296.00	
1.21	1	MPR	5/1/2020	5/31/2020	25,289.00	
				Total	133,102.00	

Task	FY19 Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	FY20 Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	FY21 Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X															
2	X	X	X	X	X	X																														
3	X	X	X	X	X																															
4	X	X	X	X	X	X																														
5	X	X	X	X	X	X	X	X	X	X																										
6		X	X	X	X	X	X	X	X	X	X	X																								
7								X	X	X	X	X	X	X	X																					
8												X	X	X	X	X	X	X	X																	
1.1	X																																			
1.2		X																																		
1.3			X																																	
1.4				X																																
1.5					X																															
1.6						X																														
1.7							X																													
1.8								X																												
1.9									X																											
1.10										X																										
1.11											X																									
1.12												X																								
1.13													X																							
1.14														X																						
1.15															X																					
1.16																X																				
1.17																	X																			
1.18																		X																		
1.19																			X																	
1.20																				X																
1.21																					X															

Project Deliverables Table

Project Deliverables (Rev. 2/2018) (RTI)

Project #	19-203	Project Name:	Traffic Safety Improvements at Low Water Crossings					Original	X	Created Date:	4/12/18
Primary 1:	TTI	FY '19	216,844.00	FY '20	221,837.00	Total	$ 438,681.00	Revised	R	Revision #	
Agency 2:		FY '19	-	FY '20	-	Total	$ -	Completed		Revision Date:	

Task	Agency #	Deliverables*	Task Start Date	Due Date (Budgeted Month End Date)	Monthly Budget Forecast **,*** Primary 1	Comments	FY19												FY20												FY21											
							Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
2	1	Value of Research -VoR	10/1/2019	10/31/2019	4,336.00			X																																		
2	1	Technical Memorandum TM 2	2/1/2019	2/28/2019	9,975.00							X																														
3	1	Technical Memorandum TM 3	1/1/2019	1/31/2019	16,047.00						X																															
4	1	Technical Memorandum TM 4	2/1/2019	2/28/2019	17,781.00							X																														
5	1	Technical Memorandum TM 5	5/1/2019	5/31/2019	18,866.00										X																											
6	1	Technical Memorandum TM 6	8/1/2019	8/31/2019	19,733.00													X																								
				Total	86,738.00																																					
7	1	Technical Memorandum TM 7	11/1/2019	11/30/2019	24,402.00																X																					
8	1	Technical Memorandum TM 8	3/1/2020	3/31/2020	26,177.00																				X																	
1	1	R1- Research Report	4/1/2020	4/31/2020	21,740.00																					X																
1	1	PSR - Project Summary Report	4/1/2020	4/31/2020	16,416.00																					X																
				Total	88,735.00																																					
				Project Total	$ 438,681.00	$ -		VoR			TM3	TM2	TM4			TM5		TM6			TM7				TM8	R1, PSR																

Comments:
Notes:
Deliverables can only be invoiced one (1) time.
*Monthly Progress Reports (MPR/Task Activities) outlining work and staff utilization are to be completed monthly and submitted to RTIMAIN@txdot.gov no later than the 3rd Business day of the following month.
**Amounts on this form are estimates of Exhibit A; see University Handbook, Chapter 3, Section 5.
Per CRIA Article 13, Universities shall submit invoices for Project Deliverables no more frequently than monthly.
See University Handbook for explanation on all items, if necessary
This electronic form contains formulas that may be corrupted when adding or deleting rows, or by conversion of the spreadsheet. The University is responsible for the accuracy of the form.

Background and Significance of Work

Almost every year Texas leads the Nation in flood-related deaths and property damage. The geography of the State makes it a unique position to receive both frontal tropical hurricanes and large air masses that can bring in air moistures in almost any direction and drop rain with world class intensity. Texas holds half of the 12 world records of rainfall in 48 hours or less, which are mainly distributed on the Golf Coast area and the Balcones Escarpment in Central Texas, also known as the Flash Flood Alley because of its typical flash storm producing extreme rainfall. Almost all Texas major cities lie in the paths of these storms, and since Texas has a predominant climate with long dry periods between storms, it is easy to forget the common cycle and become victim of Texas flood. For the cities of Austin and San Antonio, in fact, flash flooding is the number one natural disaster threat. Although both cities manage programs to help prevent and /or reduce flood problems, still in the past three decades Texas has done little to secure its floodplains against torrential downpours.

Figure 6. Example of Low-Water Crossing Site.

Texas has been reported to lead the nation in flood-related deaths, with the majority of deaths caused by people attempting to drive through moving water (Figure 6). Flash flooding is most severe in urban areas since urbanization increases runoff by 2 to 6 times over what would occur in natural terrain. Flood waters can fill streets, freeway underpasses, and parking lots and can sweep away cars. People might attempt to cross a flooded roadway not realizing its depth or, especially at nighttime during heavy storms, it might be difficult to see that a road is flooded. It was established that it only takes 18-24 inches of moving water to sweep away a truck, and 6 inches to carry away a small car.

The National Weather Service (NWS) records an average of 94 flood fatalities between 1980 and 2011. The US Department of Commerce and the NWS also report that approximately 53% of flood fatalities are related to driving.

The National Climate Data Center records suggest the year 2015 was the most expensive year in Texas' history regarding floods-related damage. In 2015, widespread flooding has caused approximately $3 billion damage to Texas, with most of these costs related to damage to soaked roads or public infrastructure. With flash flooding typically lasting on the order of 6 hours or less, less warning lead time is provided which requires quick action on the part of the public.

In the past, a common practice was to wait for someone to report flooding on roads, and then send out a crew to place barricade to prevent motorists from driving in the flooded roadway (Figure 7). Placing

Figure 7. Temporary Signs and Barricades at Low-Water Crossing.

temporary signs and barricades requires significant field crew effort and they cannot be everywhere at once.

Relevant Studies

Low water crossings have been widely used as an economical alternative to culverts and bridges where there is low number of floods. The lack of appropriate countermeasures has posed safety concerns for many low water crossings in Texas. A 2011 TxDOT study, TxDOT project 0-6262-1, developed guidelines and recommendations for signing uniformity for low water crossings (3). Signing guidelines were created for the following situations: 1) roadway sections that have several low water crossings during heavy rainfall, 2) locations with low water crossings, and 3) temporary road closures due to high water. This study surveyed 200 participants in four Texas cities: San Antonio, San Angelo, Odessa, and College Station. The survey questions were designed to test participant responses to and preferences for selected warning signs and flood gauges. The driver comprehension survey results supported the findings from the focus groups regarding drivers' decision processes when confronted with a water-covered road. This project also developed criteria for when to implement active water level detection and advance warning systems at low-water crossings and flood-prone roadway sections.

The Iowa Department of Transportation (IOWADOT) conducted a study in 2003 to provide a low water crossing location database and design guidelines for those locations (4). The study included three types of low water crossings: a) unvented fords, b) vented fords, and c) low water bridges. This guide provided a simplified approach to low water crossing selection and design. After weighing public opinion and considering potential liability, the study developed steps that the jurisdictions needed to follow (as shown in Figure 1). This study provided design guidelines for three types of crossings. Additionally, guidelines for inspection and maintenance, and application of traffic control devices were described.

The Illinois Department of Transportation (IDOT) recently conducted a study to design the guidelines for low water crossings (5). The results from a survey conducted among the county engineers in Illinois about their experience with low water crossings are presented, along with commonly used low water crossings, site considerations, selection criteria, and signage requirements. Additionally, case studies, design examples, and permitting requirements for low water crossings are included in the report.

Crash Data Analysis

Improving the safety of road users remains a top priority of transportation agencies. Traffic safety research includes a wide variety of research areas and the most prominent one is crash data analysis. The established approach to traffic safety analysis has been to determine relationships between the traffic characteristics (e.g., flow, speed), roadway and environmental conditions (e.g., roadway geometry, weather conditions), driver characteristics (e.g., age, gender, intoxication), and crash occurrence. Another most important tasks in highway safety analysis is the identification of locations, sites, scenarios, countermeasures that might be in need of engineering improvements, to reduce the number of crashes or crash severities. Part of the reason why some drivers enter flooded roadway sections is that they have trouble judging the speed and depth of the water. This is especially true if the water is muddy or if visibility is low (such as during a heavy rain or at night).

The CRIS database of crashes in Texas does not explicitly distinguish low water crossing or flood related crashes. Therefore, the exact number of crashes involving low water crossings in Texas is unknown, but anecdotal evidence suggests many crashes occur annually. The daily rainfall data from National Oceanic and Atmospheric Administration (NOAA) will be useful in identifying the temporal patterns of flood occurrences. An existing database with 8,339 low water crossings in Texas can be used in identifying low water crossing related crashes. The Performing Agency envisions to develop a low water crossing crash database by using latest five years of CRIS data. Additionally, key contributing factors will be identified using predictive modeling tools.

The extant literature contains several examples of studies and road agencies that have put a lot of thought and invested significant resources in determining how to effectively identify low water crossing crashes with inclusion of design guidelines and traffic control measures.

Pavement Markings and Markers

Retroreflective pavement markings and markers [raised retroreflective pavement markers (RRPMs)] are commonly used on roadways to provide delineation of the travel path and to provide other information to road users. The retroreflectivity property of the markings and markers makes them visible at night when illuminated by vehicle headlamps. The presence of water in the form of rain and typical sheeting of rainfall across a roadway, will reduce the visibility of most markings. RRPMs are not affected by the rain as substantially as markings due to their raised profile above the road surface. The following sections will describe a selection of past work that has looked at the visibility of markings and markers, with a focus on wet conditions.

Markings

There are specific types of preformed markings (pavement marking tape) and retroreflective optics that have been designed to perform better in wet conditions than standard materials. The marking tape generally has a structured texture, and the optics are usually larger than standard optics and have a high refractive index. Several research studies have been completed that evaluated the visibility performance of these marking systems compared to standard markings in wet-night conditions (*6*-*11*). These studies looked at the photometric performance and human factor visibility performance of the various systems to establish their benefits in wet-night conditions. The performance of the wet weather designed products was always superior to that of the standard pavement marking products. These studies evaluated the markings in typical rainfall conditions. There have not been studies where the performance of markings in a submerged condition was part of the evaluation.

A research study conducted by the Texas Transportation Institute (3) evaluated signing and marking strategies for low-water crossings and flood-prone areas. The study had several findings and recommendations related to pavement markings. Focus group results indicated that, "markings or railing should be used to identify the edges of the road under the water." Visibility of the pavement markings was noted as a clue that drivers use to judge water depth to determine if the roadway is passable or not. The study found that the inclusion of a stop bar marking upstream of the water crossing did not alter participant responses.

Markers

Pavement markers are visible at night due to their retroreflectivity properties or from internal illumination. RRPMs are typically used to supplement pavement markings to improve visibility during wet-night conditions. In wet-night visibility tests RRPMs have been shown to provide substantially longer preview distances than standard or wet-reflective pavement markings (*6*). The testing was conducted during standard rain fall rates. The performance of RRPMs or internally illuminated markers when they are fully submerged in water has not been evaluated. Additional evaluation techniques to evaluate markers in a variety of conditions are under development (*3*). These tests include evaluating the markers using an imaging spectroradiometer. The imaging spectroradiometer evaluation technique will allow for markings and markers to be evaluated when they are view in a submerged situation.

Many accidents at low water crossings occur at night. Retroreflective pavement markings and markers are commonly used on roadways to provide delineation of the travel path and to provide other information to road users. The retroreflectivity property of the markings and markers makes them visible at night when illuminated by vehicle headlamps. A common problem with pavement markings is that during wet-night situations the markings often lose their retroreflectivity properties, and thus their visibility. Advances in technologies in recent years have yielded new marking technologies that allow markings to maintain their retroreflectivity in wet situations (Figure 8).

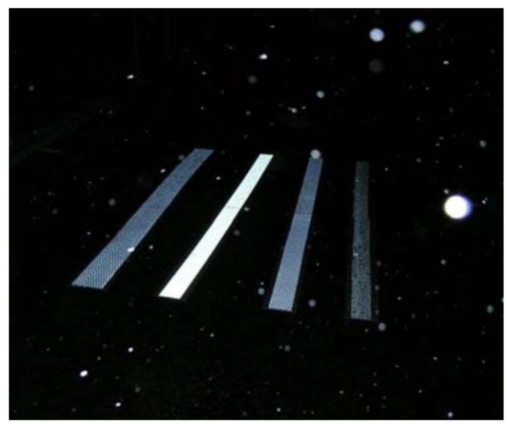

Figure 8. Pavement Marking Samples at Night in Rain.

Markers are visible at night due to their retroreflectivity properties or from internal illumination. Technological advances in LEDs and in solar power sources have allowed markers to be internally illuminated without the need for wiring connected to a power source. Typical markers are surface applied and are raised slightly off the road, generally referred to as raised retroreflective pavement markers (RRPMs). Internally illuminated markers can either be surface applied (raised) or recessed into the road surface. Figure 9 **Error! Reference source not found.** provides an example of recessed, internally illuminated markers delineating the roadway. RRPMs are typically used to supplement pavement markings. Due to their raised nature RRPMs perform very well in wet conditions, but will they be beneficial when fully submerged in water? Would internally illuminated markers provided greater benefits when fully submerged in water, because they do not rely on the vehicle headlamps as the light

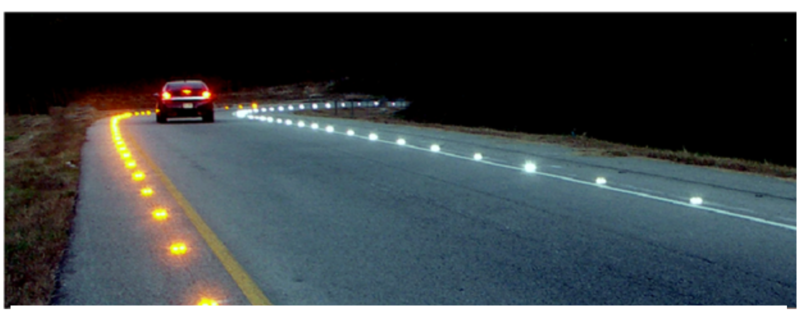

Figure 9. Recessed Illuminated Pavement Markers. (Photo courtesy of LaneLight.com)

source? Internally illuminated markers can be a variety of colors. Specific use of red, yellow, or white markers may be beneficial as part of a comprehensive warning system.

In daytime conditions the difference in color between the marking and the surrounding pavement typically dictates the visibility of a marking. In situations where contrast may be low or additional visibility is needed, pavement markings are placed with additional black material to increase visibility (Figure10). This addition of black material may be beneficial during the day and at night, but would it be beneficial when the markings are submerged in water?

Figure 10. Yellow and White Bordered Contrast Pavement Markings.

Houston Solution

Recent efforts were sustained by the city of Houston to exploit technology with the scope of developing methods for quickly assisting motorists during floods. Specifically, the Houston's Street and Drainage Division has installed the first ever electronic gate at underpasses that are known to be flooded during rainstorms (Figure 11). When electronic sensors detect flooding, warning lights will flash and a gate will lower, like at a railroad crossing (1). A Flood Information Graphical System (FIGS) is also being developed as a web-based system to show where water is covering roadways and display data on online traffic maps and to effectively informing and navigating emergency vehicles through flooded streets. Installing permanent gates (or even signs), however, has proven to be costly and difficult to maintain.

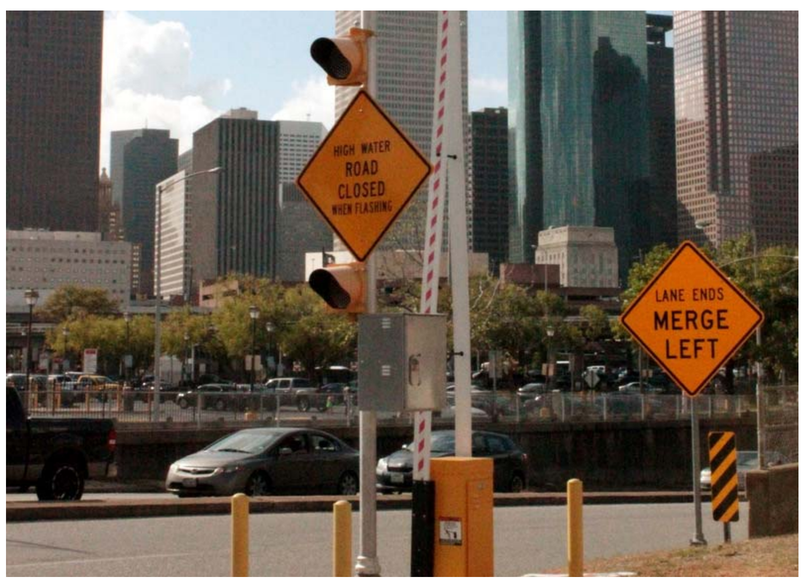

Figure 11. Flood Warning Gate Installed in Houston.

Austin ATXFloods Website

With a general 75% of flood fatalities occurring in vehicles, the City of Austin and its partnering communities independently monitor and close flooded roads in their respective jurisdictions. ATXFloods is maintained by the City of Austin Flood Early Warning System (FEWS) team, which monitors weather and road conditions 24-7 on an on-call basis (Figure 12). FEWS keeps the map and closure information as up-to-date as possible based on the best information currently available. ATXFloods Alerts subscribers are notified of Austin's first road closure during a storm by text and/or email, and additional updates on road closures are posted in real-time at ATXFloods website.

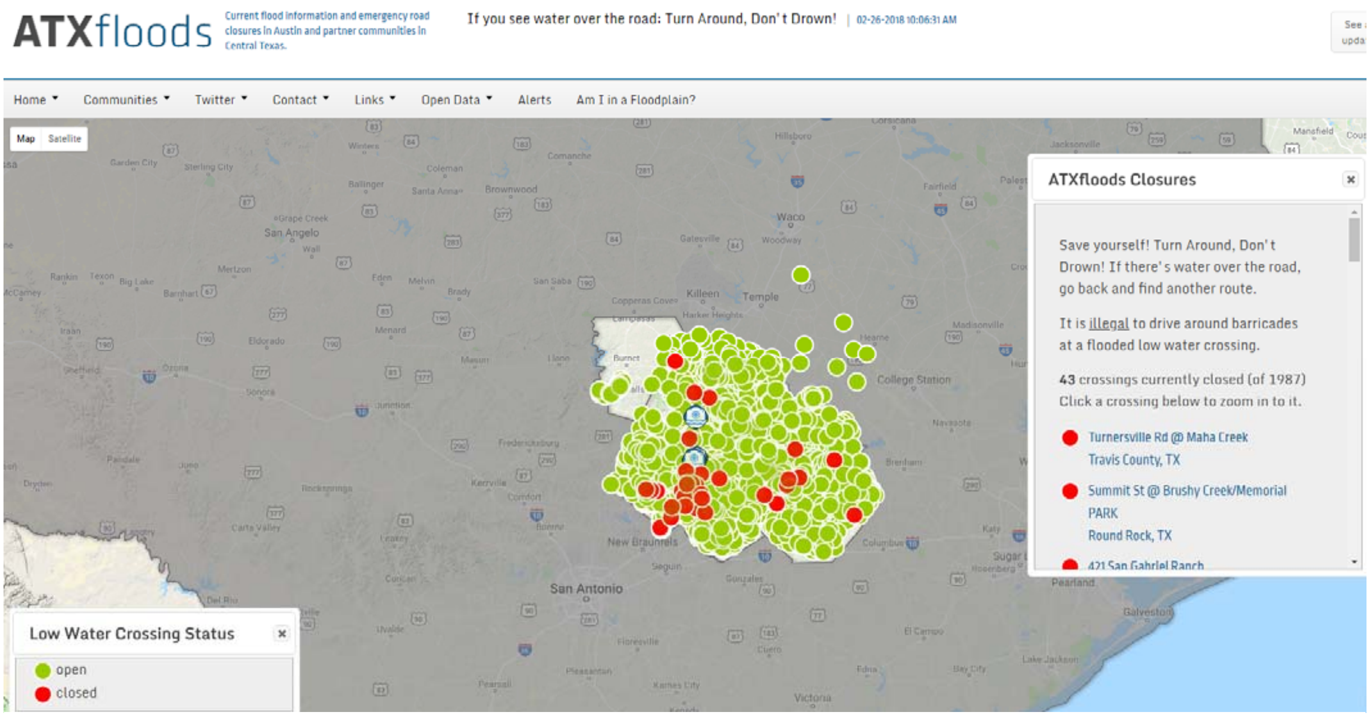

Figure 12. ATXFloods Website (2).

Both above methods, however, lack the ability to directly communicate in real time to motorists whether the road on which they are traveling has been flooded to a level that it becomes dangerous to be traversed. For the City of Austin, for example, motorists need to be subscribers of the ATXFloods Alerts to receive notifications, and even in that case, notification is only related to first road closure, based on monitoring road conditions on an on-call basis. Subsequent updates and other road closures notifications are only available in real-time on their website. Therefore, it can be extremely hard, sometimes maybe impossible for the motorists to have a complete knowledge of the road closures. As for the system adopted by the Houston's Street and Drainage Division, once the sensors detect flooding, a gate is supposed to lower and impede the motorists to proceed on that specific road. However, still no system directly notifies the motorists of a street flooding and the drivers realize of the road closure only once reached that specific location. Developing a system that is able to directly alert drivers of a road closure before they reach that location would allow the motorists to have the time to make appropriate decision on alternative routes. Thus, it would increase safety by re-directing the drivers to safer itineraries, and considerably lower the traffic around those areas that are flooded, allowing maintenance workers and /or emergency vehicles to more safely and rapidly reach those areas when needed.

Connected Vehicle Technology

The term "Connected Vehicle" refers to a vehicle that has been equipped with advanced communications and other technologies that allows it to "talk" and exchange information with other vehicles, the roadside infrastructure, and other devices (such as smartphones or similar devices) without the intervention of the driver (12). Through this connectivity, "applications" running on these devices provide drivers with better "situational awareness" of the operating environment, and issue alerts and notifications. Better situational awareness can lead to improved safety through reduced collisions, improved mobility, and enhanced environmental sensitivity.

Connected vehicles (CV) depend on low latency, highly reliable communications system. Currently, most deployments use dedicated short-range communication (DSRC) to facilitate vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-other device (V2X) communications. DSRC is a two-way radio communication operating on the 5.9GHz band. The FCC set aside this band specifically for purposes of providing connected vehicles communications. Efforts are underway to require automobile manufacturers to equip all new light vehicles sold in the U.S. with DSRC radios. These radios would transmit basic information about the location, speed, and critical operations of the vehicle. Applications that run either on vehicles or infrastructure devices would use the data to improve safety, mobility, and the environment. Public agencies could also use this information to augment existing detection systems to increase their awareness of the operating conditions of the infrastructure and make better command and control decisions to improve mobility and operating efficiency of the transportation system.

The term "automated vehicle" refers to a class of vehicles where automated processes are responsible for performing some or all of the driving functions (13). As shown in Figure 13, the vehicle can operate with different levels of automation ranging from no automation to fully autonomous. A fully autonomous

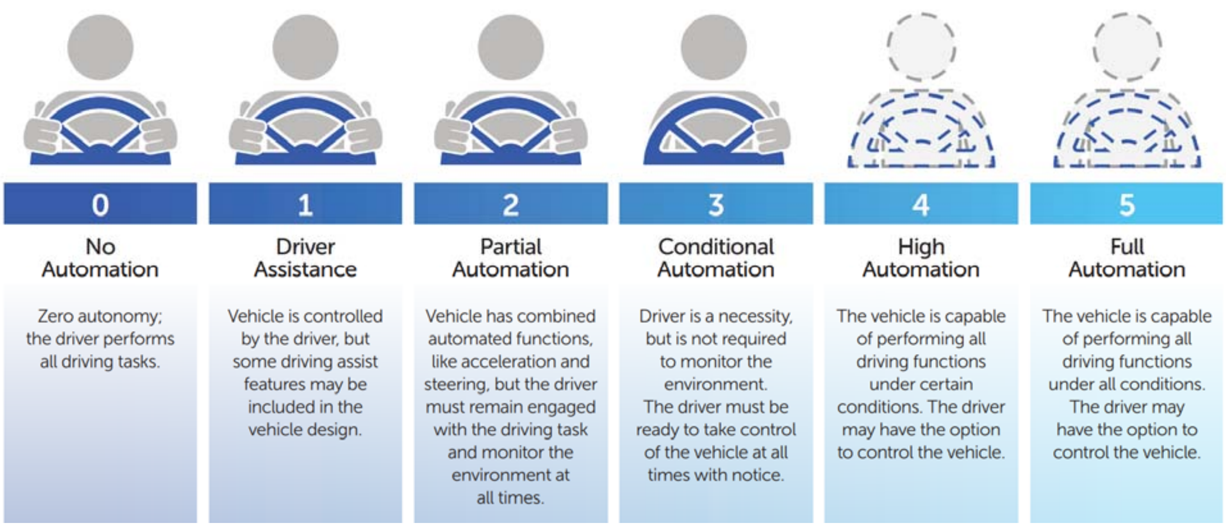

Figure 13. Levels of Vehicle Automation (adapted from the Society of Automotive Engineers

vehicle is one in which automation controls all the driving functions to the point where the vehicle can operate safely without intervention from a human operator. A connected vehicle does not have to have any level of automation, but it is highly likely that a vehicle cannot be fully autonomous without any level of connectivity to other vehicles and the infrastructure.

Other the past decades, the US Department of Transportation (USDOT) has made significant investments in the connected vehicle program. One of USDOT's early deployment was the Safety Pilot

Model Deployment (SPMD). The objective of SPMD was to provide data to support the evaluation of DSRC in V2V safety applications. As part of the SPMD, the National Highway Transportation Safety Administration (NHTSA) deployed connected vehicle technologies in over 2,800 vehicles and 25 infrastructure sites in Ann Arbor, Michigan. Safety-oriented applications, such as forward collisions warning, electronic brake lights, red-light running, etc. were tested in an operational environment. This model deployment demonstrated the value of implementing connected vehicle technologies to improve safety.

The Connected Vehicle Pilot Deployment (CVPD) program is another example of an ongoing connected vehicle initiative. The purpose of the CVPD program is to spur innovation among early adopters of connected vehicle application concepts, using the best available and emerging technologies (12). The CVPD integrate connected vehicle research concepts with traditional traffic management assets to enhance existing operational capabilities in a real operational region or corridor. The U.S. Department of Transportation (USDOT) awarded three cooperative agreements to design, build, and test the ability of connected vehicle technologies to improve safety, mobility, the environment, and public agency efficiencies. The three sites selected for this effort were New York City (NYC), Tampa, and I-80 in Wyoming (14, 15)

TxDOT has also been active in investigating the potential safety and mobility benefits of connected vehicles. Recently, TxDOT completed a research project that looked at applying connected vehicle technologies to issue of wrong-way driving (16). As part of this effort, the research team developed a concept of operations, functional requirements, and high-level system design for a Connected Vehicle (CV) Wrong-Way Driving (WWD) Detection and Management System. This system was designed to detect wrong-way vehicles, notify the traffic management entities and law enforcement personnel, and alert affected travelers. The system uses roadside alert (RSA) messages to provide warning to CVs about approaching wrong-way drivers. The research team recommended the development of a proof-of-concept test bed at an off-roadway location before implementing a model field deployment of the system on an actual roadway in Texas. The purpose of the test bed is to provide an offline location for the research team to test and fine-tune the system components and operations prior to installing them on the open roadway.

References

1. Dave Fehling, City of Houston Installing Warning Gates at Flood-Prone Underpasses, Houston Public Media, Last retrieved April 09, 2018, https://www.houstonpublicmedia.org/articles/news/2015/08/19/119096/city-of-houston-installing-warning-gates-at-flood-prone-underpasses/
2. ATXfloods, Last retrieved April 09, 2018, https://www.atxfloods.com/
3. Balke, K., Higgins, L., Chrysler, S., Pesti, G., Chaudhary, N., and Brydia, R., 2011. Signing Strategies for Low Water and Flood-Prone Highway Crossings. Report No. FHWA/TX-12/0-6262-1.
4. Iowa Highway Research Board, 2003. Low Water Stream Crossings in Iowa: A Selection and Design Guide.
5. Bhattarai, R., Kalita, P. Gautam, S., Howard, H., Svendsen, N., and Gambill, D, 2016. Development of Low-Water Crossing Design Guidelines for Very Low ADT Routes in Illinois. Report No. FHWA-ICT-16-020.
6. Carlson, P., J. Miles, A. Pike, E. Park. Evaluation of Wet-Weather and Contrast Pavement Marking Applications: Final Report. Report 0-5008-2. Texas Transportation Institute, College Station, TX. August 2007.

7. Pike, A., H.G. Hawkins, P. Carlson. Evaluating the Retroreflectivity of Pavement Marking Materials Under Continuous Wetting Conditions. Transportation Research Record: Journal of the Transportation Research Board, No. 2015, Transportation Research Board, Washington DC, 2008.
8. Pike, A., P. Carlson, J. Meyer, R. Gibbons. Florida's Wet Weather Demonstration Project. Report BDI91. Texas Transportation Institute, College Station, TX. January 2009.
9. Pike, A., and B. Schwenn. Evaluation of ASTM Standard Test Method E2177. Transportation Research Record: Journal of the Transportation Research Board, No. 2272, Transportation Research Board, Washington DC, 2012.
10. Pike, A., P. Carlson. Pennsylvania Turnpike: Dry and Wet Retroreflectivity Test Results of Different Combinations of Retroreflective Optics Installed in an Epoxy Binder. Texas A&M Transportation Institute, College Station, TX. November 2013.
11. Pike, A. Laboratory-Based Retroreflectivity Assessment of Raised Retroreflective Pavement Markers. Transportation Research Record: Journal of the Transportation Research Board, No. 2612, Transportation Research Board, Washington DC, 2017.
12. Connected Vehicle Basics. Website. US Department of Transportation, ITS Joint Program Office. Available at https://www.its.dot.gov/cv_basics/cv_basics_what.htm. Accessed January 8, 2018.
13. Automated Driving Systems 2.0: A Vision for Safety. US Department of Transportation, National Highway Safety Administration. Washington D.C. September 2017. Available at https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/13069a-ads2.0_090617_v9a_tag.pdf. Accessed January 8, 2018.
14. Connected Vehicle Pilot Deployment Program. Factsheet. Available at https://www.its.dot.gov/factsheets/pdf/JPO_CVPilot.pdf Accessed January 8, 2018.
15. Connected Vehicle Pilot Deployment Program. Available at https://www.its.dot.gov/pilots/pilots_overview.htm. Accessed January 8, 2018.
16. Melisa D. Finley, Kevin N. Balke, Rajat Rajbhandari, Susan T. Chrysler, Chiara Silvestri Dobrovolny, Nada D. Trout, Paul Avery, David Vickers, and Cameron Mott. Conceptual Design of a Connected Vehicle Wong-way Driving Detection and Management System. FHWA-TX-16/0-6867-1. Texas A&M Transportation Institute, Texas A&M University System. College Station, TX. April 2016.

Research Staff and Facilities

Project No: 19-203 **Date:** April 12, 2018

Research Agency(s): Texas A&M Transportation Institute

1. Project Supervisor's Experience

Chiara Silvestri Dobrovolny, Ph.D.
Associate Research Scientist
Roadside Safety and Physical Security Division
Texas A&M Transportation Institute
(979) 845-8971 | c-silvestri@tti.tamu.edu

Dr. Silvestri Dobrovolny is an Associate Research Scientist at the Roadside Safety and Physical Security Division at TTI. She holds a Laurea in Aerospace Engineering from Politecnico of Milan, Italy, and a Ph.D. in Civil Engineering from Worcester Polytechnic Institute (WPI). Dr. Silvestri Dobrovolny directs research for various State Departments of Transportation (DOTs), Federal Highway Administration (FHWA), Roadside Safety Pooled Fund Group, and University of Transportation Center (UTC) that design and test roadside safety hardware and physical security systems to improve the safety of transportation. These projects have used computer modeling, statistical evaluation, full-scale crash testing, and benefit-cost analysis to develop improved roadside hardware and installation practices aimed at improving roadside safety.

Dr. Silvestri Dobrovolny specialized in the field of structures with an emphasis on occupant protection and highway safety. She has extensive experience with the evaluation of a number of roadside safety devices, including guardrails, median barriers, guardrail/bridge rail transitions, and breakaway sign supports, and has developed guidelines for their use. She has co-authored more than 50 publications and presentations in this field.

Her active research includes finite element methods applied to different fields, from impact and structural mechanics to biomechanical applications. Dr. Silvestri Dobrovolny has a wide range of experience in the development, validation, and use of computer simulation in the design, analysis, and evaluation of highway safety appurtenances and roadside geometric features. Dr. Silvestri Dobrovolny's research is aimed at reducing the risk of injury in motor-vehicle crashes by investigating the causes and patterns of injury in real-world crashes, by performing computational simulations to evaluate the human mechanical response to mechanical loading, and by developing criteria for assessing the occupant injury risk. Her engagement includes investigation of motorcycle impacts with employment of anthropomorphic test devices (ATDs). She is involved in the evaluation of human dynamics and injury mechanism for motorcycle riders deriving from upright oblique impacts against roadside safety hardware. Dr. Silvestri Dobrovolny has lead multiple efforts through computer simulations and full-scale testing to develop motorcycle-friendly barriers with the scope to reduce riders' injury severity derived from upright impacts.

Dr. Silvestri Dobrovolny is active with multiple technical groups and organization within the roadside safety community: she is currently serving as a member of Transportation Research Board Committee ANF30, "Motorcycles and Mopeds", and she is also involved with the TRB AFB20 "Roadside Safety Design", the TRB ANB45 "Occupant Protection", as well as the American Association of State Highway and Transportation Officials (AASHTO) Task Force 13 and the Roadside Safety Pooled Fund Group.

Her research accomplishments include suggestion of selection, placement, crashworthy analysis and policy definition with regards to roadside barrier installation, evaluation of roadside safety motorcycle-friendly retrofit systems through finite element modeling and full-scale crash testing with employment of anthropomorphic test devices (ATDs).

2. Research Staff Experience

Kevin Balke, PH.D., P.E., PMP
Senior Research Engineer
System Reliability Division
Texas A&M Transportation Institute
Tel: (979) 845-9899 | E-mail: k-balke@tti.tamu.edu

Dr. Balke has more than 31 years of overall experience in the field of transportation. His specific areas of expertise include Intelligent Transportation Systems (ITS), Connected Vehicles, Freeway Operations and Management, Traffic Signal Systems and Control, Weather Responsive Traffic Management, Traveler Information Systems, Incident Management, and Work Zones. Dr. Balke has extensive experience in the design and evaluation of traffic management strategies, control devices, and technology. From 2002-2012, he served as the Program Manager of the TransLink® Research Program, a multi-modal, public/private research program to develop and implement new concepts and technologies for linking together the different elements of the transportation system to improve the overall operation and efficiency of the entire transportation system. In addition to overseeing the daily operations of the Program, he was also active in many TransLink® research projects related to regional transportation operations, traffic signal systems, ITS data management and archiving, system evaluations, and connected vehicles. Sponsors of his research include FHWA and the Texas Department of Transportation. In addition to these research activities, he has been active at the national level in conducting training courses for the National Highway Institute, assisting in standards development, and conducting research of national significance. He has served as principal investigator on several connected vehicle projects, including the development of a prototype Signal Phase and Timing (SPaT) application, a queue warning/speed harmonization prototype, and an integration of roadside equipment – all for the Federal Highway Administration. Dr. Balke is serving as a primary researcher on a study to develop a queue warning/traffic delay forecast application for the Insterstate-35 construction project. Dr. Balke is also active at the national research level, completed a NCHRP Synthesis on Institutional

Agreements and Arrangements for Regional Traffic Signal Operations, and has conducted numerous research projects for FHWA's Road Weather Management Program and Work Zones Program. Before returning to TTI, Dr. Balke worked as a traffic engineer in the Transportation and Public Works Department with the City of Austin, Texas.

Roger P. Bligh, Ph.D., P.E.
Senior Research Engineer
Manager, Roadside Safety Program
Director, Center for Transportation Computational Mechanics
Regents Fellow
Texas A&M Transportation Institute
(979) 845-4377 | 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 30 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 $26 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 is also currently co-chairman of the “Bridge Rail and Transitions” subcommittee of Task Force 13, “Standardization of Details for Bridge and Road Hardware,” and a member of American Traffic Safety Services Association’s (ATSSA’s) “Guardrail Committee,” “Education Task Force,” and “MASH Joint Task Force.” Dr. Bligh 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 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.

Adam Pike, P.E.
Associate Research Engineer
Program Manager
Signs & Marking Program
Texas A&M Transportation Institute
(979) 862-4591 | A-Pike@tti.tamu.edu

Adam M. Pike is an Associate Research Engineer and Program Manager in the Signs and Markings Program at the Texas A&M Transportation Institute. Mr. Pike has over 13 years of experience in the signs and markings program, participating in research studies for the Texas Department of Transportation, the Federal Highway Administration, state agencies, and private industry. He has conducted research in areas of traffic signing, pavement marking, and work zones with an emphasis on traffic engineering principles, visibility needs, human factors, cost-benefit analysis, safety implications, and infrastructure needs of advanced driver assistance systems and autonomous vehicles. Mr. Pike has been the author or co-author on over 30 articles, papers, or reports.

Mr. Pike’s primary research topics currently under evaluation are the impact of milled rumble strip alternatives, total cost of pavement markings, pavement markings for autonomous vehicles, retroreflective raised pavement markers, and wet-retroreflectivity for pavement markings. Mr. Pike has conducted research focusing on pavement markings and markers in wet conditions, and has helped develop specifications and test methods to implement and test these devices in wet conditions. Mr. Pike is currently the program coordinator for the Texas A&M Transportation Institute Mobile Retroreflectometer Certification Program that is being conducted in cooperation with the Texas Department of Transportation. Mr. Pike is conducting research evaluating mobile retroreflectometers, and verification of contractor collected mobile retroreflectivity data.

Mr. Pike holds a Master of Science degree in Civil Engineering from Texas A&M University in College Station, Texas, and a Bachelor of Science degree in Civil Engineering from Clarkson University in Potsdam, New York. In 2009, Mr. Pike received the TTI/Trinity New Researcher Award. In 2012, Mr. Pike received a Young Professional Best Paper Award from the Transportation Research Board, Maintenance and Preservation Section. In 2016, Mr. Pike received the Fred Burggraf Award, for the best young professional paper from the Transportation Research Board. Mr. Pike is active with multiple committees of the Transportation Research Board, and is a member of the Signing and Marking Materials Committee (AHD55). Mr. Pike is active with ATSSA and multiple committees of ASTM International. Mr. Pike is a registered professional engineer in Texas, No. 105117.

Stefan Hurlebaus, Ph.D.
Research Scientist
Texas A&M Transportation Institute
(979) 845-9570 | shurlebaus@civil.tamu.edu

Dr. Hurlebaus has significant background in experimental testing in the laboratory and in the field as well as in structural modeling. He is teaching class on ‘Structural Analysis’, ‘Sensor Technology’, ‘Smart Structures’ and ‘Experimental Methods in Civil Engineering’ at Texas A&M University. Dr. Hurlebaus is the Division Head for the Construction, Geotechnical and Structural Engineering (CGS) Division within the Zachry Department of Civil Engineering. Dr. Hurlebaus is the PS on the TxDOT funded projects 0-6893 “Strengthening of Existing Inverted-Tee Bent Cap Ledges” and 0-6893 “Fracture Critical Steel Twin Tub Girder Bridges”. He was the principal investigator of the NCHRP funded project 14-28 “Condition Assessment of Bridge Post-Tensioning and Stay Cable Systems Using NDE Methods” and was a researcher in the TxDOT project 0-4588 “Effect of Voids in Grouted Post-tensioned Bridges”, where he was responsible for the inspection and repair. He was involved on a SHRP2 project sponsored by the Federal Highway Administration on “A Plan for Developing High-Speed, Nondestructive Testing Procedures for Both Design Evaluation and Construction Inspection” and was involved in a SHRP2 on “High Speed Nondestructive Testing Methods for Mapping Voids, Debonding, Delaminations, Moisture, and Other Defects Behind or Within Tunnel Linings”. Dr. Hurlebaus has successfully completed the Grouting Certification Training of the American Segmental Bridge Institute (ASBI).

Subasish Das, Ph.D.
Associate Transportation Researcher
Roadway Safety
Texas A&M Transportation Institute
(979) 845-9958 | subaishsn@gmail.com

Dr. Das has been working as an associate transportation researcher at the Texas A&M Transportation Institute (TTI). He has more than nine years of experience in conducting national and state level studies on transportation safety, operations, and planning. His has extensive experience on statistical modeling and machine learning. Dr. Das is an Eno Fellow. One of his research projects won 2014 AASHTO High Value Research Sweet Sixteen Award. Dr. Das is the recipient of the 5th Urban Street Symposium Best Paper award in 2017; the 2015 Gulf Region ITS First Place Award; the 2015 ULL STEM Best Paper Award. He has published more than 40 research reports and peer reviewed journal papers. He is an active member of the TRB Committee for Library and Information Science for Transportation (ABG40), and Alcohol, Other Drugs, and Transportation (ANB50). He has been working as the Co-Principal Investigator of two recently awarded research projects: NCHRP 14-40: Comparison of Cost, Safety, and Environmental Benefits of Routine Mowing and Managed Succession of Roadside Vegetation; and Louisiana’s Alcohol-Impaired Driving Problem: An Analysis of Crash and Cultural Factors.

David Florence, E.I.T.
Associate Transportation Researcher
Connected and Automated Transportation
Texas A&M Transportation Institute
(979) 845-9898 | d-florence@tti.tamu.edu

Mr. Florence is a recent graduate of the Texas A&M Civil Engineering department who specialized in Traffic Engineering. In his studies, he focused on connected and autonomous vehicles. Additionally, Mr. Florence served as the Vice President of the Texas A&M Institute of Transportation Engineers student chapter where he was responsible for managing traffic study projects. During his time with the student chapter he developed a Microsoft Excel macro to automatically pair license plates for a study done in downtown Bryan.

Mr. Florence has four years of experience working at TTI. His expertise includes traffic signal systems and control, microsimulation, macrosimulation, Intelligent Traffic Systems (ITS), freeway operations, weather responsive traffic management, and traveler information systems. Mr. Florence has experience using connected vehicles for traffic controller detection and analyzing wrong-way driver detection and warning systems. Mr. Florence participated in developing concepts of operations, high level designs, and connected vehicle deployments for wrong-way driving and optimized signal approach and departure. Mr. Florence has experience with deploying weather responsive signal timing systems to improve corridor performance during inclement weather.

He is skilled at using VISSIM to model connected and automated vehicles, and his VISSIM expertise has enabled him to work on projects that continue to broaden his depth of experience in traffic operations, such as the simulation of transit signal priority in downtown Dallas. Mr. Florence is developing his career around real time traffic management and connected vehicle operations. His current work includes simulating special even light rail operations in downtown Dallas and developing a mobile application to allow pedestrians to send, receive, and display connected vehicle messages.

Geza Pesti, Ph.D., P.E.
Research Engineer
System Reliability Division
Texas A&M Transportation Institute
(979) 845-9878 | g-pesti@tti.tamu.edu

Dr. Pesti is a Research Engineer at the System Reliability Division of TTI. He has over 30 years research, 6 years teaching and 2 years consulting experience. He had significant roles in research projects sponsored by federal and state agencies such as FHWA, USDOT, USAID, NSF, DOE and TxDOT. He holds both a MS and Ph.D. in Civil Engineering from the University of Nebraska-Lincoln, and a Diploma in Civil Engineering (MSc) with specialty in water resources and hydrology from the Budapest University of Technology, Hungary. He conducted postdoctoral research at the University of Arizona and post-graduate studies in mathematics at the Eotvos Lorand University in Budapest, Hungary.

Dr. Pesti's recent research at TTI has primarily focused on traffic operations and control for freeways, arterials and work zones. He is currently involved in a U.S.DOT funded research project to deploy and pilot-test the Reduced Speed Zone Warning/Lane Closure (RSZW/LC) application developed by the Crash Avoidance Metrics Partners (CAMP) consortium under the V2I Safety Applications Project. He is also working on TxDOT projects that evaluate freight management strategies for urban areas, and provide advanced traveler information for the I-35 corridor expansion project. He has studied and evaluated a number of active traffic management technologies such as dynamic queue warning systems, condition-responsive speed advisory (variable speed limit) and advance traveler information systems, various merge control strategies including the dynamic late merge concept. He studied queue spillover from exit ramps, evaluated the effect of ramp spacing on weaving traffic operation and assessed the mobility and emission impacts of night-time vs. day-time road construction. He extensively used microscopic traffic simulation and modeling in these research projects. He was a key researcher in a project that developed guidelines for the effective use of traffic responsive signal control on arterial closed loop systems, and led another project that applied these guidelines to implement traffic responsive signal operation on several arterial corridors in Texas. He has experience with mesoscopic dynamic traffic assignment models, and used them in several projects to predict traffic pattern changes, identify bottleneck locations and assess the expected network-level impacts of incidents, road construction activities, and evaluate the effectiveness of various traffic and demand management strategies.

Prior to joining TTI, he worked at the University of Nebraska-Lincoln (UNL), where he was involved in transportation research and education for over six years. He has 2 years of consulting experience with WS Atkins, a UK-based consulting firm. His research results have been published in over 50 peer-reviewed journal and conference papers and in a number of research reports. He is member of ITS America and ITE, and has been actively involved with several committees of the Transportation Research Board. He is a registered professional engineer in Texas.

Timothy P. Barrette, Ph.D.
Associate Transportation Researchers
Signs and Markings Program
Texas A&M Transportation Institute
(979) 845-6174 | t-barrette@tti.tamu.edu

Dr. Timothy Barrette is an Associate Transportation Researcher who joined TTI in 2017 while completing his Ph.D. in Civil Engineering at Iowa State University, having previously earned B.S. and M.S. degrees in Civil Engineering from Michigan Technological University in 2009 and 2011, respectively. Since coming to TTI, Dr. Barrette has been involved in research projects, such as NCHRP 20-102 (06), investigating the effect of visibility characteristics and physical properties of various types of pavement markings relative to machine vision, and NCHRP 5-21 examining the influence of performance characteristics of raised retroreflective pavement markers on human driver behavior.

Prior to joining TTI, Dr. Barrette was a contributing author on a variety of refereed journal articles, reports, projects, and conference proceedings that have focused on traffic safety and intelligent transportation systems. In addition to his academic pursuits, Dr. Barrette has been an active participant in the Brazos Valley Institute for Transportation Engineers and is involved in developing action plans to implement crash countermeasures which will be included in the upcoming Texas Strategic Highway Safety Plan. Dr. Barrette is active in journal article review as a young member of the Transportation Research Board standing committee on Law Enforcement (ANB 40).

Hassan H. Charara
Software Applications Developer III
System Reliability Division
Texas A&M Transportation Institute
Tel: (979) 845-1908 | E-mail: h-charara@tti.tamu.edu

Mr. Charara's specialty is in Software Engineering. He has more than 25 years of experience in the design, development, and deployment of Connected Vehicle, ITS, Real-time Traffic Signal Monitoring, and Advanced Data Collection applications.

Mr. Charara was a key researcher in the development of the Concept of Operations (ConOps), User Needs, System Requirements, and a prototype system for the generation and broadcast of Infrastructure-to-Vehicle (I2V) Signal Phase and Timing (SPaT) and related messages to vehicles in a Connected Vehicle Environment. The SPaT prototype was deployed and tested at the FHWA Turner Fairbank Highway Research Center (TFHRC). He was a key researcher in the Prototype Development and Small-Scale Demonstration of the Intelligent Network Flow Optimization (INFLO) bundle of Dynamic Speed Harmonization (SPD-HARM) with Queue Warning (Q-WARN) in a Connected Vehicle Environment project for USDOT. The prototype was field deployed and tested in a small scale demonstration on I-5 in Seattle, Washington using 25 connected vehicles.

Richard A. Zimmer
Senior Research Specialist
Roadside Safety & Physical Security Division
Texas A&M Transportation Institute
Tel: (979) 845-6388 | E-mail: d-zimmer@tti.tamu.edu

Mr. Zimmer has more than 40 years of diversified transportation research experience with emphasis on the development and use of research vehicle instrumentation and control systems. He has functioned as program manager, designer, project supervisor and operations coordinator. Mr. Zimmer also currently serves as the American Association for Laboratory Accreditation, ISO17025, Quality Manager for the TTI Proving Ground.

Responsibilities entailed: electronic and mechanical system design, software development, supervision of proving ground test system operations and technical personnel. He has developed test procedures for both full scale crash testing and pavement evaluation. As head of the Proving Grounds Support Program within the Safety Division of Texas A&M Transportation Institute, he has been instrumental in the development of currently used, high speed, crash test, data acquisition systems and the use of wireless telemetry. His expertise in telemetry was also central to the development of instruments for measuring load-bearing capacities of offshore oil platforms.

Prior to joining TTI, Mr. Zimmer designed and fabricated electronic instrumentation for the U.S. Air Force, Uniroyal Tire Proving Ground and NASA's Lunar Landing Program. Mr. Zimmer has served as the Principal Investigator on both state and federally sponsored research projects all of which were successfully completed and produced usable products for the sponsoring agencies. He has authored or coauthored about forty publications in the area of transportation safety research.

While Principal Investigator of the Central / Western Field Test and Evaluation Center he has assisted many state highway agencies in maintaining a high level of accuracy of their ASTM E274 roadway friction measurement systems and has authored several ASTM standards on the subject. His team has been responsible for evaluating and calibrating over five hundred state owned systems, since 1970, and providing a detailed report for each.

TTI Subcontractor: Southwest Research Institute (SwRI)

John C. Esposito
Engineer
Cooperative System Section
Southwest Research Institute
(210) 522-5609 | john.esposito@swri.org

John Esposito is an Engineer in the Cooperative System Section at Southwest Research Institute (SwRI). He holds an M.Sc. in Mechanical Engineering from the University of Florida where he developed custom dedicated short-range communications (DSRC) applications for both human-driven, automated vehicles and intelligent intersections. Since joining the institute in July of 2017, he has developed a road-side unit application that communicates with dynamic messages signs to populate content in traveler information messages. He evaluated the entire Roadway Characteristics Inventory for the Florida Department of Transportation (FDOT) in order to determine which of the data elements might be recorded using new types of sensors that are being added to vehicles. John has assisted in a number of technology demonstrations at SwRI including running an automated Freightliner demo for ROS-I Conference. Currently, he is working on new features to SwRI DSRC test tools that evaluate on-board units performance based on the SAEJ2735 and SAEJ2945 standards.

Cameron Mott
Senior Research Analyst
Cooperative Systems Section
Southwest Research Institute
(210) 522-2583 | cameron.mott@swri.org

Cameron Mott has more than a decade of experience and is a Senior Research Analyst at Southwest Research Institute in San Antonio, TX, where he leads research and development activities for connected vehicles and cybersecurity. Mr. Mott serves as a project manager, principal investigator, system engineer and software architect on projects that contribute to the development and protection of tomorrow's vehicles. With experience in connected vehicle application development, prototype autonomous vehicle software development and testing, secure embedded software design and agent-based artificial intelligence, Mr. Mott brings a broad range of skills to any project focused on transportation.

Mr. Mott is a principal investigator for the project "Secure Software Update Over-The-Air for Ground Vehicles Specification," which provides an open-source software framework to secure updates for automobiles. Through this project, software updates for automobile ECUs will be secured and compromise-resilient through an open-source methodology. Participants for over three-quarters of the nation's automobiles are involved with the project, which is funded by the Department of Homeland Security Technology & Science Directorate. The open-source nature of the project allows concerned security professionals the opportunity to review and contribute to the security architecture in order to keep the framework at the cutting edge of security research.

Mr. Mott is the project manager for a project that will demonstrate the advantages that connected vehicle technology can bring to the problem of wrong-way driving in Texas. State transportation officials are greatly impacted by the number and severity of wrong-way driving incidences, and together with TTI, connected vehicle applications and traffic management support software will be prototyped to represent the improvement that can occur with the latest technology.

With a focus on integrating sensors into the traffic management system software, Mr. Mott is the technical lead and developer for a project to integrate the Lonestar™ ActiveITS software with image and radar-based wrong-way driver detector sensors. The project includes systems to read the status of sensors and integrates with a back-end communication system to provide on-screen alerts and immediate email alerts with attached images of the possible issue. The project is in experimental use with multiple devices and multiple municipalities as they assess the options for reducing the impact of wrong-way drivers in their jurisdiction.

Mr. Mott utilizes his project management capabilities to provide on-time and on-budget deliverables for both government and commercial clients. His focus is leveraging vehicle-to-any (V2X) communication to improve the performance of both autonomous vehicles and manually operated vehicles. Mr. Mott believes that the future safety and security of the global transportation system can be improved through the application of advanced research and technology.

Darin Parish
Senior Research Analyst
Cooperative Systems Section
Southwest Research Institute
(210) 522-5669 | dparish@swri.org

Mr. Parish is a member of the Cooperative Systems Section of the Applied Sensing Department and is currently supporting a broad range of Commercial Vehicle Operations (CVO) and

Connected Vehicle (CV) projects. He has participated in the development of a variety of software systems by developing drivers, databases, testing and validation tools, simulators, and user interfaces.

Mr. Parish has developed systems for a number of DOT Connected Vehicle programs, including development of a Retrofit Safety Device (RSD) that was installed in a number of long-haul vehicles to collect vehicle-specific performance data over a number of months. The data collected will aid the USDOT in the further development of connected vehicle safety applications such as hard-braking alerts, curve speed warnings, and forward collision warnings. He developed the driver vehicle interface for the devices utilizing an Android tablet. He developed the graphical user interface for the Connected Vehicle Traveler Information Message system, which integrates the display of vehicle safety application alerts with virtual sign information in addition to real-time vehicle data.

Mr. Parish developed the user interface for an automated attenuator truck system which allows users to easily and intuitively configure lateral and longitudinal offsets for an automated attenuator vehicle. This interface utilizes an Android tablet and uses YAML for communication with vehicle autonomy systems. Mr. Parish has substantial experience integrating C/C++ with Java for use in Android applications and has used a variety of C/C++ libraries to optimize Android interfaces. In addition, Mr. Parish developed a Bluetooth application to collect and parse data from the CAN/OBD bus. Mr. Parish is a developer on several projects implementing safety and data analysis applications, utilizing data collected and derived using these technologies.

Mr. Parish manages a project with the Crash Avoidance Metrics Partnership (CAMP) to develop automated test tools for the validation, verification, and certification of the J2735/1 specification. These test tools are designed as modules and implemented using a variety of languages including C, C++, C#, and Python.

Mr. Parish provides database and user interface design, development, and support services for statewide programs in Texas and Alaska that are focused on the enhancement of freight mobility and safety. He is leading the development, testing, and deployment of these systems to enable the sharing and processing of data between local systems and the National Safety and Fitness Electronic Records (SAFER)/Performance and Registration Information Systems Management (PRISM) systems. He was instrumental in successfully accomplishing SAFER Certification Testing for the Alaska and Texas programs and the development of a web-based user interface.

Mr. Parish conducted a detailed analysis for the state of Alaska of existing software used by state bridge design engineers which analyzes forces generated on a bridge by specific truck load configurations. He has also been integral to a team of hardware and software engineers providing engineering services for Border Safety and Inspection Facilities (BSIF) for the state of Texas. Specifically, he is assisting with software system development, installation, integration, and testing of BSIF systems along the Texas-Mexico border.

Purser Sturgeon, II
Senior Research Analyst
Cooperative Systems Section
Southwest Research Institute
(210) 522-3924 | purser.sturgeon@swri.org

Purser Sturgeon is a developer and project manager at Southwest Research Institute in San Antonio, TX, where he has 12 years of experience in developing and designing hardware and software systems focusing on communications networks and cooperative systems. Mr. Sturgeon serves as a project manager and technical lead on several projects where he has led teams that have developed and provided integrated solutions combining data from numerous disparate sources, creating intelligent decision-making tools for monitoring, tracking, and providing information to and from intelligent, connected, and automated vehicles.

At the Traffic Engineering Research Laboratory (TERL) in Tallahassee Florida, Mr. Sturgeon performed the foundational design and development of a Connected Vehicle system within the ActiveITS software called SunGuide®. This involved deploying a roadside unit and utilizing multiple demonstration vehicles to perform several demonstrations. Scenarios included Wrong Way Driver Detection and Alerting, Vehicle Over-Height Detection and Alerting, multiple Emergency Braking scenarios, Emergency Vehicle Alerting (where cars are alerted to the presence of an emergency vehicle and given instructions on how to move out of the way), and a Mayday message scenario (where a vehicle outside the coverage range will activate an emergency beacon, have it picked up by passing vehicle, and dropped off at the nearest roadside unit so the traffic management system may be alerted and send help). This project was highlighted at the 2014 Florida AV Summit where the overheight vehicle automatically applied the brakes prior to striking the bridge.

Mr. Sturgeon is the technical lead and developer for a project to automate and manage commercial vehicle safety screening in facilities along the Texas-Mexico border. The project includes systems to control traffic signals and DMS, read traffic sensors including Radio Frequency Identification readers and Video Imaging Vehicle Detection System detection units, and integrates with a vendor-supplied commercial vehicle weighing system. Mr. Sturgeon recently contributed to a project under this program to develop a connected automation solution to enhance work zone safety. This project is focusing on automating the truck mounted attenuator (TMA) vehicles that serve as protection for work zones. The vehicle will be fully automated and uses 5.9 GHz DSRC to communicate with other work zone vehicles to implement slow-moving convoy operations (for sweeping, mowing, and striping type scenarios) as well as human gesture control for stop-and-go type work zone scenarios such as tar-patching. This project combines BasicSafetyMessage following with vehicle tracking using LIDAR and fiducial markers on the lead vehicle. Mr. Sturgeon is also leading a project to develop a pilot Connected Vehicle system deployment within the San Antonio district. This project includes replication and distribution of all static road signage over DSRC along a 12-mile stretch of I-410 and a system for identifying and notifying overheight vehicles approaching a low bridge or overpass.

Mr. Sturgeon is the software lead on the CVII project to develop a system for commercial vehicles to generate vehicle probe data, handle and manage displaying traveler information messages, integrate with a back-office system for driver credential verification and wireless roadside inspections, and detect and provide railroad grade crossing warnings. In addition to infrastructure based applications, Mr. Sturgeon also developed vehicle-to-vehicle applications, including emergency vehicle alert detection and notification, blind spot detection and notification, safe/unsafe-to-pass and safe/unsafe-to-merge support.

Mr. Sturgeon has contributed to multiple projects with the FHWA that have included integrating real-time, dynamic vehicle probe data into an advanced traffic management system from both standard light-duty vehicles and heavy-duty commercial vehicles, and include development on platforms ranging from standard PCs to PDAs to Linux-based Dedicated Short Range Communications radios. This includes the Commercial Vehicle Retrofit Safety Device project, in which led the development and implementation of the Forward Collision Warning, Emergency Electronic Brake Lights, and Curve Speed Warning applications for use on commercial vehicles. He has also developed the software for On-Board Equipment and Road-Side Equipment to enable vehicle-to-vehicle communications for a wireless adaptive cruise control system. The project provided a portable system that allows vehicles to form dynamic platoons on roadways to improve the safety and efficiency of the vehicles.

3. Staffing Plan

An exceptionally qualified research team has been assembled with the necessary experience and expertise to successfully perform the research project. The research team consists of Dr. Chiara Silvestri Dobrovolny, Dr. Kevin Balke, Dr. Subasish Das, Mr. Adam Pike, Dr. Tim Barrrette, Dr. Stefan Hurlebaus, Mr. Hassan Charara, Dr. Roger P. Bligh, Mr. Dick Zimmer, Dr. Geza Pesti, Mr. David Florence, and John C. Esposito, Cameron Mott, Darin Parish, and Purser Sturgeon, II. These individuals are all well qualified for the work to be done, as demonstrated by their expertise and previous accomplishments in the areas of crash analysis, pavement marking testing, connected vehicle design, testing, and evaluation.

As Research Supervisor, Dr. Silvestri Dobrovolny shall be responsible for the overall management and administration of the project. Dr. Kevin Balke shall serve as Co-PI for the project and shall support technical requirements of the project and lead technical Tasks 7 and 8. Dr. Subasish Das will serve as Researcher for this project. Dr. Das will be responsible for Task 2 State-of-the-art Synthesis and he will support Tasks 3 and 4. Mr. Pike and Dr. Barrette shall lead markings and marker testing and evaluation, in task 5. Dr. Hurlebaus will be responsible for Task 6 Flood Sensors and Warning Device Evaluation and he will support Tasks 7 and 8. He will assist in the other tasks as well. Mr. Charara, Pezi, and Florence shall assist with technical support to accomplish technical objectives in Tasks 7 and 8. Dr. Bligh and Mr. Zimmer shall support with testing preparation and coordination for Tasks 7 and 8. Mr. Esposito, Mott, Parish, and Sturgeon shall support technical needs in Tasks 7 and 8.

The project team will be supported by other technical support staff of the TTI Proving Ground. The staff of the TTI Proving Ground has extensive expertise and experience in conducting testing. They shall 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.

Performing Agency Research Team Members and Responsibilities

TTI Personnel			
Name	**Role**	**FY Salary Estimate**	**Tasks and Responsibility**
Chiara Silvestri Dobrovolny	Research Supervisor	FY19 $18,538 FY20 $7,254	Manage overall project and be technical support on selected Tasks. Tasks 1 through 8.
Kevin Balke	Co-PI/Sr. Research Engineer	FY19 $17,473 FY20 $15,932	Technical support on selected Tasks. Tasks 1 through 8.
Subasish Das	Associate Transportation Researcher	FY19 $15,019 FY20 $0	Technical support on crash analysis and survey conduction. Tasks 2 through 4.
Adam Pike	Associate Research Engineer	FY19 $11,640 FY20 $1,408	Technical support on markings and marker testing and evaluation. Task 5.
Timothy Barrette	Associate Transportation Researchers	FY19 $6,756 FY20 $1,021	Technical support on markings and marker testing and evaluation. Task 5.
Stefan Hurlebaus	Research Scientist	FY19 $8,909 FY20 $10,183	Technical support on flood sensors testing and evaluation. Tasks 6 through 8.
Hassan Charara	Software Applications Developer III	FY19 $18,674 FY20 $29,595	Technical support on selected Tasks. Tasks 6 through 8.
Geza Pesti	Research Engineer	FY19 $8,143 FY20 $14,011	Technical support on selected Tasks. Tasks 7 through 8.
David Florence	Associate Transportation Researcher	FY19 $6,618 FY20 $13,942	Technical support on selected Tasks. Tasks 7 through 8.
Roger Bligh	Senior Research Engineer	FY19 $1,186 FY20 $8,269	Technical support for testing preparation and conduction. Tasks 7 and 8.
Richard Zimmer	Senior Research Specialist	FY19 $1,702 FY20 $12,570	Technical support for testing preparation and conduction. Tasks 7 and 8.
Kyle Kingsbury	Research Specialist I	FY19 $6,051 FY20 $0	Technical support for testing preparation and conduction. Tasks 7 and 8.

TTI Personnel			
Name	**Role**	**FY Salary Estimate**	**Tasks and Responsibility**
Ph.D. graduate student	Graduate Research Support	FY19 $9,549 FY20 $5,639	Research support for technical activities. Tasks 2 through 8.
Rebecca Heck	Research Specialist II	FY19 $1,322 FY20 $1,163	Provides technical support to meet project needs.
SwRI	Subcontractor	FY19 $25,000 FY20 $55,000	Technical support on selected Tasks. Tasks 7 through 8.

4. Past Performance

The research team comprised of researchers from the TTI has successfully accomplished many research studies sponsored by FHWA, NCHRP, TxDOT, other State transportation agencies, and private concerns in the roadside safety area. The knowledge and experience gained through the administration and conduct of these projects will be a positive factor in ensuring the timely and successful completion of the research project. Through this previous work, TTI has achieved a reputation for practical and useful research results, and is considered a leader in design, analysis, testing, and evaluation in the roadside safety area.

Summarized below is a selected list of recent and ongoing research projects supervised by members of the research team that demonstrates the contributions and accomplishments of the research team in areas directly relevant to the scope of the research project. Additionally, these projects demonstrate the ability of the research team to administer and conduct projects of this type and magnitude.

Selected Projects

Project No.: TxDOT 0-4162
Title: Evaluation of Barrier Systems & Placement Issues
Period of Performance: September 2000–August 2003
Total Budget: $452,650

Project No.: TxDOT 0-5210
Title: Roadside Crash Testing Program for Design Guidance & Standard Detail Development
Period of Performance: September 2004–August 2009
Total Budget: $1,255,000

Project No.: TxDOT 0-5526
Title: Impact Performance Assessment of Roadside Safety Appurtenances
Period of Performance: September 2005–August 2006
Total Budget: $123,025

Project No.: TxDOT 9-1002
Title: Roadside Safety Device Crash Testing Program
Period of Performance: September 2010–August 2011
Total Budget: $1,000,000

Project No.: TxDOT 9-1002-12
Title: Roadside Safety Device Crash Test Program
Period of Performance: September 2011–August 2014
Total Budget: $1,670,629

Project No.: TxDOT 9-1002-15
Title: Roadside Safety Device Crash Testing Program
Period of Performance: September 2014–August 2017
Total Budget: $1,670,010

Project No.: NCHRP 22-14(03)
Title: Evaluation of Existing Roadside Safety Hardware Using Updated Criteria
Period of Performance: April 2007–June 2010
Total Budget: $530,000

Project No.: NCHRP 20-07 / Task 395
Title: MASH Equivalency of NCHRP 350-Approved Bridge Railings
Period of Performance: June 2016–June 2017
Total Budget: $150,000

Project No.: TxDOT 0-6946
Title: Establishing Comprehensive Manual on Assessing Safety Hardware (MASH) Compliance for Roadside Safety Systems in Texas
Period of Performance: May 2017–December 2019
Total Budget: $3,317,945

Project No.: TxDOT 0-6912
Title: Innovative Tools and Techniques in Identifying Highway Safety Improvement Projects (HSIP)
Period of Performance: September 2015–August 2017
Total Budget: $300,000

Project No.: TxDOT 5-9052
Title: A Data-Driven Safety Analysis Framework for the Beaumont District
Period of Performance: September 2017–August 2019
Total Budget: $819,201

Project No.: FHWA DTFH - 6116D – 00039
Title: Evaluation of Safety Improvements, Phase X
Period of Performance: September 2017–September 2018
Total Budget: $500,000

Project No.: NCHRP 17-79
Title: Safety Effects of Raising Speed Limits to 75 mph and Higher
Period of Performance: September 2016–September 2019
Total Budget: $500,000

Project No.: TxDOT 0-6705-1
Title: Evaluating the Effectiveness of Performance Based Pavement Marking Maintenance Contracts in Texas
Period of Performance: September 2011–August 2013
Total Budget: $256,935

Project No.: FHWA HRT-12-048
Title: Pavement Marking Demonstration Projects: State of Alaska and State of Tennessee
Period of Performance: May 2006–December 2011
Total Budget: $2,363,512

Project No.: FDOT BDI91
Title: Florida's Wet Weather Demonstration Project
Period of Performance: August 2007–November 2008
Total Budget: $140,000

Project No.: TxDOT 0-5008-2
Title: Evaluation of Wet-Weather and Contrast Pavement Marking Applications: Final Report
Period of Performance: September 2004–February 2007
Total Budget: $342,860

Project No.: TxDOT 409139-1
Title: Historic Bridges of Tarrant County
Period of Performance: September 2011–August 2013
Total Budget: $150,000

Project No.: TxDOT 0-5997
Title: Structural Assessment of "D" Region affected by Premature Concrete Deterioration
Period of Performance: September 2007–August 2011
Total Budget: $1,200,000

Project No.: TxDOT 0-5722
Title: Lap Splice and Development Length Performance in ASR and/or DEF Damaged Concrete Elements
Period of Performance: September 2006–August 2010
Total Budget: $999,987

Project No.: TxDOT 0-4588
Title: Effects of Voids in Grouted, Post-Tensioned Concrete Bridge Construction
Period of Performance: September 2003–August 2008
Total Budget: $1,020,000

Project No.: NCHRP 14-40
Project Title: Comparison of Cost, Safety, and Environmental Benefits of Routine Mowing and Managed Succession of Roadside Vegetation.
Period of Performance: September 2017–August 2019
Total Budget: $300,000

Project No.: TxDOT 0-6961
Project Title: Evaluation of Safety Improvement Projects and Countermeasures.
Period of Performance: September 2017–August 2019
Total Budget: $300,000

Project No.: TxDOT 0-6932
Project Title: Developing Pavement Safety-Based Guidelines for Improving Horizontal Curve Safety.
Period of Performance: September 2017–August 2019
Total Budget: $274,912.

Project No.: FHWA DTFH6116D00004
Project Title: Technical Support for Focus Approach to Roadway Departure (RwD) Safety.
Period of Performance: September 2016–August 2018
Total Budget: $300,000

Project No.: FHWA DTFH6116D00039
Project Title: Identifying Infrastructure-Based Motorcycle Crash Countermeasures – Phase I.
Period of Performance: August 2017–July 2017
Total Budget: $230,000

Project No.: NCHRP 17-76
Project Title: Guidance for the Setting of Speed Limits.
Period of Performance: September 2016–December 2018
Total Budget: $500,000

Project No.: Atlas 2017-19
Project Title: Safety Impacts of Reduced Visibility in Inclement Weather
Period of Performance: March 2016–December 2016
Total Budget: $44,000

Project No.: NCHRP 20-102 (06)
Project Title: Evaluation of the Effects of Pavement Marking Characteristics On Detectability by ADAS Machine Vision
Period of Performance: July 2016–May 2018
Total Budget: $200,000

Project No.: NCHRP 5-21
Project Title: Safety and Performance Criteria for Retroreflective Pavement Markers, NCHRP
Period of Performance: September 2015–June 2018
Total Budget: $675,000

Project No.: TxDOT/USDOT
Project Title: I-35 Connected Work Zone
Period of Performance: January 2015–December 2018
Total Budget: $2,000,000

Project No.: TxDOT 0-6262
Project Title: Signing Strategies for Low-Water and Flood-Prone Highway Crossings
Period of Performance: September 2008–August 2010
Total Budget: $253,010

Project No.: TxDOT 0-6769
Project Title: Wrong-Way Driving Countermeasures
Period of Performance: September 2012–August 2014
Total Budget: $321,889

Project No.: TxDOT 0-4023
Project Title: Effective Message Design for Dynamic Message Signs
Period of Performance: September 2000–March 2006
Total Budget: $632,100

Project No.: TxDOT 0-4128
Project Title: Countermeasures for Wrong-Way Movement on Freeways
Period of Performance: September 2002–August 2003
Total Budget: $77,444

Project No.: TxDOT IAC 09-1XXIA003
Project Title: Traveler Information During I-35 Reconstruction
Period of Performance: December 2010–August 2015
Total Budget: $12,389,290

Project No.: DTFH61-06-D-00007, 600112-44
Project Title: SPaT – Signal Phase and Timing
Period of Performance: February 2011–June 2013
Total Budget: $556,609

Project No.: DTFH61-12-D-00040, 601305-2
Project Title: INFLO - Intelligent Network Flow Optimization
Period of Performance: July 2013–March 2015
Total Budget: $199,206

Project No.: DTFH61-14-C-00003, PO#48-30-13062
Project Title: New Approaches for Testing Connected Highway and Vehicle Systems
Period of Performance: January 2014–December 2016
Total Budget: $999,217

Project No.: 9-1002-12
Project Title: Roadside Safety Device Crash Test Program
Period of Performance: September 2011–August 2014
Total Budget: $1,670,629, match $417,657

Project No.: TxDOT B442009020777000
Title: TxDOT Development, Implementation, Integration, and Maintenance of ITS (DIIMS)
Period of Performance: January 1998–Ongoing
Total Budget: $84,545,900

Project No.: NCHRP 03-127
Title: "Cybersecurity of Traffic Management Systems"
Period of Performance: August 16, 2017–August 15, 2019
Total Budget: $750,000

Project: TxDOT - 0-6838
Title: Bringing Smart Transport to Texans
Period of Performance: March 2015–April 2018
Total Budget: $775,000

Project No.: TxDOT B442009020777000
Title: TxDOT Development, Implementation, Integration, and Maintenance of ITS (DIIMS)
Period of Performance: January 1998–Ongoing
Total Budget: $84,545,900

Project No.: FHWA 16993
Title: Retrofit Safety Device (Supporting USDOT Safety Pilot)
Period of Performance: September 2011–April 2014
Total Budget: $1,163,039

Project No.: TxDOT CSJ: 0015-13-391
Title: Overheight Vehicle Detection System (OHVeDS)
Period of Performance: February 2014–Ongoing
Total Budget: $365,000

Project No.: TxDOT B442009020777000
Title: TxDOT Development, Implementation, Integration, and Maintenance of ITS (DIIMS)
Period of Performance: January 1998–Ongoing
Total Budget: $84,545,900

Project No.: FHWA 16993
Title: Retrofit Safety Device (Supporting USDOT Safety Pilot)
Period of Performance: September 2011–April 2014
Total Budget: $1,163,039

Project No.: TxDOT CSJ: 0015-13-391
Title: Overheight Vehicle Detection System (OHVeDS)
Period of Performance: February 2014–Ongoing
Total Budget: $365,000

5. Research Facilities

Texas A&M Transportation Institute

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 transportation safety and economics, to railway, border mobility, and ports and waterways research.

With headquarters and laboratories on the Texas A&M 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 and to create and test future innovations, such as automated and connected transportation technologies.

TTI operates real-world research implementation testing sites in seven cities across the state and has locations on the campus of Texas A&M University at Qatar and at the Texas A&M University Center in Mexico City, Mexico. As a member of the Texas A&M University System, researchers have access to other Texas A&M facilities, including the prestigious Sterling C. Evans Library and world-class computing resources to support them in their research endeavors.

A member of The Texas A&M University System, the Institute annually works with over 200 sponsors at all levels of government and the private sector on an operating budget of approximately $53 million. Over 400 TTI professionals and 200 students team across divisions, and with partners and sponsors, to work on over 600 projects a year. The Institute is well-positioned to offer objective and credible guidance on a wide range of transportation topics and emerging issues with Recognized as one of the premier higher education-affiliated transportation research agencies in the nation, TTI's research and development program has resulted in significant breakthroughs across all facets of the transportation system. TTI research is widely known as an excellent value with a proven impact of saving lives, time and resources in over 20 countries and in all 50 states.

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 Section 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 photo-instrumentation group, in addition to film, also provides a full array of professional videotape cameras and editing equipment. All videotape documentary footage of highway safety research is shot on the professional Sony Betacam Tape format. Additional cameras utilize SVHS, 3/4 inch, VHS, and digital mini DV videotape formats. The facility also includes an AVID Media Composer 1000 and Avid Express Elite non-linear digital editing workstations that provide a full range of special production tools to produce professional high quality videotape output.

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.

Researchers at TTI have significant expertise in areas such as materials and structural engineering, planning, economics, policy, landscape architecture, environmental sciences and the social sciences. They contribute to the growth of the transportation profession by leading and participating in hundreds of local, state and national organizations. TTI's nine state and national research centers, all approved by the A&M System Board of Regents, illustrate the breadth and significance of the Institute's research program. Center research emphasis areas span the areas of transportation safety, economics, and policy, to railway, border mobility, and ports and waterways, to computational mechanics and intelligent transportation systems (ITS). Implemented TTI research, supported by its state and national sponsors, has saved the state of Texas and the United States billions of dollars and thousands of lives by developing and putting innovative strategies and products into practice.

TTI Research Facilities and Equipment — TTI maintains state-of-the-art laboratories, buildings and outdoor test beds. The 67,000-square-foot Gibb Gilchrist Building, located in the Texas A&M University Research Park, was designed and built specifically to house TTI's transportation research programs. The TransLink Gilchrist Laboratory for traffic operations, a fully interactive driving and pedestrian environment simulator, and extensive video, photography, web and publishing facilities are located in the Gilchrist Building. The CE/TTI Building, on the main campus of Texas A&M University, houses a portion of TTI staff, many of whom are also faculty in Texas A&M's Dwight Look College of Engineering. The CE/TTI Building connects to several laboratories in the areas of pavements and materials, soils and aggregates, as well as the High Bay Structural and Materials Testing Laboratory. The new three-story, 66,700-square-foot TTI State Headquarters and Research Building houses additional TTI research programs and TTI's administrative offices. Other highlights of the building include the Visibility Research Laboratory, which features a 125-foot-long corridor and is used to test materials for traffic signs and pavement markings, as well as vehicle headlamps, sign lighting and roadway lighting.

Library Facilities and Support — TTI's Library Services group contributes to the broader mission of TTI by providing resources to support research. The TTI library maintains a highly specialized collection of reports from TTI, TCRP, and NCHRP, as well as Transportation Research Circulars, Transportation Research Record series, and subscriptions to 48 journals. Staffed by a research librarian and a library assistant, the TTI library offers a full range of services to researchers, including reference and research assistance, help with online literature searches, and the obtaining of needed documents. The library also provides a current-awareness service to TTI researchers by circulating journal tables of contents and announcing new library acquisitions through Check It Out, the library's monthly newsletter. TTI publications and software can be found using the TTI Catalog.

When documents are not available in the TTI library collection, the TTI library staff uses the resources available through the Texas A&M University Library. Currently the university library holdings include 4.5 million volumes, 936,270 eBooks, 5.7 million microform units, 221,431 maps, 21,000 linear feet of archival and manuscript collections, and 108,064 serial titles (including some 150 state, national, and foreign newspapers). The university library also offers access to more than 19,000 electronic journals and 500 electronic databases, and maintains an outstanding collection of science and engineering technical reports. Materials not owned by the university library can be obtained through interlibrary loan services.

Visibility Research Laboratory

TTI has a one-of-a-kind Visibility Research Laboratory (Figure) at TTI's State Headquarters Building, located at the Texas A&M University main campus in College Station, Texas. The Visibility Research laboratory is 125 feet long with adjacent office space for reviewing live data, data post-processing, and conducting meetings. While the main focus of the laboratory is to initially test retroreflective materials, the facility has been equipped to study vehicle headlamps, LED sign lighting, roadway lighting, and other retroreflective or self-illuminating devices. With the laboratory, the TTI researchers will be able to evaluate nighttime scenarios regardless of the time of day or weather. The facility has been designed to be retrofit to complete photometric measurements under rain conditions and laboratory human factors studies should a sponsor require these capabilities.

Figure 14. TTI Visibility Research Laboratory.

Visibility & Photometric Equipment

TTI has a wide array of photometric equipment that can be used for visibility and photometric research of pavement markers and markings. A short list of these items includes the following:

Luminance Meters

- Radiant Vision Systems Prometric I29 series CCD Imaging Colorimeter – This device is a 12-bit temperature stabilized image photometer and colorimeter with 29 megapixel 6576 x 4384 resolution. This device has three color wheels for assessing color, and two different ND filters for measuring brighter objects beyond the capabilities of the f-stops of the lenses.
- LMT1009– This device is a spot luminance meter with 3˚, 1˚, 20’, and 6’ field aperture settings.
- Minolta CS-100 – This device is a spot luminance meter with a single 1˚ field aperture setting.

Illuminance Meters

- Konica Minolta CL-70F - Measurers and evaluates the illuminance, color temperature, and color rendering index (CRI) of various illumination sources such as LEDs and fluorescent lamps.
- Minolta T-10 – This device is a cosine corrected spot illuminance meter. We currently have 3 units and several measurement heads that can be daisy-chained to one unit.

Colorimeters

- SpectraScan PR670 – This device is a portable spectroradiometer that can evaluate daytime and nighttime color, spectral power distribution, source color temperature, and luminance.
- Hunter Mini-Scan – This device is a colorimeter that illuminates the sample at 45˚ with respect to the detector at 0˚ and the reflected light is 90˚ with respect to the sample (45˚/0˚). The device has a 2˚ and 10˚ standard observer observation area and measures both with respect to illuminant A and D65.

Pavement Marking Retroreflectometer

- RoadVista Laserlux LLG7 – This device is a fixed geometry mobile retroreflectometer that is used to measure pavement marking retroreflectivity (RL) at highway speeds.
- Delta LTL-M - This device is a fixed geometry mobile retroreflectometer that is used to measure pavement marking retroreflectivity (RL) at highway speeds.
- Delta LTL-X – This device is a fixed geometry handheld retroreflectometer that is used to measure pavement marking retroreflectivity (RL).
- Delta LTL-XL – This device is a fixed geometry handheld retroreflectometer that is used to measure pavement marking retroreflectivity (RL) and retroreflected diffuse illumination (QD).
- Delta LTL-Y – This device is a fixed geometry handheld retroreflectometer that is used to measure pavement marking retroreflectivity (RL) and retroreflected color.
- RoadVista StripeMaster II Touch– This device is a fixed geometry handheld retroreflectometer that is used to measure pavement marking retroreflectivity (RL).
- Gamma Scientific/RoadVista 1200F – This device is a fixed geometry handheld retroreflectometer that is used to measure the retroreflectivity of reflectorized raised pavement markers (RRPMs).

Visibility Research Laboratory

- Gamma Scientific 940D retroreflectometer – This device is used to quantify retroreflectivity of retroreflective materials placed in the goniometer.
- Gamma Scientific GS-1290 RADOMA spectrophotometer – This device is used to quantify the color of materials placed in the goniometer.

Sediment Retention Device (SRD) Testing Facility

The Sediment Retention Device (SRD) testing facility is designed to measure the soil holding and erosion resistant characteristics of sediment retention devices. TTI researchers can modify this facility to serve many purposes. One option is to create a dam to retain water at certain depths so that pavement markings and markers can be evaluated in the presence of varying depths of water. The clarity of the water can be modified to generate different scenarios that may be experienced at low water crossings or at flooded highway areas.

Equipment

The SRD facility consists of polypropylene tank with a capacity of approximately 1600 gallons (Figure), an 18 foot X 15 foot concrete testing channel with a 4 foot clay installation zone (Figure), Two Hach SOLITAX model TS-line turbidity sensors, Hach model sc100 controller, and Two ISCO model 4230 Bubble flow meter are used to monitor the testing.

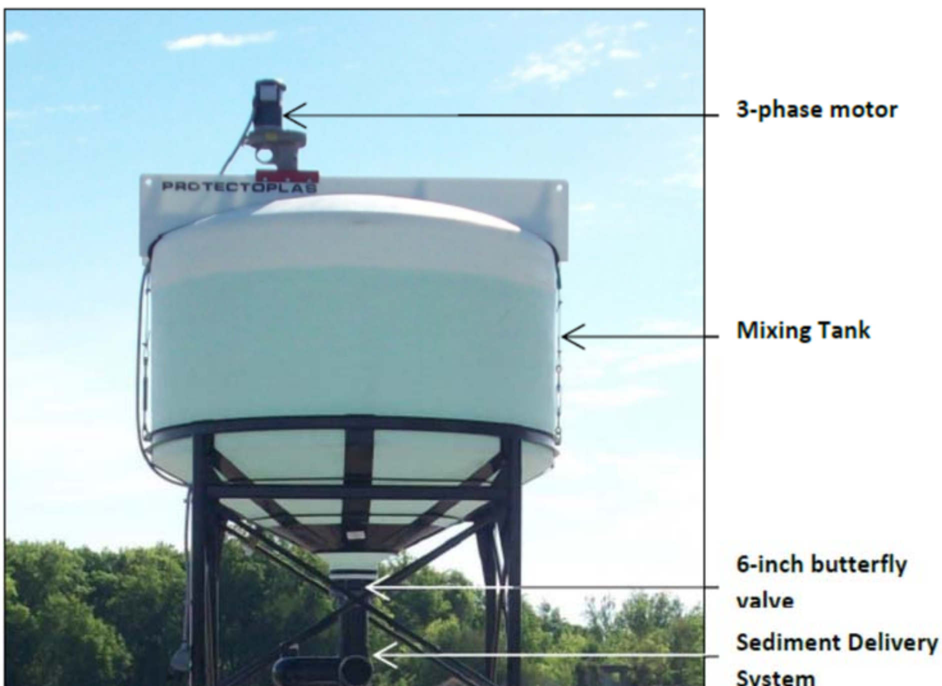

Figure 15. Tank for Mixing Sediment into Test Water.

Figure 16. Testing Channel for SRD Evaluation.

Instrumentation:
The turbidity probes and bubbler tubes are connected to their appropriate locations at the sediment delivery system on the bottom of the mixing tank and the outlet tube of the collection zone. The flow meters and turbidity meters are then turned on and evaluated to ensure that the data is being collected and recorded correctly at each location. Monitoring both the turbidity meters and flow meters during testing is necessary in keeping the system running efficiently and accurately.

Sediment Preparation:
A sediment mixture of 12.5 lbs. of SIL-CO-SIL 49 and 12.5 lbs. of ball clay are combined in the mixing tank with 1500 gallons of water to create a suspended solid concentration of 2000 mg/L. The mixture needs to be constantly agitated throughout testing to maintain a consistent suspended solid concentration. This combination of silica and clay allows this test to target devices for larger particles and treated products that contain flocculants that are designed to remove small clay particles. It was found that the combination of silica and clay provided the best data to evaluate and compare all sediment retention devices. Modifications to these quantities may be necessary to generate the proper water clarity for the testing that will be conducted.

Sensors Laboratory
The Sensor Laboratory is equipped with vibration measurement techniques, and nondestructive testing techniques. For vibration measurement a four-channel FFT analyzer with software, different digital storage oscilloscopes, data acquisition system, an impact hammer, a shaker, several accelerometers, wireless sensors, force cell, and charge amplifiers are available. For nondestructive testing, an arbitrary function generator, RF amplifier, a pulser-receiver, different transducers, and data acquisition systems are available. Furthermore, the laboratory is equipped with a laser vibrometer, which measures vibrations and ultrasound in a non-contact, high fidelity and broadband (0 - 20 MHz) manner. Finally, the laboratory also has an ultrasonic tomography system and an ultrasonic phased array system.

Big Concrete Ditch

To conduct the demonstration, the Performing Agency shall install the system in its test facility where flooding conditions can be simulated on a roadway. In 2010, a concrete ditch was constructed at the test site indicated in Figure 17. It is located on Runway 17, Section 2, on the northwest side. The Performing Agency's controlled environmental test facility shall be used for conduction of the developmental testing. This environmental test facility is best suited to meet the needs to conduct the research test plan, only requiring minimal adaptation for testing completion (Figure 18). The concrete ditch is a recessed trench, 12.5 ft. wide, 400 ft. long, and 30 inches deep. A reinforced concrete liner was constructed on the bottom and both sides.

Figure 17. Location of the Concrete Ditch.

Figure 18. Big Concrete Ditch.

Automated Vehicles/Connected Vehicles Lab

Connected transportation is a major evolution in how vehicles and infrastructure will interact in the future, affecting every facet of transportation safety and mobility. Vehicles and the infrastructure will be able to talk to each other and communicate their real-time conditions.

The Automated Vehicles/Connected Vehicles Laboratory (AVCV Lab) is a fully equipped collaborative work space where different disciplines can work together to develop, test and deploy next generation sensors and data applications for the connected and automated vehicle environment, as well as the overall infrastructure arena. The facilities will also be a living laboratory for undergraduate and graduate students to develop expertise in connected transportation to be the future leaders in this emerging discipline.

Connected Vehicle Assessment Simulation Test Bed

TTI has developed an augmented-reality environment where real entities (vehicles and traffic signal operation) are combined with simulated traffic and displayed on a screen. The first-of-its-kind approach — called CONnected Vehicle Assessment Simulation (CONVAS) — marries the cost-effectiveness of computer simulation with actual roadway operations to produce an efficient yet dependable evaluation mechanism for the Federal Highway Administration. TTI researchers developed an enhanced hardware-in-the-loop (HITL) simulation by incorporating an actual CV on a roadway network into a simulation model and displaying simulated CVs inside the real vehicle at the same time. This enables development and testing of advanced CV applications or strategies by allowing assessments of how CVs respond to each other and other entities such as pedestrians, emergency vehicles and transit vehicles in a controlled environment. This is the first time HITL simulation has ever been applied in this way.

Southwest Research Institute (SwRI)
Thomas Baker Slick Jr. – an adventurer, philanthropist and oilman – founded SwRI on a South Texas ranch in 1947. After recruiting talent from across the nation, he challenged his team of scientists and engineers to seek revolutionary advancements through advanced science and applied technology. That spirit lives on today. SwRI endures as one of the oldest, independent nonprofit organizations in the United States, providing innovative science, technology, and engineering services to government and commercial clients around the world. SwRI's mission statement summarizes the drive that is shared by our diverse experts: "Benefiting government, industry and the public through innovative science and technology."

Over the past decade, SwRI has performed in excess of $40 million in research and development related to connected vehicle (CV) and autonomous vehicle (AV) technologies for commercial, military, and state and federal government clients. SwRI-developed connected vehicle technologies, including vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) applications such as curve speed warnings, emergency brake warnings, bridge over-height warnings, and wrong-way driver alerts, have been deployed in Florida, Michigan, New York and Texas. Through integration with ActiveITS, CV applications benefit from AMTS data and traffic management centers benefit from integration with CV applications (Figure 19).

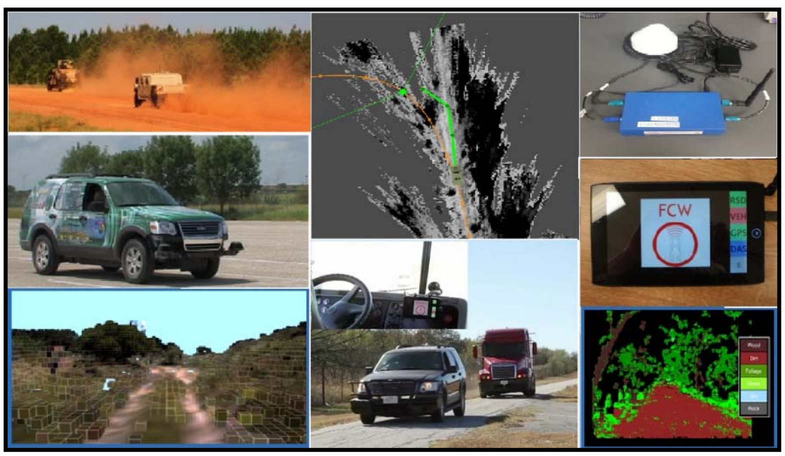

Figure 19. SwRI has experience deploying connected and autonomous vehicles. The proposed ATMS is connected vehicles ready.

SwRI also performs testing and certification of CV-related hardware, such as dedicated short-range communication (DSRC) radio, and is heavily involved in national standardization efforts related to CV technology. SwRI has fielded fourteen fully autonomous vehicle platforms, performed hardware and software integration, and developed a large variety of automated vehicle enabling technologies (multi-modal perception, sensor fusion, world modeling/situational awareness, absolute and relative localization, global and local motion planning, vehicle control) for commercial vehicle manufacturers and the U.S. Army, Navy, and Marine Corps, as well as several European defense ministries. SwRI-developed autonomy software is platform agnostic and is configurable to work in both on-road and off-road scenarios. SwRI has commercialization rights of our perception, localization, and navigation autonomy software.

SwRI has developed a portable system that contains a Dedicated Short Range Communication (DSRC) radio, antennas, power interface, WiFi access point and a vehicle-mountable Android-based tablet. This system, the Portable Onboard Device (POD), enables any vehicle to become a "connected vehicle," bringing this technology out of the lab environment and enabling real-world demonstrations. SwRI can utilize up to 4 of these devices in direct support of demonstrations for this project (See Figure 20).

Figure 20. Example of POD.