UNIVERSITY TRANSPORTATION CENTER FOR RAILWAY SAFETY

Exhibit F - UTCRS

UTC Project Information	
Project Title	Structural Integrity of Railroad Bearing Adapters with Modifications for Onboard Monitoring Applications
University	The University of Texas Rio Grande Valley (UTRGV)
Principal Investigator	Arturo A. Fuentes, Ph.D., Mechanical Engineering (PI) Constantine Tarawneh, Ph.D., Mechanical Engineering (Co-PI)
PI Contact Information	Mechanical Engineering ENGR 3.256 Dept. (956) 665-2394 Office (956) 665-7099 arturo.fuentes@utrgv.edu
Funding Source(s) and Amounts Provided (by each agency or organization)	Federal Funds (USDOT UTC Program): $24,741 Cost Share Funds (UTPA): $12,668
Total Project Cost	$37,409
Agency ID or Contract Number	DTRT13-G-UTC59
Start and End Dates	November2013 – December 2014
Brief Description of Research Project	The primary purpose of this project is to study the structural integrity of railroad bearing adapters modified for onboard monitoring applications. The UTPA Railroad Research Group funded by a private railroad industry (Amsted Rail) is attempting to provide one of the first economical, reliable sensors for keeping track of both dynamic and static loads on a railcar. The sensor is embedded in a bearing adapter under a thermoplastic elastomer suspension element patented as the AdapterPlus™ Pad. Bearing adapter modifications (e.g. cut-outs) were necessary to house the sensor and, thus, it is imperative to determine the structural integrity of the modified railroad bearing adapter to ensure the safe operation of the modified adapter in field service operating conditions. To that end, work performed under the University Transportation Center for Railway Safety aimed at developing CAD models of the railroad bearing adapters with the suggested modifications, and constructing finite

The University of Texas Rio Grande Valley   Texas A&M Transportation Institute   Nebraska Transportation Center

	element (FE) models using the ALGOR commercial software. The devised finite element models were used to conduct finite element analyses using some of the expected operational boundary conditions and loads. The FE models were validated with some physical experiments that were carried out in a laboratory setting.
Describe Implementation of Research Outcomes (or why not implemented) Place Any Photos Here	One of the major goals of the University Transportation Center for Railway Safety (UTCRS) is to increase the railway reliability by, among other things, developing advanced technology for infrastructure monitoring and developing innovative safety assessments and decision-making tools. Along these lines, the Railroad Research Group at the University of Texas-Pan American has been working on onboard monitoring systems for the railroad industry. Future technologies are focusing on continuous temperature tracking of railroad bearings (e.g. IONX motes). Since placing sensors directly on the bearing cup is not feasible due to cup indexing during field service, the next logical location for such sensors is the bearing adapters. The railroad bearing adapters act as a medium between the axle assembly (bearings and wheels) and the side frames. Modifications (e.g. cut-outs) to the bearing adapters were necessary in order to house the sensors. Therefore, it is necessary to determine the structural integrity and reliability of the modified railroad bearing adapter. The performed research produced experimentally validated Finite Element Analysis (FEA) stress results, and explored the fatigue life of conventional and modified adapters under different extreme case loading scenarios for the bearing adapters, which included the effect of a railroad flat wheel. In this worst case scenario, the flat wheel translated into a periodic impact load on the bearing adapter. The Stress-Life approach was used to calculate the life of the railroad bearing adapters made out of cast iron and subjected to cyclic loading. From the known material properties of the adapter (cast iron), the operational life was estimated with a mathematical relationship. The finite element analysis and experimental results (samples shown in Figure 1 and 2, respectively) revealed that conventional and modified adapters would have an infinite life at all studied loading conditions. The worst case scenario studied for the adapters was the case when it is subjected to periodic dynamic loading such as a wheel impact load which translates into an equivalent static load of 90,000 lb on the bearing adapter.

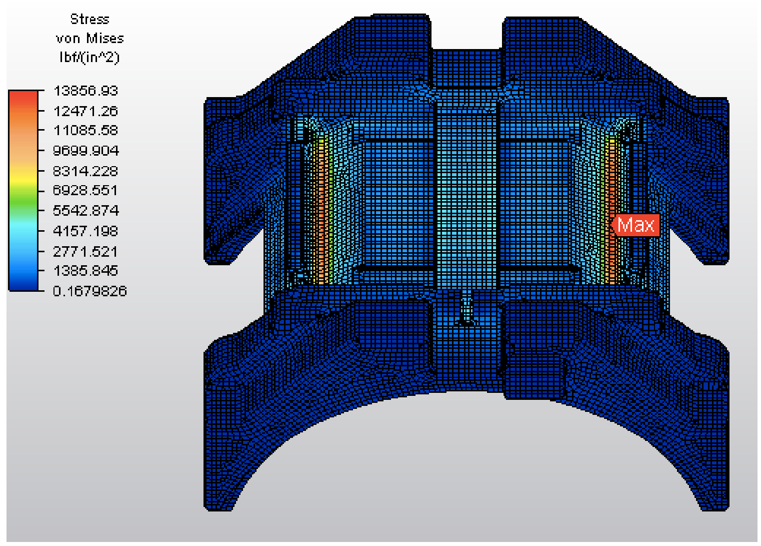


Figure 1: Sample FEA Result for Class K Modified Adapter

Figure 2: Sample Experiment for Class K Bearing Adapter

Additional work is recommended to look at other worst case scenarios with loading conditions that may develop in the field through the operating life of the railroad track, the railcar truck assembly, and the railroad bearing.

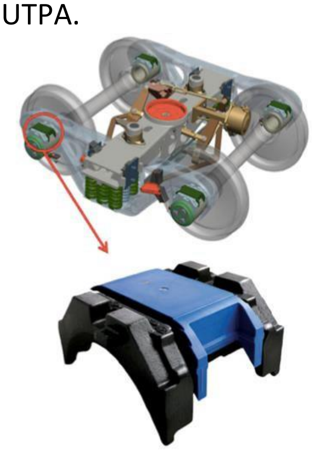
Figure 3 is a picture of the research team composed of UTPA Mechanical Engineering Faculty and undergraduate students.

	 **Figure 3: Research Team**
Impacts/Benefits of Implementation (actual, not anticipated)	The researchers at the University of Texas-Pan American have established an important track record in the area of experimentally validated finite element analysis related to railroad components including railway safety. The research results from this UTC project have been presented at different local, national, and international conferences with different audiences that include science and engineering students and faculty, railroad industry representatives, and researchers in the private and public sectors. The list of publications and/or presentations for this UTC project include the following: 1. Trevino, A., Fuentes, A. A., Tarawneh, C., and Montalvo, J., " FEA Fatigue Life Estimation of Modified Railroad Bearing Adapters for Onboard Monitoring Applications," *Proceedings of the 2015 ASME Joint Rail Conference*, San Jose, California, USA, March 23-26, 2015. 2. Montalvo, J., Trevino, A., Fuentes, A. A., and Tarawneh, C., "Structural Integrity of Conventional and Modified Railroad Bearing Adapters for Onboard Monitoring Applications," *Proceedings of the ASME International Mechanical Engineering Congress and Exposition*, Montreal, Canada, November 14-20, 2014.

	3. Montalvo, J., Trevino, A., Fuentes, A. A., and Tarawneh, C., "Structural Integrity of Conventional and Modified Railroad Bearing Adapters for Onboard Monitoring Applications," poster presented at *HESTEC Science Symposium*, Edinburg, TX, September, 2014. 4. Montalvo, J., Trevino, A., Fuentes, A. A., and Tarawneh, C., "Structural Integrity of Conventional and Modified Railroad Bearing Adapters for Onboard Monitoring Applications," poster presented at *University Transportation Center for Railway Safety Inauguration*, Edinburg, TX, February, 2014. An important benefit of this project is the training of a critical mass of students in Finite Element Analyses pertaining to the field of transportation, with emphasis on railway safety.
Web Links • Report • Project Website	http://www.utrgv.edu/railwaysafety/research/mechanical/2014/modified-railroad-bearing-adapter-for-onboard-monitoring/index.htm

Exhibit F - UTCRS

UTC Project Information	
Project Title	Effects of Vapor Grown Carbon Nanofibers on Electrical and Mechanical Properties of a Thermoplastic Elastomer
University	The University of Texas Rio Grande Valley (UTRGV)
Principal Investigator	Robert Jones, Ph.D., Mechanical Engineering (PI) Constantine Tarawneh, Ph.D., Mechanical Engineering (Co-PI)
PI Contact Information	Mechanical Engineering ENGR 3.246 Dept. (956) 665-2394 Office (956) 665-5019 robert.jones@utrgv.edu
Funding Source(s) and Amounts Provided (by each agency or organization)	Federal Funds (USDOT UTC Program): $52,068 Cost Share Funds (UTPA): $14,628
Total Project Cost	$66,696
Agency ID or Contract Number	DTRT13-G-UTC59
Start and End Dates	November 2013 – December 2014
Brief Description of Research Project	This research developed a formulation of conductive additives for use in thermoplastic elastomers currently in use in railcar steering pads. Plain elastomers are insulators and prevent transmission of current from rail to frame to signal door or gate opening devices. In addition, the thermal insulating properties of these materials slow heat flow from bearings through the bearing adapter into the side-frame where it can be dissipated. Traditional conductive additives such as carbon black must be applied at high volume fraction and result in substantial increases in pad stiffness and degradation of pad durability. Carbon nano-fibers are extremely efficient conductive additives and can produce the desired conductivity at much lower concentrations and with less impact on mechanical performance.
Describe Implementation of Research Outcomes	Project achieved its goal of developing a combination of TPU and conductive polymer which met application requirements. The final

(or why not implemented) Place Any Photos Here	formulation involved the use of a lower stiffness TPU than that traditionally used in the application to allow for the stiffening effect of the conductive additive. The minimum additive level which produced the necessary conductivity was determined and lab scale batches produced. The trial material was subjected to extensive small scale material testing including tensile testing, wear resistance, thermal stability, thermal conductivity, and impact. The formulation which was developed is currently in scale-up trials for use in a conductive pad. Development was necessarily done with laboratory scale equipment and transfer molding procedures due to limits on material quantity. Scale-up of the blending process has not been a problem and commercial quantities have been prepared. These have been successfully molded into conductive parts by transfer molding. However, commercial production requires use of plasticizing screw fed injection molding. If subjected to a high enough stress during melting, the material can lose conductivity as fibers fracture. This is the current technical barrier being addressed by the PI, working with commercial providers and members of the railroad research team at UTPA.  Figure 1 Elastomeric Steering Pad  Figure 2 Test Puck of Compounded TPU (Picture courtesy of Amsted Rail)
Impacts/Benefits of Implementation (actual, not anticipated)	The program produced a commercially viable conductive TPU formulation which can make the standard pad design conductive without changing the mechanical response of the pad/adapter system. In the process, the UTCRS also developed new capabilities for molding test quantities of material by transfer molding, acquired expertise working with nanofibers, and advanced the state of the art in understanding the effects of high fiber fractions on the behavior of elastomeric polymer systems. Production of material for field trials is underway as a first step before going into commercialization by the

	railroad industry. Furthermore, the work done in this area has resulted in a Master's Thesis entitled: 1. Basaldua, D., Effects of Vapor Grown Carbon Nanofibers on Electrical and Mechanical Properties of a Thermoplastic Elastomer," Master's Thesis, The University of Texas Rio Grande Valley, December 2014.
Web Links • Report • Project Website	http://www.utrgv.edu/railwaysafety/research mechanical/2014/ conductive-railroad-bearing-suspension-element/index.htm

Exhibit F - UTCRS

UTC Project Information	
Project Title	Modeling the Residual Useful Life of Bearing Grease
University	The University of Texas Rio Grande Valley (UTRGV)
Principal Investigator	Douglas Timmer, Ph.D., Manufacturing Engineering (PI) Robert Jones, Ph.D., Mechanical Engineering (Co-PI) Constantine Tarawneh, Ph.D., Mechanical Engineering (Co-PI)
PI Contact Information	Manufacturing Engineering ENGR 3.258 Dept. (956) 665-2606 Office (956) 665-2608 douglas.timmer@utrgv.edu
Funding Source(s) and Amounts Provided (by each agency or organization)	Federal Funds (USDOT UTC Program): $54,351 Cost Share Funds (UTPA): $10,977
Total Project Cost	$65,328
Agency ID or Contract Number	DTRT13-G-UTC59
Start and End Dates	November 2013 – December 2014
Brief Description of Research Project	This research developed an analytical model to predict the residual useful life of bearing grease. Modeling techniques that were employed include mechanistic or first principle models based upon process kinetics and empirical models including physics-based reliability models, non-linear regression, and neural networks. The analytical model provides users the ability to predict residual life based upon operational characteristics.
Describe Implementation of Research Outcomes (or why not implemented) Place Any Photos Here	A linear regression model was developed based on a split, split-plot design to predict residual life of grease based upon operational characteristics. Some of the outcomes are listed hereafter: 1. Characterized residual life of bearing grease as the Oxidation Induction Time (OIT). 2. Novel utilization of statistical design of experiments and linear regression to model residual life of bearing grease. The data

	was collected as a split, split-plot design and analyzed using restricted maximum likelihood technique implemented in Matlab™. 3. Mathematical model that predicts residual life of bearing grease. The following findings were established: (a) the mileage had the most significant impact upon the life of the bearing grease and the relationship was negative, (b) the bearing temperature had the second largest impact upon bearing grease and the correlation between temperature and OIT was negative, and (c) OIT values were higher, indicating larger remaining life, for the grease samples at the spacer ring location than grease sampled at the inner and outer bearing raceway.
Impacts/Benefits of Implementation (actual, not anticipated)	The research performed for this project has resulted in two national conference papers and presentations, and a Master's Thesis. The following are benefits resulting from this research: 1. Timmer, D., Martinez, T., Jones, R., and Tarawneh, C., "Modeling the Residual Useful Life of Railroad Bearing Grease," 2014 Informs Conference, San Francisco, CA, November 9-12, 2014. 2. Martinez, T., Timmer, D., Jones, R., and Tarawneh, C., "Developing Empirical Models of Railroad Bearing Grease," *Proceedings of the 2015 ASME Joint Rail Conference*, San Jose, CA, March 23-26, 2015. 3. Martinez, T., "Modeling the Residual Useful Life of Bearing Grease," Master's Thesis, The University of Texas Rio Grande Valley, December 2015.
Web Links • Report • Project Website	http://www.utrgv.edu/railwaysafety/research/mechanical/2014/life-of-bearing-grease/index.htm

Exhibit F - UTCRS

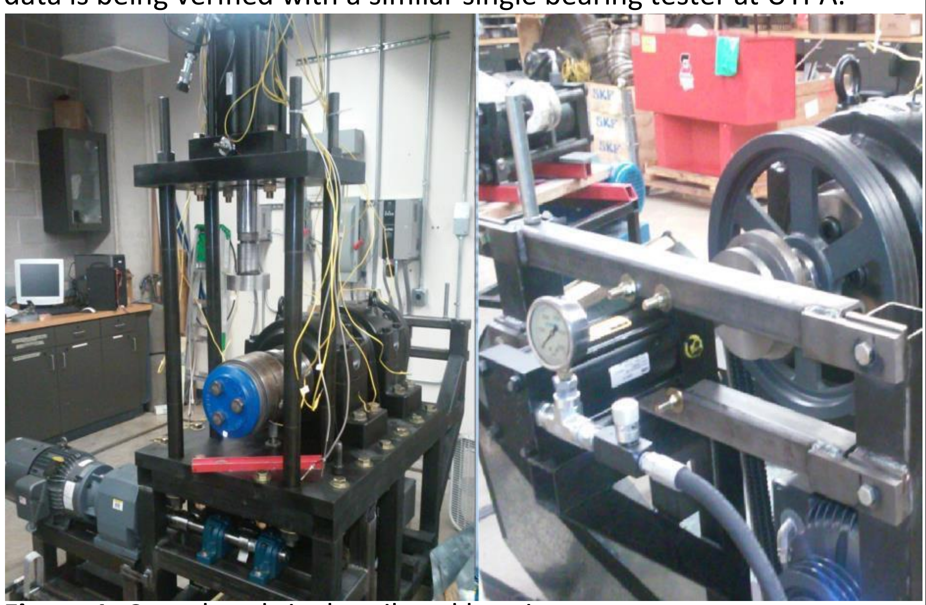
UTC Project Information	
Project Title	Applications of Magnetostrictive Materials for Real-Time Monitoring of Vehicle Suspension Components
University	The University of Texas Rio Grande Valley (UTRGV)
Principal Investigator	Heinrich Foltz, Ph.D., P.E., Electrical Engineering (PI) Constantine Tarawneh, Ph.D., Mechanical Engineering (Co-PI)
PI Contact Information	Electrical Engineering ENGR 3.214 Dept. (956) 665-2609 Office (956) 665-5016 heinrich.foltz@utrgv.edu
Funding Source(s) and Amounts Provided (by each agency or organization)	Federal Funds (USDOT UTC Program): $44,820 Cost Share Funds (UTPA): $15,249
Total Project Cost	$60,069
Agency ID or Contract Number	DTRT13-G-UTC59
Start and End Dates	November 2013 – December 2014
Brief Description of Research Project	The purpose of this project is to investigate applications of magnetostrictive materials for real-time monitoring of railroad suspension components, in particular bearings. Monitoring of such components typically requires measurement of temperature, static load, and vibration, among other parameters. In addition, real-time, long-term monitoring can be greatly facilitated through the use of wireless, self-powered sensors. Magnetostrictive materials, such as Terfenol-D, have the potential to address both requirements. In this project, Terfenol-D was characterized in three applications: (a) as a static load sensor, (b) as a vibration sensor, and (c) as an energy harvesting device. Currently, piezoelectrics are used for many vibration and energy harvesting applications; however, they are fragile and are difficult to use for static load measurements. Magnetostrictive metals are tougher, and their property of variable

	permeability when stressed can be exploited to measure static loads. Deliverables for this project include: (a) characterization of Terfenol-D materials over a range of loads and frequencies appropriate for railroad bearing applications, (b) demonstration and performance measurements of Terfenol-D energy harvesting, (c) demonstration and performance measurements of a Terfenol-D load sensor, (d) demonstration and performance measurements of a Terfenol-D vibration sensor, and (e) support electronics allowing integration into a data collection system. In addition, the possibility of using a single Terfenol-D core to perform all three functions was explored, and the viability under conditions typically encountered in a railroad bearing adapter were tested.
Describe Implementation of Research Outcomes (or why not implemented) 	(a) Terfenol-D samples were acquired and tested on a universal test system for conventional mechanical properties as well as change in magnetic properties under load. One issue of importance that was investigated in this phase was hysteresis in both the stress/strain curves, and in the permeability versus stress curves. It was found that a significant component of the hysteresis can be eliminated through proper fixture design to eliminate "walking" of the material under cyclic load, and through elimination of soft materials such as epoxy during mounting. Additional hysteresis can be eliminated through application of appropriate bias magnetic field. (b) A pilot study of energy harvesting was completed, using cyclic loading comparable to that found in typical railroad bearing pads. Multiple steel fixtures to provide proper mounting combined with a closed, low reluctance magnetic circuit were examined (see photo at left), and a study of optimum static magnetic field bias was conducted. 75 mW of peak available power was obtained from a 13-mm diameter x 13-mm long sample, using a sinusoidally varying load with a maximum load rate of 120 kip/s and a 3300 Gauss bias field. (c) A pilot study of static load sensing using Terfenol-D was completed. The basic mechanism is change of inductance in a coil wound on a Terfenol-D core. A key finding of this work is that there is significant time delay in the inductance versus load relationship, giving the appearance of hysteresis when the load is cyclically varied. However, careful attention to timing shows that a repeatable curve can be obtained for nearly static loads. The relationship is nonlinear but monotonic, so a calibration curve can be produced. (d) Some testing of response to vibrations was conducted; however, the initial testing showed that the range of parameters (sample size,

	coil size and turns, and magnetic field bias) needed for vibration sensing would be significantly different from that needed for static load sensing and energy harvesting. Furthermore, it appeared that performance would not be competitive with conventional MEMS based accelerometers when cost is considered. Therefore, further study of vibration sensing applications was deferred. (e) For the work completed in this phase of the study, the support electronic systems were implemented using off-the-shelf laboratory instrumentation (inductance bridges and a data acquisition system). A follow up project, already funded, will have the goal of producing selfcontained, self-powered electronics using Terfenol-D for power production and load sensing, with enough surplus power to support temperature sensing, accelerometer-based vibration sensing, signal conditioning, and wireless data transmission.
Impacts/Benefits of Implementation (actual, not anticipated)	1. Estrada, R., "Applications of Magnetostrictive Materials in the Real Time Monitoring of Vehicle Suspension Components," Master's Thesis, The University of Texas Rio Grande Valley, December 2014. 2. Estrada, R., Foltz, H., Tarawneh, C., "Energy Harvesting Potential of Terfenol-D for On-Board Bearing Health Monitoring Applications," *Proceedings of the ASME 2015 Joint Rail Conference*, San Jose, CA, March 23-26,2015. This work provided the basis for a newly funded University Transportation Center for Railway Safety project, and the expertise developed in magnetostriction was the basis for an NSF proposal currently under review.
Web Links • Report • Project Website	http://www.utrgv.edu/railwaysafety/research/mechanical/2014/applications-of-magnetostrictive-materials/index.htm

Exhibit F - UTCRS

UTC Project Information	
Project Title	Single Bearing Test Rig with Vertical, Lateral, and Impact Load Capabilities
University	The University of Texas Rio Grande Valley (UTRGV)
Principal Investigator	Stephen Crown, Ph.D., Mechanical Engineering (PI) Constantine Tarawneh, Ph.D., Mechanical Engineering (Co-PI) Robert Jones, Ph.D., Mechanical Engineering (Co-PI)
PI Contact Information	Mechanical Engineering ENGR 3.234 Dept. (956) 665-2394 Office (956) 665-5015 stephen.crown@utrgv.edu
Funding Source(s) and Amounts Provided (by each agency or organization)	Federal Funds (USDOT UTC Program): $57,117 Cost Share Funds (UTPA): $91,399
Total Project Cost	$148,516
Agency ID or Contract Number	DTRT13-G-UTC59
Start and End Dates	November 2013 – December 2014
Brief Description of Research Project	Testing of tapered-roller bearings for railroad cars is an area of active research at The University of Texas-Pan American (UTPA). Current efforts are aimed at bearing health monitoring utilizing emerging temperature and vibration sensor technologies. UTPA currently possesses two four-bearing test rigs that are used to perform laboratory experiments required to support the ongoing development of rolling stock condition monitoring research projects. These two testers only provide static vertical loading that can simulate railcar cargo loads. A thorough literature review revealed that there are no testers with vertical, lateral, and impact loading capabilities in a dynamic single railroad bearing configuration. The need for a single bearing test rig has been motivated by the desire to create a testing environment that more closely simulates the conditions experienced by railroad bearings in field service. To this

	end, a design has been proposed for a single railroad bearing tester that incorporates up to 5000 lbf of lateral loading as well as a variable frequency (0-4 Hz) impact loading in addition to the applied static vertical loading (up to 60,000 lbf). The fabricated tester will be used to compile a library of bearing defects with the purpose of characterizing bearings based on the acquired temperature and vibration signatures under normal and abnormal operating conditions. The data can then be used to identify defective bearings at an early stage so that appropriate preventative measures can be taken to avoid potential catastrophic derailments.
Describe Implementation of Research Outcomes (or why not implemented) Place Any Photos Here	The single railroad bearing test rig with vertical, lateral, and impact load capabilities for use by the University Transportation Center for Railway Safety (UTCRS) projects is instrumented and operational. The single railroad bearing tester allows for 5000 lbf of lateral loading, variable frequency (0-4 Hz) impact loading, and applied static vertical loading (up to 60,000 lbf). The completed system is shown in Figure 1. The right hand side of Figure 1 shows the lateral loading system. A schematic of the proposed design is shown in Figure 2. The impact motor was moved to the opposite side to provide better access to the bearing and shaft during maintenance operations. The test rig is currently being used to monitor railroad bearing health and collected data is being verified with a similar single bearing tester at UTPA.  **Figure 1:** Completed single railroad bearing tester

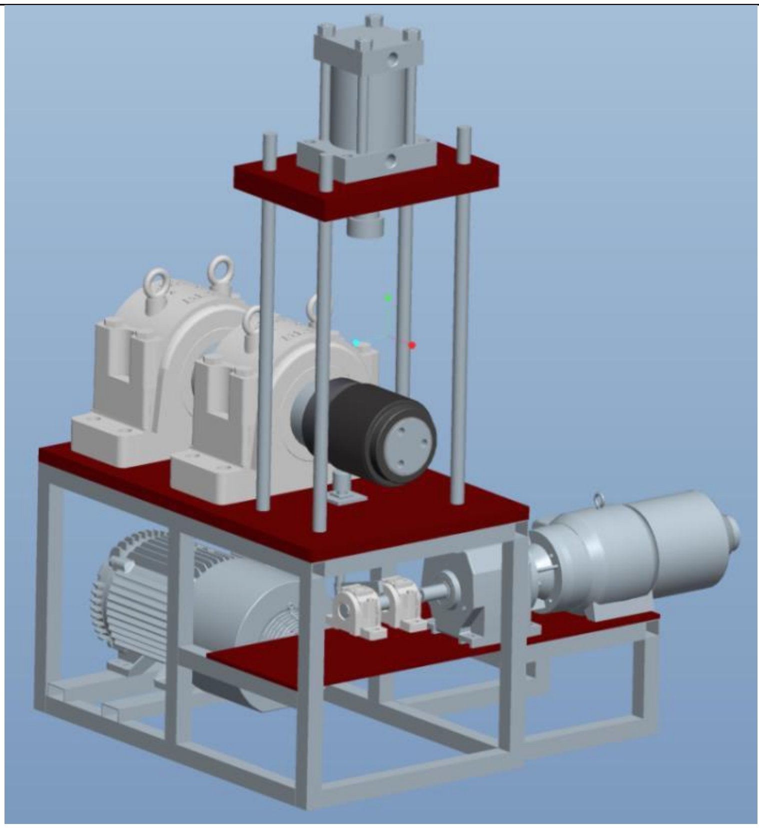


Figure 2: Single railroad bearing tester design

The initial vertical impact system did not produce the required impact forces and was completely redesigned. The new design has been tested and provides the required impact forces. The redesigned vertical impact loading system is shown in Figure 3. A variable frequency drive on the 10 hp impact motor allows for variation in the frequency of impacts. The profile of the cam is used to control the impact force which can be adjusted to a maximum of 5000 lbf. Varying the material of the removable impact head can be used to control the profile of the impact. An accelerometer mounted on the impact head will be used to dynamically measure and record impact data.

A high quality lubricant was used for the pillow block bearings as a substitute for the active cooling system that allows for high speed testing on the single bearing tester. As part of the continuation project that has approved for funding by the UTCRS, two active cooling systems are currently under development including an enhanced forced air system and a water cooled jacket that uses a small chiller. Moreover, the current fixture being used for the compliant element of the suspension is a modified bearing adapter. Additional fixtures are still under development.

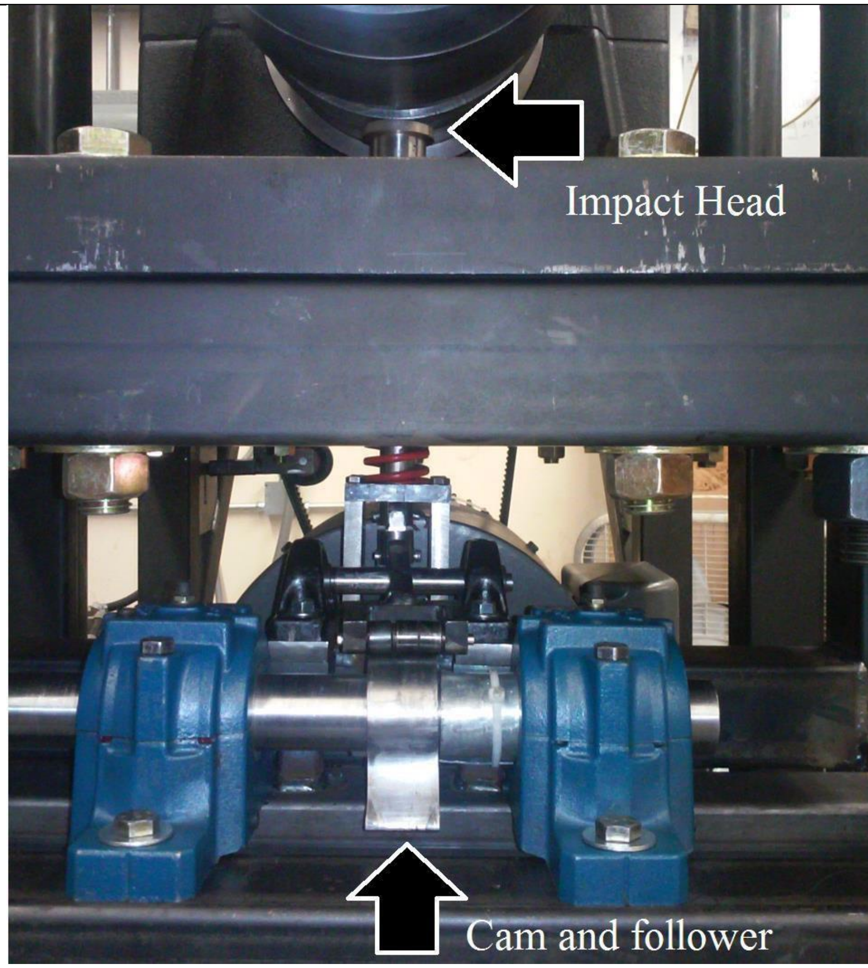


Figure 3: Vertical impact loading system

The hydraulic cylinder used to control the vertical loading provides both static and dynamic loading of up to 60,000 lbf. The pressure in the main hydraulic cylinder is controlled through the use of a smaller secondary hydraulic cylinder that is used as a low volume pump that only displaces the volume of the piston rod. The secondary cylinder is driven by a threaded rod and computer controlled stepper motor. The control system is shown in Figure 4. The system allows for low frequency dynamic control of vertical load, ramping loads, and accurately controlled static loads for long testing periods that prohibit manual control.

	 **Figure 4:** Hydraulic pressure control system for vertical loading
Impacts/Benefits of Implementation (actual, not anticipated)	Recent track data shows that sensors developed and tested on the single bearing tester correlate well with field data, which validates the design concept and proves that the single bearing test rig closely mimics field operation. The later implies that testing performed on this test rig in the laboratory setting will provide data that is applicable for field service. A railroad bearing manufacturer recently contacted UTPA regarding running tests using the center's single bearing tester. The contact was made through information posted on the UTCRS web site demonstrating the need for and interest in a single bearing tester. A newly submitted UTCRS project has been approved for funding which will use the single bearing tester to better optimize wayside hot box detection systems. Work on this project involved four undergraduate students who gained invaluable expertise in design, optimization, and fabrication of this test rig. The project also created opportunities for two senior design projects which helped students academically as well as gaining valuable hands-on experience.
Web Links • Report • Project Website	http://www.utrgv.edu/railwaysafety/research/mechanical/2014/single-bearing-test-rig/index.htm

UNIVERSITY TRANSPORTATION CENTER FOR RAILWAY SAFETY

Exhibit F - UTCRS

UTC Project Information	
Project Title	Rail Neutral Temperature In-Situ Evaluation
University	Texas A&M University (TAMU)
Principal Investigator	Stefan Hurlebaus, Ph.D., Civil Engineering (PI)
PI Contact Information	3135 TAMU College Station, TX 77843-3135 Office (979) 845-9570 shurlebaus@tamu.edu
Funding Source(s) and Amounts Provided (by each agency or organization)	Federal Funds (USDOT UTC Program): $104,653 Cost Share Funds (TAMU): $54,911
Total Project Cost	$159,564
Agency ID or Contract Number	DTRT13-G-UTC59
Start and End Dates	January 2014 – December 2016
Brief Description of Research Project	Continuous welded rails (CWR) are rails that are welded together to become long continuous members that are fixed at both ends. When the ambient temperature significantly increases or decreases from the rail neutral temperature (RNT), the temperature at which the rails experience zero stress, the metal can expand and cause the rails to buckle, or contract and cause the rails to fracture. These effects can, in a worst-case scenario, result in train derailment. However, even installing CWR at a median ambient temperature does not guarantee that a rail will not buckle or fracture in the future, and it is sometimes necessary to reinstall the entire rail. A means of preventing these faults is to measure RNT and longitudinal rail stress of CWR to determine if the reinstallation of the entire rail is warranted to increase safety. Several methods for measuring RNT and longitudinal stress exist, but they each have various pitfalls. RNT is traditionally determined by cutting the rail, measuring the gap, performing calculations, and re-welding the rail, but this method is destructive and labor intensive.

	Nondestructive methods exist, but they can be costly, are not always accurate, and may require contact with the rail. The technique being created is a nondestructive and noncontact method of measuring RNT and longitudinal stress. This technique uses a pulse laser to generate Rayleigh waves, which can be used to determine the longitudinal stress on the rails, and the RNT can be calculated using the relationship between the longitudinal stress, ambient temperature, and material properties. Rayleigh wave polarization is more sensitive and more robust than Rayleigh wave speed; thus, it results in more accurate and more precise measurements.
Describe Implementation of Research Outcomes (or why not implemented) Place Any Photos Here	The first objective of this research was to further test the method of measuring the longitudinal stress in rails using Rayleigh wave polarization. This technique has proven effective in a controlled laboratory environment; however, it had to be proven as a robust method before finding any success in the field. To this end, a study was performed on the effects of rail condition on the Rayleigh wave polarization measurement. This study found that a rail's surface condition affects the measurement results more than the rail's composition or history. Other factors affecting the measurement could include temperature, non-uniform internal stresses, and edge defects caused by using small rail samples. With these facets of the polarization measurement technique examined, a series of guidelines have been established that allowed this measurement to be recreated outside the laboratory. These essentials, including the use of a fully noncontact stress measurement technique, maneuverability on or off the tracks, minimal downtime between measurements, modular framing, and protected and easily accessed instrumentation, have been expressed through an iterative 3D modeling process. A design for a full-scale prototype has been developed that adheres to the above guidelines. The second objective of this research was to provide an apparatus to simplify the measurement process. Endeavors included the construction of the full-scale functioning prototype (Figure 1). This prototype enabled measurements previously carried out only in the laboratory to be performed in the field. This accessibility allowed the measurement of a wider range of rails.

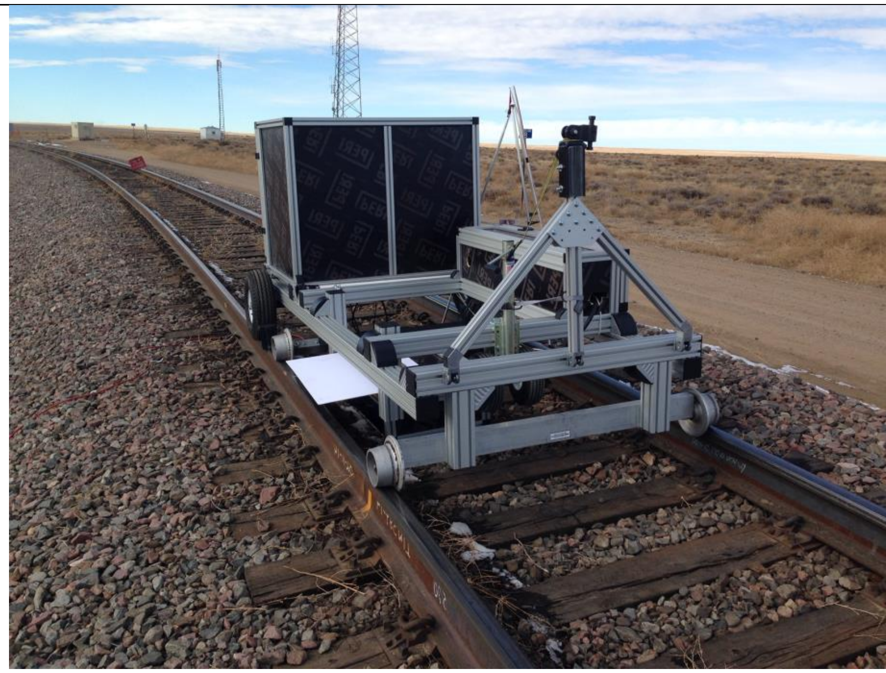
	 Figure 1: Rail Stress Measurement Prototype
Impacts/Benefits of Implementation (actual, not anticipated)	This rail stress measurement prototype was initially developed as a stop-and-go measurement device; however, the apparatus can be easily upgraded to a fully mobile stress measurement system. The method of measuring stress was developed so that the same technique can be used to determine the condition of the rail at the time of installation, and then monitored at any time during the lifespan of the rail. Some obstacles, such as the LDV heads interfering with rail clearance restrictions, was resolved for an in-motion system. Other factors like instrument vibrations and laser misalignments induced by vehicle motion, which are inherent in a mobile measurement situation, will need to be accounted for as the in-motion system develops. The work performed for this project has also resulted in a Master's Thesis listed below ➢ Hurley, S. J., "Development of a Longitudinal Rail Stress Measurement Device," Master's Thesis, Texas A&M University, December 2014.
Web Links • Reports • Project website	http://www.utrgv.edu/railwaysafety/research/infrastructure/evaluation-of-rail-neutral-temperature/index.htm

Exhibit F - UTCRS

UTC Project Information	
Project Title	Ultrasonic Tomography for Infrastructure Inspection
University	Texas A&M University (TAMU)
Principal Investigator	Stefan Hurlebaus, Ph.D., Civil Engineering (PI)
PI Contact Information	3135 TAMU College Station, TX 77843-3135 Office (979) 845-9570 shurlebaus@tamu.edu
Funding Source(s) and Amounts Provided (by each agency or organization)	Federal Funds (USDOT UTC Program): $104,653 Cost Share Funds (TAMU): $54,909
Total Project Cost	$159,562
Agency ID or Contract Number	DTRT13-G-UTC59
Start and End Dates	January 2014 – December 2016
Brief Description of Research Project	The structural integrity of railroad infrastructure is critical in order to address structural repair needs in a timely fashion and ensure rail safety. This includes the regular inspection and maintenance of railroad tunnel linings and timber beams and ties. Since tunnels are naturally in an aggressive environment that is not conducive to lane closures, early detection that leads to preventive maintenance is a necessity. The occurrence of damage and deterioration in railroad timber beams and ties can lead to failure of the components and, in the worst case, derailment of the train. According to the Federal Railroad Administration (FRA), wide gages due to defective/missing crossties accounted for the highest percentage (17.1%) of all railway accidents in the US from 2008-2011 (FRA, 2011). It is, therefore, crucial to detect damage at an early stage so that, by taking appropriate measures, failure can be prevented. The proposed project will examine the use of Ultrasonic Tomography (UST) to examine the interior of wooden beams and crossties as well as railroad tunnel linings on-site. The Ultrasonic Tomographer employs

	a matrix (4x12) of low-frequency, shear transducers that generate shear waves through the depth of a specimen under test. The waves are reflected by internal discontinuities and changes in medium (such as concrete, air, and steel). This behavior is utilized to map voids, delamination, cracks, and other defects, as well as structural depth and reinforcement presence. The waves are sequentially emitted and received by 66 paired transducers per single scan, causing repeated reflections and patterns to stand out for inspection. Through the use of dry-point-contact piezoelectric sensors, the transducers do not require the use of a coupling agent, making it practical for on-site applications. The recorded signals undergo automated signal processing to identify the existence, location, and size of the potential discontinuities. The UST technique can be used to map entire 3D images of concrete sections as well as single-point evaluations.
Describe Implementation of Research Outcomes	**INTRODUCTION** The Synthetic Aperture Focusing Technique (SAFT) algorithm is a post-processing algorithm that converts reflected ultrasonic data into a high-resolution image. The first one-dimensional implementation of the SAFT algorithm was in the late 1970s, following the wide use of radar technology. For smaller transducers at lower frequencies, the SAFT algorithm performs with higher accuracy when compared to other imaging techniques (Dengzhi, 2007). In 1982, Pacific Northwest Laboratory conducted studies to incorporate the SAFT algorithm in field equipment, following extensive research conducted by Hall et al. (1986). It is important to note that the basic theory for the SAFT algorithm is only applicable to homogeneous materials, but it can be modified in order to accurately work for non-homogenous materials like reinforced concrete. The SAFT algorithm creates high-resolution images by superimposing several pulse echo signals that have been measured at various positions (Kotoky and Shekhar, 2013). The linear SAFT algorithm aides in the clarity of the images by numerically superimposing the data transmitted and received by the array of dry contact transducers. SAFT creates images based on results from either B- or C-scans, series of received signal that are perpendicular and parallel to the surface, while filtering out scattering. This leads to a clear and more precise image that can accurately depict the defects (Burr et al., 1998).

To minimize attenuation, transducers using low frequencies between 30 and 80 kHz are typically used for the inspection of concrete (Kotoky and Shekhar, 2013). For reinforced concrete, which has nonhomogeneous property causing noise, minimizing the structural noise is critical because it can disguise some defects and inaccurately display others.

Most commercial SAFT algorithms in nondestructive testing are inaccessible and designed for specific geometries of devices. Therefore, an in-house SAFT algorithm based on time-domain for the prototype device was developed.

GEOMETRY OF SAFT ALGORITHM

As measurements are required at various positions, it is necessary to have the device send pulse echoes in an array. Using the post-processing algorithm, engineers can translate ultrasonic data into images that can accurately identify the vast majority of defects, such as; delamination, water filled void, air voids, and honeycombing.

It is critical to know the path travelled by the ultrasonic wave from the emitting transducer to the defect and back to the receiving transducer, for SAFT to create images from the ultrasonic transmission data. Therefore, an A-scan is necessary to provide geometric guidance and restore the image. Once the receiving transducers have received all emitted signals, the algorithm superimposes this computed data, resulting in a high resolution image. A time-frequency template of the signals is used over a Fourier transform. The time-frequency analysis is based on Wigner-Ville distribution.

Kotoky and Shekhar (2013) explain that the basics of the SAFT algorithm rely on geometrical reflection of the wave. For this, the focus of the ultrasonic transducers can be assumed to be in constant phase (so, the amplitude is consistent) before diverging at various angles in a cone shape. The angle of deflection is determined by transducer properties, primarily focal length and diameter. Because of this, it is necessary for the system to use a single type of transducer, because waves propagating at various angles would make the algorithm difficult, if not impossible. The properties of the transducer can be calculated easily knowing the path length and travel time for a signal moving along that path. The aperture of the transducer, and the diameter of wave perpendicular to wave propagation, are critical because it assists in the layering of the A and B scan. The aperture width of the transducer corresponds to the width of the cone, and at what range it can be applied. The path length that the signal must travel corresponds to the phase shift seen in the signal. From these geometric properties, an engineer can construct images that simplify the detection of defects below the concrete surface (Kotoky and Shekhar, 2013). This geometric interpretation can be seen in Figure 1 through Figure 3.

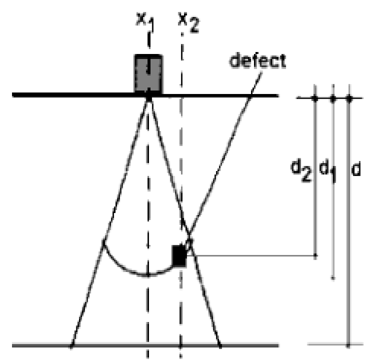


Figure 1: Display of the Waves Passing through the Defect Zone (Kotoky and Shekhar, 2013).

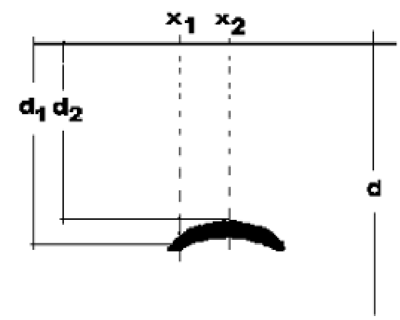


Figure 2: B-Scan of the Iron Defect (Kotoky and Shekhar, 2013).

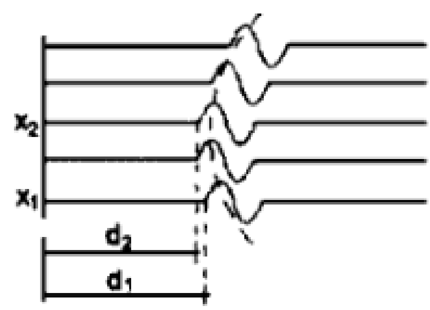


Figure 3: Resulting Image Produced from the Wave Passing Through the Defect (Kotoky and Shekhar, 2013).

As shown in Figure 1, the wave is sent from the transducer at a distance x_1 in a conical shape, interacting with the defects at x_2. When the wave interacts with the defect, which is at a depth d_2, the same wave is at a depth d_1 from the surface directly below the transducer. From this, Figure 2 can be obtained showing the shape of the waves and the various distances. This image displays the detection of a single round hole in an iron block. The final broad image is then produced using the transducer aperture width. With this technique, the A-scan is focused below the transducer as shown in Figure 1, which corresponds to the B-scan in Figure 2. These images are ultimately used to produce the final image in Figure 3.

With SAFT, the intention is to determine a parabola at each data point where a significant amount of energy is dispersed. If the summation of energy values over this parabola at a point is high, it is marked as a scattering point. For the scattering of signal in non-homogeneous materials, it is important to know properties of this parabola, or conical shape, to reduce noise. In order to successfully reduce scattering, the parabola must be short in comparison with the whole array of transducers because of its larger size. In addition, by producing a smaller parabola, the algorithm is more efficient. Apart from relative shortness, it is important that the parabola be thick in order to average out noise due to small changes in the material. By using a thicker line, the amplitude indicating flaws is not as large, and it evens out noise for non-homogeneous material. Only a flaw with the same length or larger than the thickness of the parabola can be detected, removing all the noise present in a non-homogeneous material (Burr et al., 1998).

NONLINEAR SAFT

In the mid-1990s, it was difficult to interpret the results using the original SAFT algorithm, and it usually required a trained engineer to decipher recorded data (Burr et al., 1998). The algorithm was later modified to overcome these shortcoming. The modifications to the SAFT algorithm, previously known as a non-linear SAFT algorithm, are necessary for concrete structures which are non-homogeneous. Non-linear modification requires that the A- or B-scan of the surface be known from the linear system.

NOISE REDUCTION

Noise reduction is relatively simple in homogeneous materials when compared to non-homogeneous materials. The spectrum of displacement may be calculated from the spectrum of the signal (at a specific location and frequency) multiplied by the signal's impulse response (from passage through the structure). From deconvolution, the incident wave scattering is easy to handle in a homogeneous material, but not with a non-homogeneous material like reinforced concrete. In non-homogeneous materials, the calculated scatter does not match with under inspection that has different stiffness or the actual scattering of the signal. The SAFT algorithm can be further modified to account for flaw lengths that are much larger than the length of the non-homogeneous particles. The correlation between two reflected signals at two different points in the transducer array may be used to differentiate between the signals from the defects and those that are related to structural noise.

BASIC THEORY OF SAFT ALGORITHM IN TIME DOMAIN

One of the main goals in developing an in-house SAFT algorithm was to devise an algorithm that will be easy to construct and implement. A time-domain SAFT algorithm was developed for this investigation. The two major assumptions that were made in this study in order to develop a SAFT algorithm were: (1) isotropic material, which means that the wave in material medium propagates at a constant speed, and (2) material homogeneity, because the prototype device has lower frequency range, which means that it has longer wave length than the size of aggregate and non-homogeneous property of reinforced concrete rarely affect the result of SAFT. So, an area density is considered to indicate an anomaly, such as a damaged region, or rebar location.

Mathematically, sectional material properties can be described using the reflectivity. The relationship between the reflectivity function, $f(x,z)$, and the A-scan data, $s(x_e,x_r,t)$, is given by

$$s(x_e,x_r,t) = \int_x \int_z f(x,z)\delta\big(t^*(t,x_e,x_r,x,z)\big)\mathrm{d}z\,\mathrm{d}x, \quad [1]$$

where δ is the transmitted impulse, x_e and x_r are the horizontal location of emitting and receiving transducers, respectively, x and z are the horizontal and vertical position in the region of interest (ROI), respectively, t is the time, and t^* is defined as

$$t^* = t - \frac{1}{c}\left(\sqrt{z^2 + (x - x_e)^2} + \sqrt{z^2 + (x - x_r)^2}\right), \quad [2]$$

where c denotes the wave velocity and is constant.

Predicting the exact behavior of transmitted impulse and calculating the reflectivity function using Eq. [1] is rarely possible since measured data contains noise. To overcome this difficulty, sectional image is reconstructed from the received A-scan data. The equation for the reconstructed image, $O(x,z)$, for a continuous system is described as

$$O(x,z) = \int_{x_{emin}}^{x_{emax}} \int_{x_{rmin}}^{x_{rmax}} \alpha(x_e, x_r, x, z) s(x_e, x_r, t_f) \mathrm{d}x_r \, \mathrm{d}x_e, \qquad [3]$$

where $[x_{emin}, x_{emax}]$ and $[x_{rmin}, x_{rmax}]$ is the range of emitting and receiving transducers, respectively, α is the apodization factor, and t_f is the time of flight that is given by (Figure 4),

$$t_f = \frac{1}{c}\left(\sqrt{z^2 + (x - x_e)^2} + \sqrt{z^2 + (x - x_r)^2}\right). \qquad [4]$$

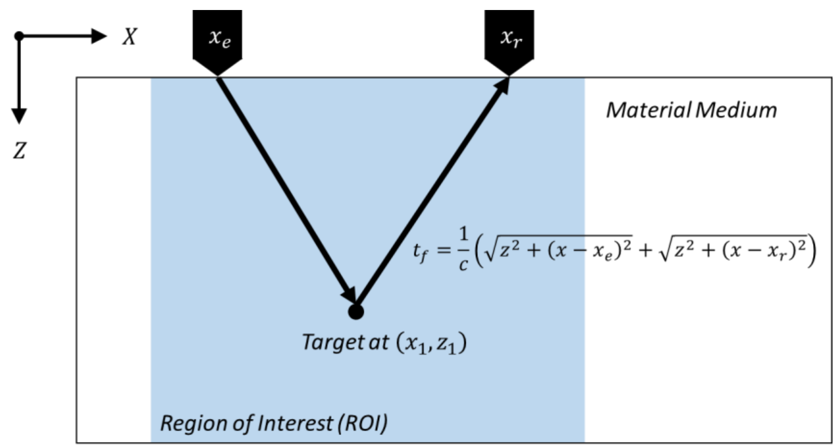


Figure 4: Geometry of Measuring Wave Propagation.

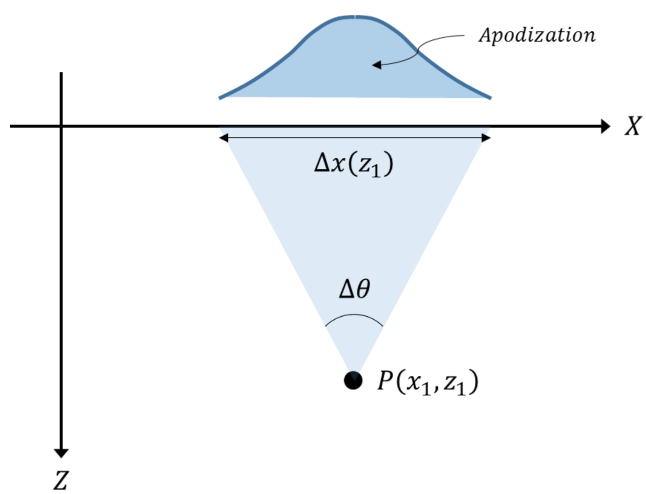


Figure 5. Illustration of Hann Function.

Apodization factor is a weighing function that reduces the effect of side lobe artifacts in the focused image. The Hann function, as shown in Figure 5, was used as an apodization function in this study. However, the transducers used in this research generate finite number of A-scan pairs. The discrete form of Eq. [3] is given as

$$O(x,z) = \sum_{e=1}^{T-1} \sum_{r=e+1}^{T} \alpha(x_e, x_r, x, z) s\left(x_e, x_r, t_f\right), \qquad [5]$$

where T is the number of sensor locations, and e and r are the indexes for the emitting and receiving transducers, respectively. Datasets with more A-scans generally have higher resolution.

VALIDATION

In order to verify the feasibility of the developed SAFT algorithm, B-scan image from the MIRA A1040 device was used. The MIRA device has 4 by 12 array of transducers and provides reconstructed B-scan images using its own embedded SAFT algorithm. The device generates a series of A-scans from the single scan. In a single scan, 1st column of transducers transmits wave impulse and 2nd to the last of arrays record wave reflections. Then, 2nd column of transducers array transmits wave impulse and 3rd to last arrays record wave reflections. This way, 66 pairs of A-scans were generated. Figure 6 shows an example of the B-scan results from the MIRA device, and the corresponding A-scan data extracted from the device. The B-scan image identifies two groups of defects located at a depth of 120 mm and 300 mm from the surface.

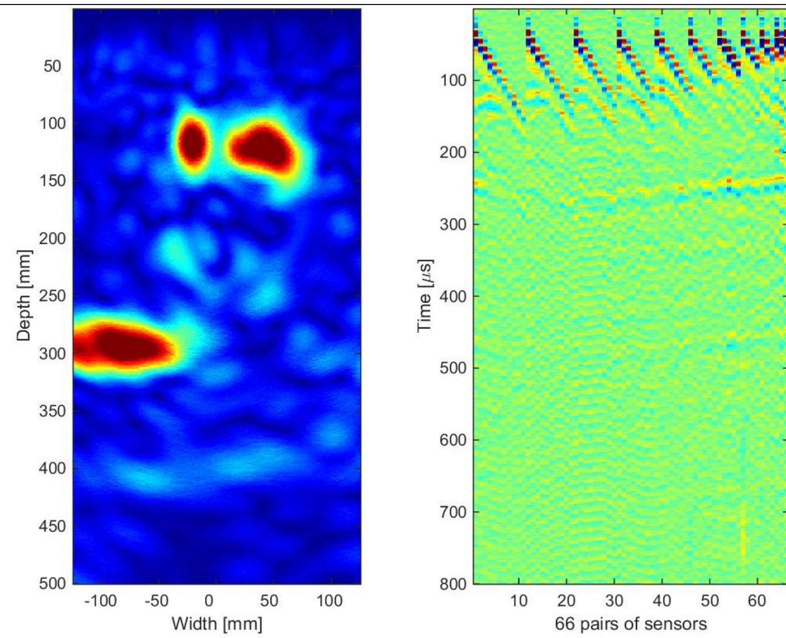


Figure 6: B-Scan Image (left), and Extracted A-Scan Data (right) from MIRA Device.

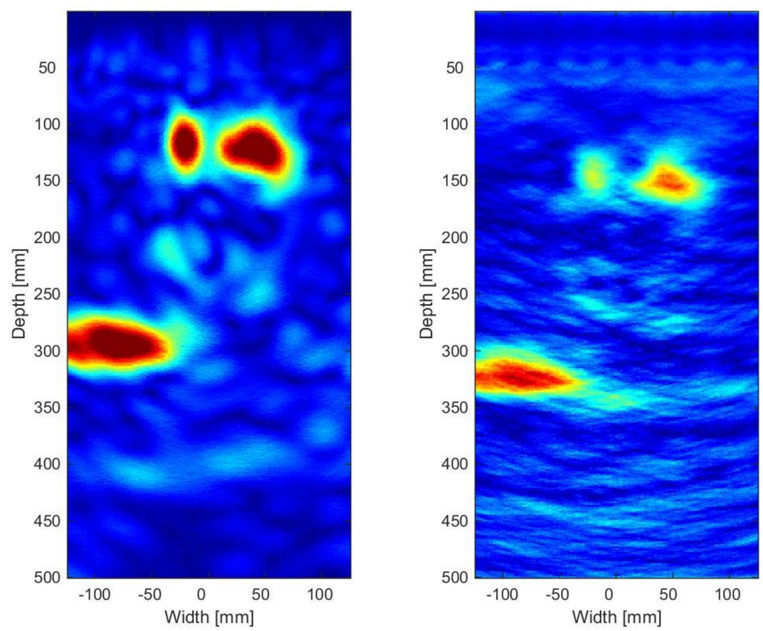


Figure 7: Comparison of B-Scan Images from the MIRA Device (left) and the developed SAFT Algorithm (right).

The A-scan data was extracted from the MIRA device and used as input data to the developed SAFT algorithm (Figure 6). Figure 7 shows a comparison of the B-scan images obtained from the MIRA device and the developed SAFT algorithm. Similar defect shapes were reconstructed in both cases. The developed algorithm generated slightly rougher image compared to the MIRA device. Both, however, are equally effective in detecting areas of high reflectivity. Additionally, the B-scan from the developed SAFT algorithm detects the defects approximately 30 mm below the defects detected in the B-scan from the MIRA device.

3D VISUALIZATION AND OTHER SECTIONAL VIEWS

The B-scans provide only sectional information, and the users may have difficulty understanding the three-dimensional distribution of defects from the two-dimensional B-scans. On the other hand, three-dimensional view of SAFT images help users to intuitively understand the location of defects relative to each other.

A three-dimensional visualization tool was developed using MATLAB. Once multiple layers of B-scan images are obtained, the reflectivity values between the layers are calculated by linear interpolation. As shown in Figure 8, points that have reflectivity above a certain value are represented in three-dimensional perspective.

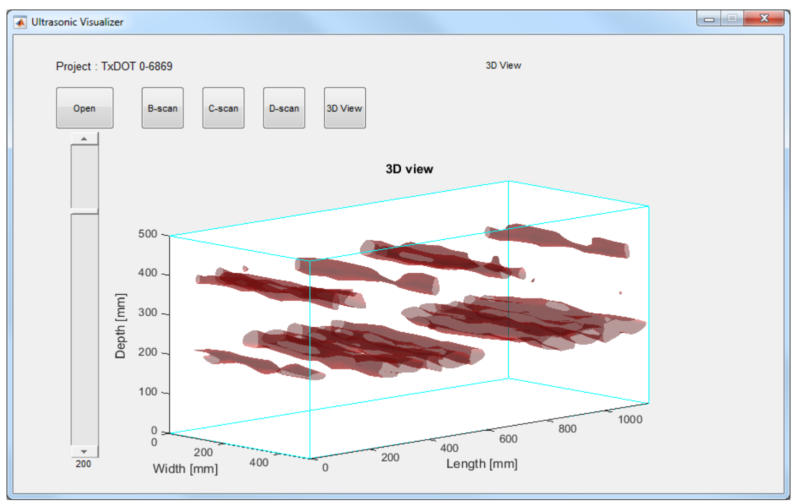
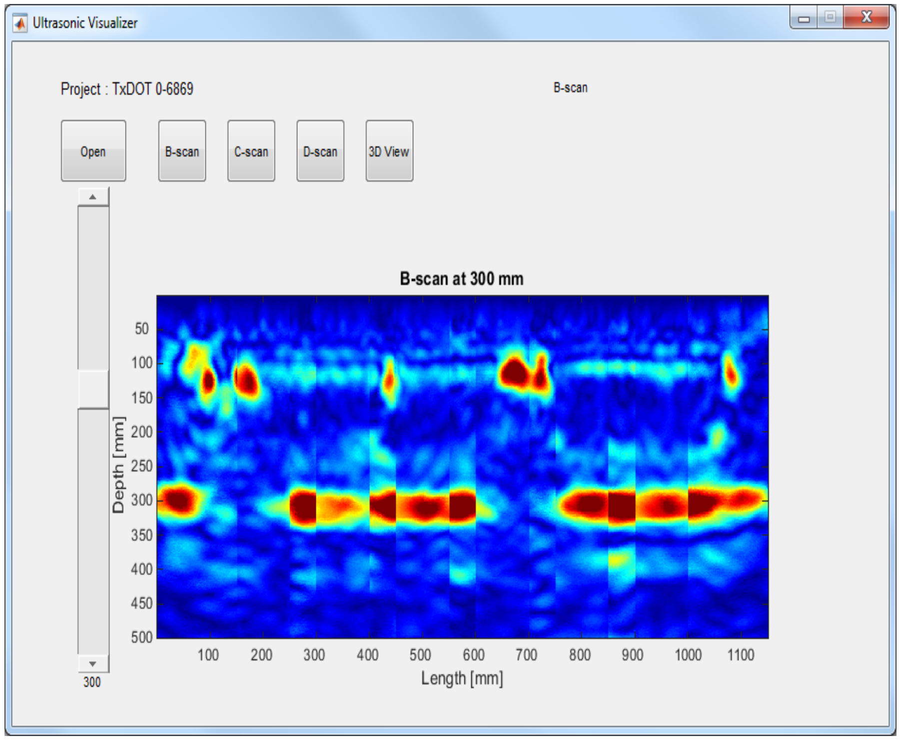
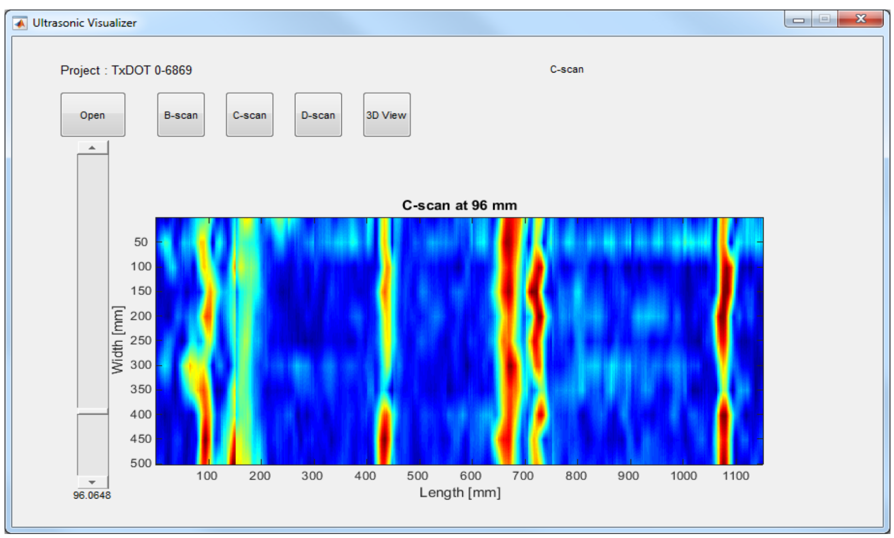


Figure 8: 3D View of Reflectivity.

The three-dimensional visualization tool allows the users to change reflectivity displayed using a slide bar. Additionally, users can also rotate the three-dimensional view. A complete section view provides the information of the entire section, so users can easily detect high reflective areas in a particular section. This visualization tool also provides sectional view functions like B-scan, C-scan, and D-scan. The B-scan of the entire section in Figure 9 is generated by combining B-

	scan images on the same plane. C- and D-scans of the entire section shown in Figure 10 and Figure 11, respectively, are extracted from three-dimensional reflectivity.  Figure 9: B-Scan of Complete Section.  Figure 10: C-Scan of Complete Section.

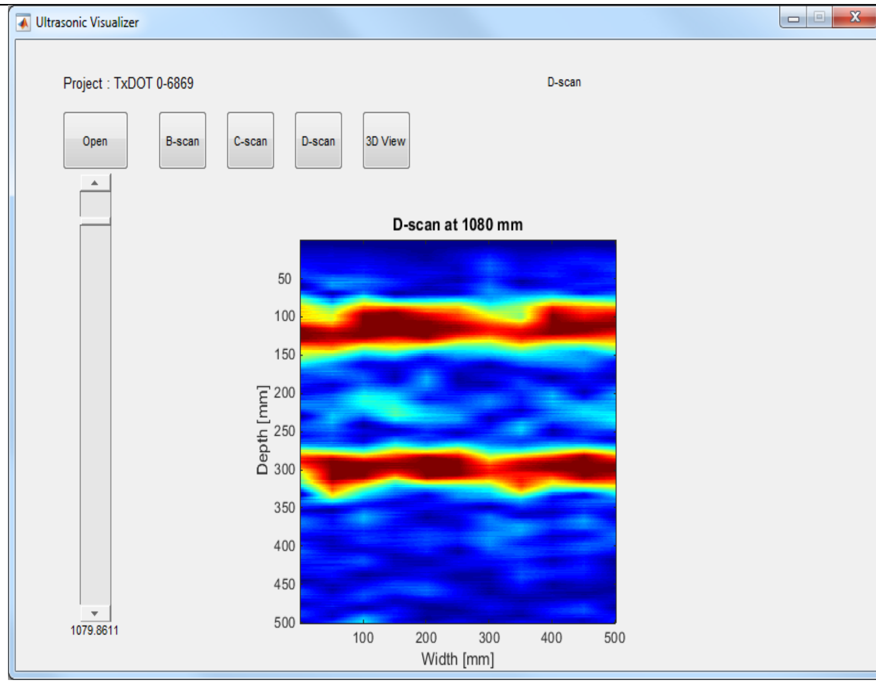


Figure 11: D-Scan of Complete Section.

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[3] Hall, T.E., Doctor, S.R. and Reig, L.D., 1986. "A Real-Time SAFT System Applied to the Ultrasonic Inspection of Nuclear Reactor Components." *Pacific Northwest Laboratory*, Richland, WA.

[4] Kotoky, N., and Shekhar, S., 2013. "Damage Identification Using SAFT Algorithm." *International Journal of Innovative Research in Science, Engineering and Technology,* 3(4), 194-199.

Impacts/Benefits of Implementation (actual, not anticipated)	A SAFT algorithm based on time-domain was developed for this study, and it shows reliable results compared to the embedded SAFT algorithm in the MIRA device. Ultrasonic visualizer for three-dimensional and other complete sectional views (B-, C-, and D-scans) was also developed by linearly interpolating B-scans resulted from the developed algorithm. It provides a lot of intuition about defects to users.

	The work performed for this project has also resulted in a Master's Thesis listed below ➢ Williams, N. D., "Nondestructive Testing of Rail Tunnel Linings," Master's Thesis, Texas A&M University, December 2014.
Web Links • Reports • Project website	http://www.utrgv.edu/railwaysafety/research/infrastructure/ultrasonic-tomography-for-infrastructure-inspection/index.htm

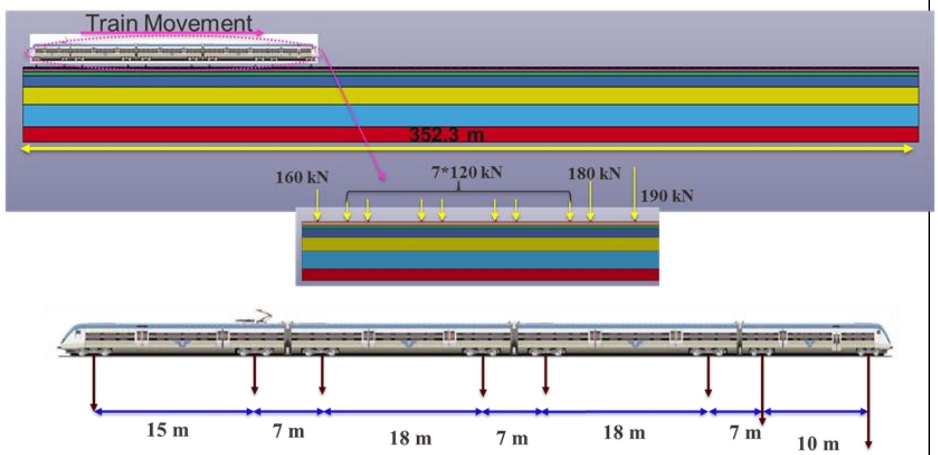
Exhibit F - UTCRS

UTC Project Information	
Project Title	High Speed Train Geotechnics
University	Texas A&M University (TAMU)
Principal Investigator	Jean-Louis Briaud, Ph.D., Civil Engineering (PI)
PI Contact Information	3135 TAMU College Station, TX 77843-3135 Office (979) 845-3795 briaud@tamu.edu
Funding Source(s) and Amounts Provided (by each agency or organization)	Federal Funds (USDOT UTC Program): $35,635 Cost Share Funds (TAMU): $0
Total Project Cost	$35,635
Agency ID or Contract Number	DTRT13-G-UTC59
Start and End Dates	January 2014 — December 2015
Brief Description of Research Project	California is planning a high speed train (HST) to link Los Angeles, San Francisco, and Sacramento. The project is estimated at 68.4 billion dollars for 1300 kilometers of rail or about 53M$ per kilometer. The first design-build contract for this project has been awarded. This is a proposal for Texas A&M University and the Center for Railroad Safety to help the project team by sponsoring a graduate student for one year to investigate issues relevant to the safety concerns. The research approach will consist of three parts. One part will be an attempt to simulate the HST passing the Rayleigh wave barrier by using LSDYNA. This is a major challenge. The second part is to help quantify the stiffness of the subgrade soil using pressure meter testing, BCD testing, and simple plate testing. The third part is to simulate the intended solution for minimizing the problem of the

	bump at the end of the bridge. Part 1 will indicate how the pressure meter modulus compares with other soil moduli measured in the test pads. This will lead to guidance on how to best use the pressure meter, the BCD, and the simple plate test in the future for HST embankments. Part 2, if successful, will show what happens when the HST passes the Rayleigh wave barrier; will there be major shaking at resonance of the HST with possible derailment or simply minor vibration. Part 3 will give information on the impact of the depth and extent of the soil cement wedge on the bump at the end of the bridge.
Describe Implementation of Research Outcomes (or why not implemented) Place Any Photos Here	**Task 1. Breaking Rayleigh wave barrier** Results from instrumented tests performed with a high-speed train on a soft soil at different sites and associated numerical analyses have indicated that a large dynamic amplification appears in the vertical dynamic movement of the HSR as the train speed approaches the Rayleigh wave speed. This Rayleigh wave speed is the equivalent Rayleigh wave speed of the rail/embankment/ ground systems. This threshold speed is called the critical speed and is known as Ground Mach 1 or GM1. In this research, the numerical simulations (Fig. 1), calibrated to the measurement from a soft soil site in Sweden, show that the maximum deflection of the rail occurs at the critical speed, at GM1, and is about three times larger than the static deflection (Fig. 2). This maximum deflection raises concerns about high maintenance cost, uncomfortable ride, if not derailment. In addition, we are performing a parametric study to determine the height and stiffness of embankments to raise the equivalent Rayleigh wave of the soil system above the top speed of the train. The guidelines (Fig. 3) will give the designers a way to choose the height and stiffness of the embankment given a natural soil stiffness. **Task 2. Long term moisture softening of compacted embankment** As documented for the China HST, softening of the soil may occur as time goes by. A loss of stiffness has been seen due to wetting of the fill; this wetting occurs by capillary action as the water is attracted upward into the dry embankment. This loss of stiffness induces uneven settlement of the embankments and associated roughness of the train ride. This process was simulated in the

laboratory by measuring the soil modulus and water tension in a manmade porcelain clay for different water contents. The results for this porcelain clay (Fig. 4) indicate that the soil modulus decreases significantly as the soil water content increases.

a)



b)

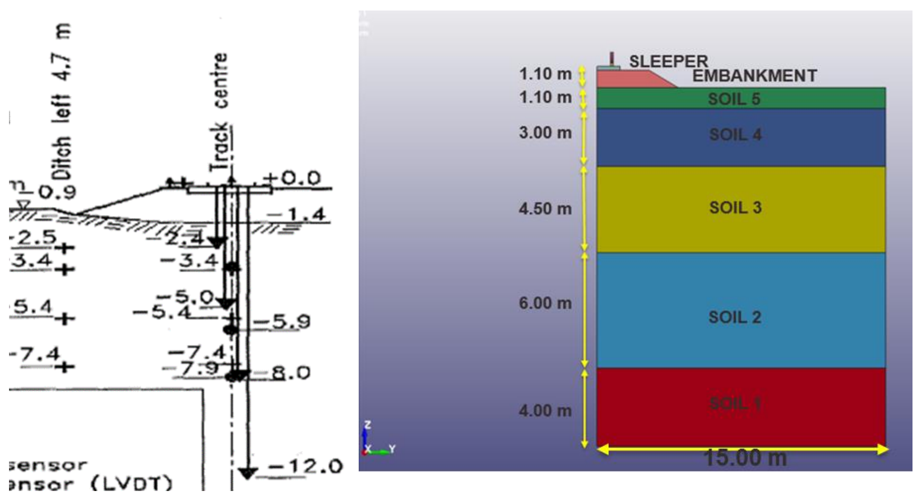


Fig. 1. a. The HST embankment model for numerical simulation and the bogie loads of the X-2000 trains, b. the embankment cross section for numerical simulation, c. cross section of the embankment in Sweden site (with curtesy of Kent Adolfsson et al., 1999)

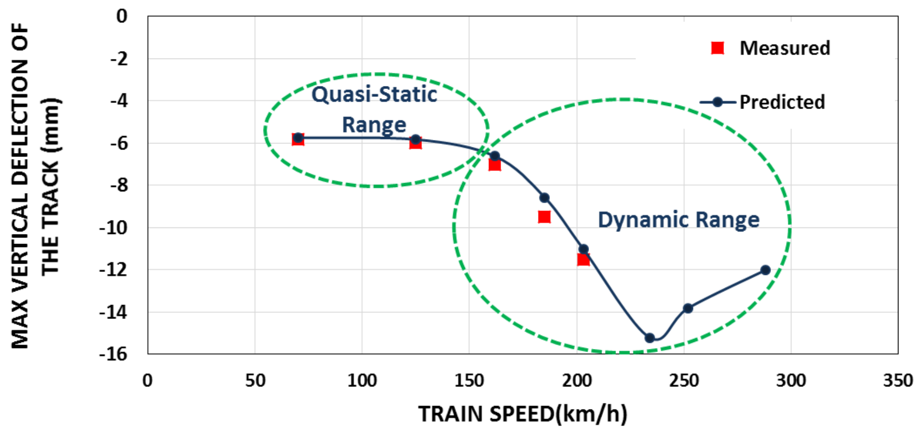


Fig. 2. Measured and predicted peak vertical track deflection vs. train speed

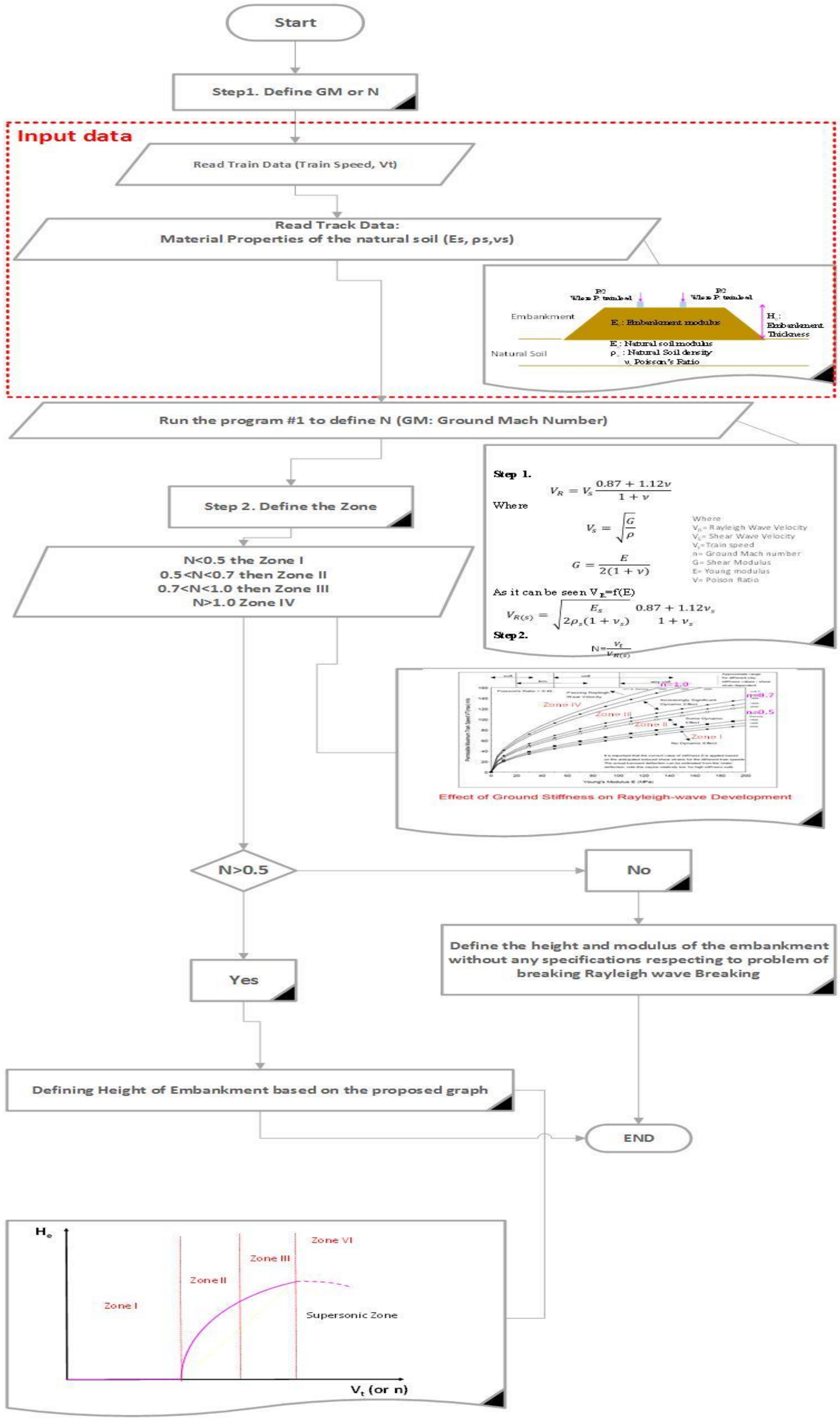


Fig. 3. Flowchart for selecting High Speed Railway Embankments

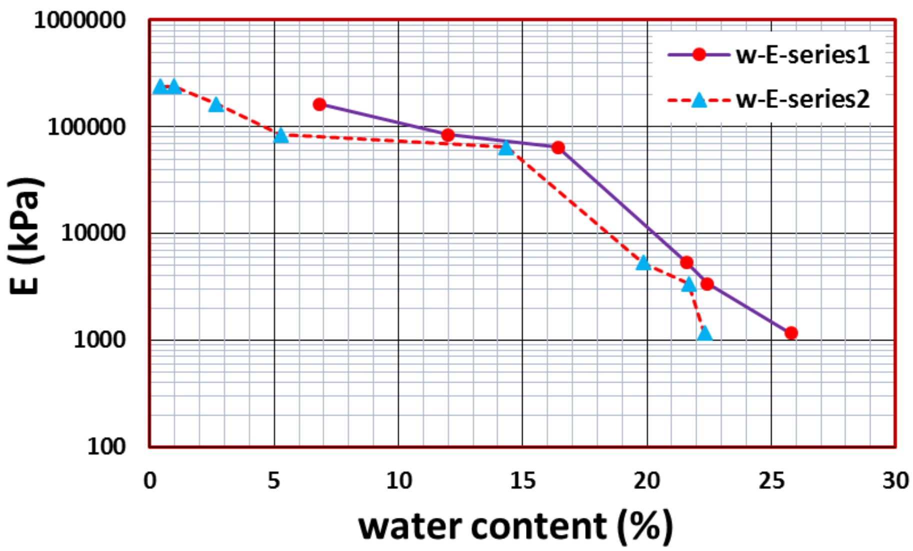
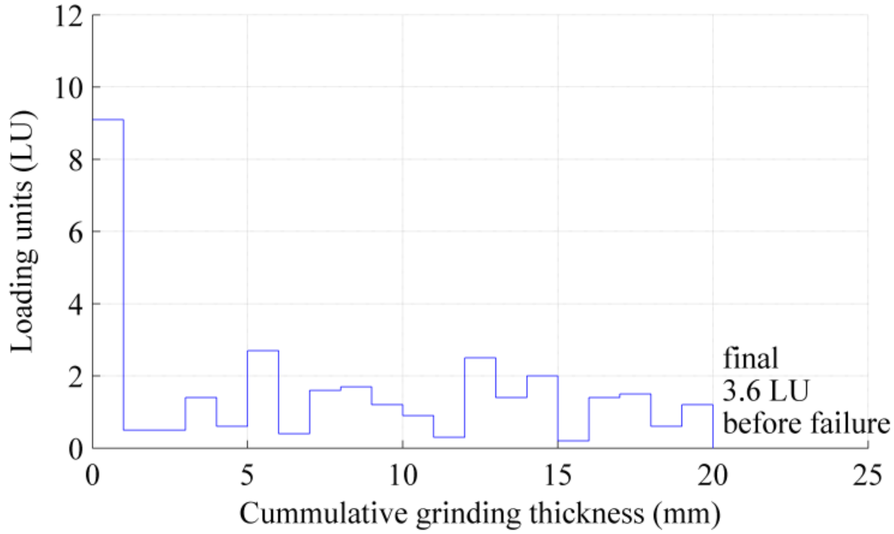
	 Fig. 4. Water content vs. Young modulus for porcelain clay
Impacts/Benefits of Implementation (actual, not anticipated)	California is planning to build a 62 billion dollar high speed rail line to link Los Angeles, San Francisco, and Sacramento. We are connected with the people who have won the first phase study (AMEC in San Francisco) and share with them the results of our study on an informal basis, which they appreciated. In addition to the California HST project, Texas is planning a 15 billion dollar high speed rail line to link Houston to Dallas. We are connected with some people working on this project at Terracon and ARUP. We had several teleconferences and meetings with them and sent them some of our outcomes. We are also cooperating with Zhejiang University in Hangzhou, China which is working on the Chinese high speed train embankments. They have made impressive measurements in a full scale laboratory experiment simulating the loading of a high speed train embankment.
Web Links • Reports • Project website	http://www.utrgv.edu/railwaysafety/research/infrastructure/high-speed-train-geotechnics/index.htm

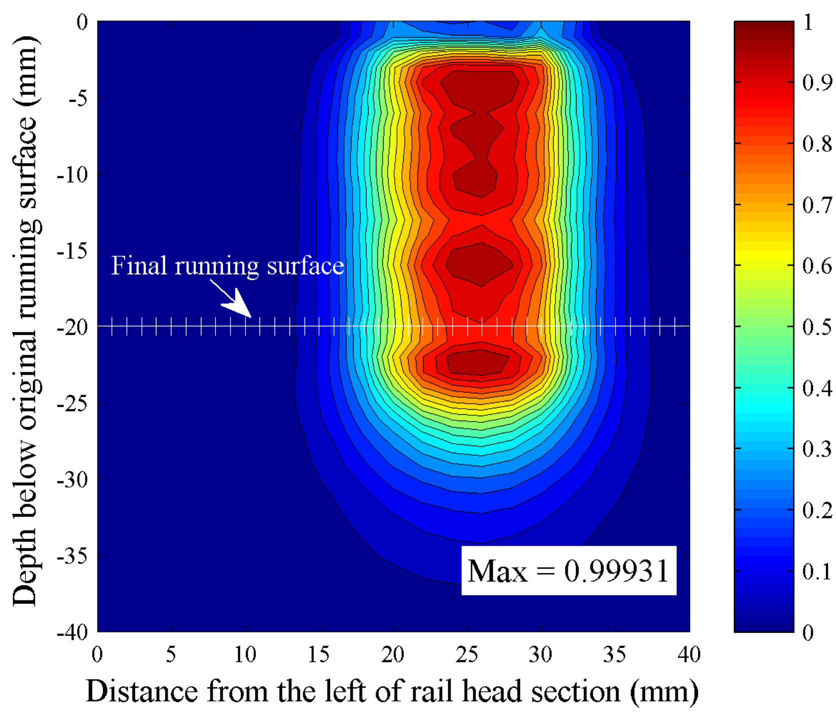
Exhibit F - UTCRS

UTC Project Information	
Project Title	Optimizing Performance of Railroad Rail through Artificial Wear
University	Texas A&M University (TAMU)
Principal Investigator	Gary Fry, Ph.D., P.E., Civil Engineering (PI)
PI Contact Information	Center for Railway Research Texas A&M Transportation Institute 3135 TAMU College Station, TX 77843-3135 Office (979) 458-5544 garyfry@tamu.edu a-pelton@tti.tamu.edu
Funding Source(s) and Amounts Provided (by each agency or organization)	Federal Funds (USDOT UTC Program): $100,681 Cost Share Funds (TAMU): $31,039
Total Project Cost	$131,720
Agency ID or Contract Number	DTRT13-G-UTC59
Start and End Dates	January 2014 – December 2016
Brief Description of Research Project	Localized plastic deformation from rolling contact and friction at the wheel-rail interface induces a severe multi-axial internal stress state in the rail-head, resulting in both surface and subsurface nucleation of cracks. Catastrophic failure of railroad rail is often caused by such rail-head fatigue defects. The objectives of the proposed project are to reduce the occurrence of fatigue-induced derailments of trains while simultaneously extending the service life of rail. There is worldwide field evidence that rail-head grinding, a form of applying artificial wear to a rail-head, is a cost-effective method to increase the useful life of rails. The current use of rail grinding in the rail industry is to maintain a smooth running surface upon which the wheels of trains roll. Other mechanical effects of rail-head grinding are not fully understood, and thus, the design of grinding schedules

	currently depends upon intuition, prior experience, and historical application. To achieve the goals of this project, wear and fatigue models were developed to simultaneously assess three volumetric regions of the rail-head: surface, near-surface, and subsurface. The proposed wear and fatigue models of this project were integrated into a generalized multi-axial analysis accounting for both natural and artificial wear at the running surface and fatigue crack nucleation within near-surface and subsurface volumetric regions. The multi-axial framework was incorporated into a genetic algorithm (GA) optimization module to help identify meaningful pareto frontiers associated with alternative scenarios of applying artificial wear through rail-head grinding.
Describe Implementation of Research Outcomes (or why not implemented) Place Any Photos Here	A set of representative dynamic wheel loads and corresponding numbers of wheel passages is used in this study. Based on field measurements of a train with nominal 173 kN wheel loads passing at 64 km/h, five representative dynamic wheel loads of 125, 144, 162, 180, and 197 kN, and their corresponding number of wheel passages of 730, 6150, 13820, 8450, and 1390, respectively, were selected. This set defines the *loading unit (LU)* used in this study as a means of comparing the fatigue life outcomes from alternative grinding strategies. Figure 1 presents a schematic and corresponding contour plot of fatigue index accumulation, just before nucleation of the first fatigue crack, for one of the best grinding schedules discovered through the optimization procedure (20 grinding steps with 35.3 LU). As a result, fatigue life increases from 10.16 LU (no-grinding) to 35.4 LU when the grinding schedules developed from an optimization with a genetic algorithm (GA) are applied. This indicates a 248% increase of fatigue life. Nevertheless, the best grinding schedule found in this study is still unlikely to be the global optimum, as the fatigue accumulation contour seems to deviate from the ideal case, where a continuous contour is expected.



(a)



(b)

Figure 1. For the optimal grinding schedule yielding 35.3 LU and 0.99931 maximum fatigue index with 20 grinding steps (from group 1): (a) a schematic of grinding schedule, and (b) a contour of maximum fatigue index accumulation before failure.

Impacts/Benefits of Implementation (actual, not anticipated)	The proposed optimization framework provides a set of rail grinding schedules that are predicted to improve the safe fatigue life of rail significantly. Specifically, the optimizations with exploratory and local-search genetic algorithm (GA) are able to increase fatigue crack nucleation life of rails by about 240% when compared to no grinding. So far, this project has resulted in three journal manuscripts under revision for submission and a conference paper, which has been accepted for the 2017 *International Heavy Haul Association Conference* to be held in Cape Town, South Africa. • Fry, G., and Tangtragulwong, P., “Analysis of Rail Grinding as a Means to Optimize Rail Head Fatigue Life under Heavy Axle Loads,” *Proceedings of the 11th International Heavy Haul Association Conference*, Cape Town, South Africa, September 2-6, 2017.
Web Links • Report • Project Website	http://www.utrgv.edu/railwaysafety/research/infrastructure/railroad-rail-performance/index.htm

UNIVERSITY TRANSPORTATION CENTER FOR RAILWAY SAFETY

Exhibit F - UTCRS

UTC Project Information	
Project Title	Vehicle-Bourne Autonomous Railroad Bridge Impairment Detection Systems
University	Texas A&M University (TAMU)
Principal Investigator	Gary Fry, Ph.D., P.E., Civil Engineering (PI)
PI Contact Information	Center for Railway Research Texas A&M Transportation Institute 3135 TAMU College Station, TX 77843-3135 Office (979) 458-5544 garyfry@tamu.edu a-pelton@tti.tamu.edu
Funding Source(s) and Amounts Provided (by each agency or organization)	Federal Funds (USDOT UTC Program): $102,176 Cost Share Funds (TAMU): $33,040
Total Project Cost	$135,216
Agency ID or Contract Number	DTRT13-G-UTC59
Start and End Dates	January 2014 – December 2016
Brief Description of Research Project	Timber bridges constitute approximately 30% of current railroad bridge inventories in North America. Inspections of these structures usually comprise visual assessments of the condition of individual, observable components of the bridge. Special inspections may call for the field personnel to observe a bridge under load: that is, while a train is crossing. When creating a prioritized list of critical bridges to be replaced or repaired, there is advantage to having complementary *measurements* of bridge structural behavior under load. The objective of the proposed research program is to develop technology that will facilitate detecting structural impairments in timber railroad bridges using data gathered from rail vehicles that cross the bridges. Such a capability would represent a significant

The University of Texas Rio Grande Valley   Texas A&M Transportation Institute   Nebraska Transportation Center

	improvement over the current approaches used to maintain timber railroad bridges. The underlying logic behind using rail vehicle measurements to determine bridge fitness can be summarized as follows: • Serious structural impairments in timber railroad bridges cause increased bridge motions under loading. • Bridge motions comprise one aspect of the overall motions rail vehicles experience when crossing a bridge. • The motions of a rail vehicle can be measured by sensors attached to the vehicle. • Once appropriate signal processing algorithms are developed, this being a key objective of the proposed research program, it might be possible to infer bridge motions from the measured behavior of a rail vehicle crossing the bridge. • Measured motions of a bridge can be compared against threshold values of motions that are considered safe. In order to meet these objectives, this research project incorporated (1) modeling of railcar-bridge system, (2) instrumentation of timber railroad bridges and railcars, (3) large scale experimentation of railcar-bridge systems, and (4) development of an Autonomous Data Reduction and Interpretation System using artificial neural networks to correlate vehicle dynamic response to bridge response and subsequently determine possible structural impairment.
Describe Implementation of Research Outcomes (or why not implemented) Place Any Photos Here	An open deck timber trestle railway bridge in service, was chosen for field testing. Two 15-foot spans were instrumented and monitored to observe the bridge's behavior under live loading. String potentiometers were used to measure the total and net mid-span stringer deflections of the test spans. The locations of the string potentiometers on the two spans are shown in Figure 1. The devices located in the center of the stringers record the total mid-span stringer deflection. The net stringer deflection is found by subtracting the average of the two end string potentiometer values of a stringer from the total deflection. The net deflection is an additional measurement that takes the settlement of the supports into account.

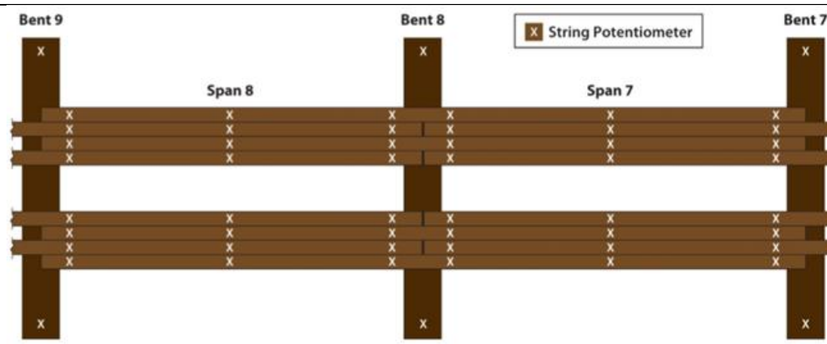


Figure 1: String Potentiometer Locations

Figure shows two rows of string potentiometers attached to the underside of the bridge during a test.

Figure 2: String Potentiometer Setup under Span 7

In addition to the instrumentation attached to the bridge, the ends of four axles of a train were instrumented with accelerometers to capture the vertical accelerations of the associated wheels. The locations of the wheel paths with respect to the rest of the work train are shown in Figure 3. Wheel path 1 was the first axle to enter a test span, and wheel path 4 was the last to exit.

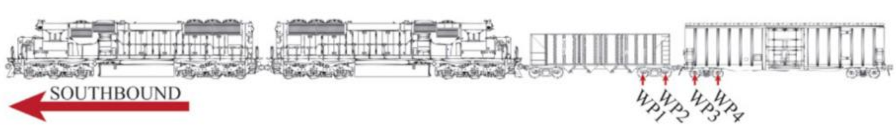
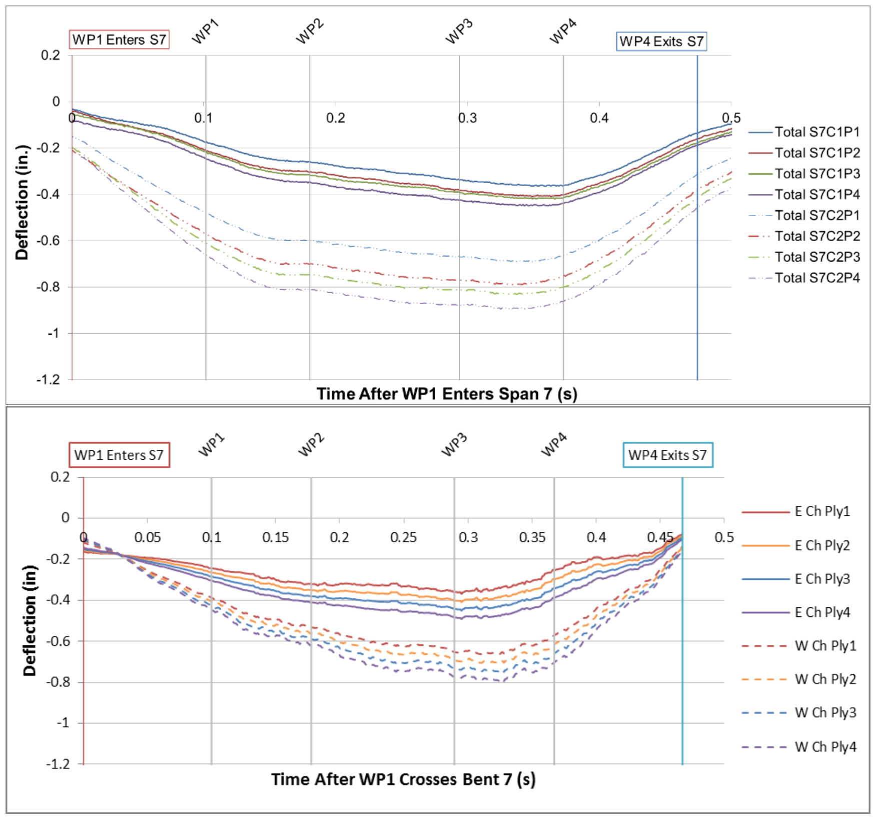


Figure 3: Work Train

	Data was collected at speeds ranging from 10 mph to 50 mph with increasing increments of 10 mph. The objective of the project was to train a neural network-based data processing system to estimate the mid-span deflection of bridge spans given only the axle-end accelerations from a train crossing the bridge. Figure 4 shows a comparison of the experimentally measured span deflections to those predicted blindly from the trained neural network processing system.  Figure 4: Span 7 Test 9 Stringer Time History Comparison: Experimental (Top), Predicted (Bottom)
Impacts/Benefits of Implementation (actual, not anticipated)	Using as input data, the vertical accelerations of the axle ends of a moving railcar, the proposed system for timber railroad bridge deflection detection is confirmed experimentally to predict the maximum mid-span deflection to within a 10% error.

	So far, this project has resulted in two journal manuscripts under revision for submission. In addition, a Ph.D. dissertation is under final revision and will be defended in May 2017. • Allard, A. J., "Vehicle Bourne Autonomous Railroad Bridge Impairment Detection Systems," Doctoral Dissertation, Zachry Department of Civil Engineering, Texas A&M University, May 2017.
Web Links • Reports • Project website	http://www.utrgv.edu/railwaysafety/research/infrastructure/railroad-bridge-impairment-detection-systems/index.htm

UNIVERSITY TRANSPORTATION CENTER FOR RAILWAY SAFETY

Exhibit F - UTCRS

UTC Project Information	
Project Title	Development of Corridor-based Traffic Signal Preemption Strategies at Signalized Intersections near Highway Railway Grade Crossings
University	University of Nebraska-Lincoln (UNL)
Principal Investigator	Laurence Rilett, Ph.D., P.E., Civil Engineering (PI)
PI Contact Information	262D Whittier Research Center P.O. Box 830851 Lincoln, NE 68583-0851 Office (402) 472-1993 lrilett2@unl.edu
Funding Source(s) and Amounts Provided (by each agency or organization)	Federal Funds (USDOT UTC Program): $65,000 Cost Share Funds (UNL): $32,500
Total Project Cost	$97,500
Agency ID or Contract Number	DTRT13-G-UTC59
Start and End Dates	November 2013 – December 2016
Brief Description of Research Project	Highway-rail grade crossings (HRGCs) and the intersections in their proximity are areas where potential problems in terms of safety and efficiency often arise if only simple or outdated treatments, such as normal signal timing or passive railroad warning signs, are utilized. When it comes to a corridor or a network with multiple HRGCs and heavy train traffic, the problems will be more complicated due to randomness of train arrivals and frequent abruptions of normal signal timing operation of the whole corridor. This project develops a methodology of signal timing optimization that is specially designed for such a corridor/network. Due to high time and money costs associated with testing the methodology in the field, and safety issues related to field experiments, the proposed optimization program was instead developed, used, and evaluated in a micro-simulation environment using the VISSIM simulation software

	package. To replicate field conditions, real train data has been collected from the field test bed using advanced train detection technologies and input into the simulation models. Moreover, the stochastic nature of traffic has been considered in the simulation experiment by conducting multiple simulation runs with random seeds. Based on the research results, it can be concluded that the methodology can significantly improve both the safety and efficiency of the study corridor with HRGCs in both offline and online scenarios, however, at the cost of higher network delay. The effects of the prediction errors on the safety and operation of the study network are also analyzed.
Describe Implementation of Research Outcomes (or why not implemented) Place Any Photos Here	Before implementation is possible, hardware-in-the-loop analysis is required, which can be done by coding the TPS_DT in a controller readable programming language and incorporating it in a traffic signal controller as an extended module. Although simulation studies have shown that the proposed optimization methodology with TPS_DT can improve safety and efficiency of the corridor, field studies are necessary to test the methodology before it is considered for field implementation.
Impacts/Benefits of Implementation (actual, not anticipated)	The proposed optimization methodology has not been implemented yet. However, work on this project has resulted in one paper presentation at the Transportation Research Board 96th Annual Meeting, with the paper being accepted for publication in the Transportation Research Records. The information on the paper that was presented at the TRB Annual Meeting is provided hereafter: • Chen, Y. and Rilett, L., "A Train Data Collection and Arrival Time Prediction System for Highway-Rail Grade Crossings," Transportation Research Records, *Journal of the Transportation Research Board*, January 2017. Moreover, this project has also resulted in a doctoral dissertation to be completed entitled: • Chen, Y., "Network Traffic Optimization in Heavily Utilized Railway Corridors," Doctoral Dissertation, Department of Civil Engineering, University of Nebraska-Lincoln, May 2015.

	A detailed report summarizing all of the work performed under this project is also made available and can be downloaded from the UTCRS website at the link provided below.
Web Links • Reports • Project website	http://www.utrgv.edu/railwaysafety/_files/documents/reports/Traffic-Signal-Preemption-Strategies-Near-HRGC_Project_Final_Report_021017.pdf http://www.utrgv.edu/railwaysafety/research/operations/traffic-signal-preemption-strategies-near-hrgc/index.htm

Exhibit F - UTCRS

UTC Project Information	
Project Title	Drivers' Perceptions of Highway-Rail Grade Crossing Safety and Their Behavior
University	University of Nebraska-Lincoln (UNL)
Principal Investigator	Aemal Khattak, Ph.D., Civil Engineering (PI)
PI Contact Information	262D Whittier Research Center P.O. Box 830851 Lincoln, NE 68583-0851 Office (402) 472-8126 akhattak2@unl.edu
Funding Source(s) and Amounts Provided (by each agency or organization)	Federal Funds (USDOT UTC Program): $74,691 Cost Share Funds (UNL): $37,346
Total Project Cost	$112,037
Agency ID or Contract Number	DTRT13-G-UTC59
Start and End Dates	November 2013 – December 2016
Brief Description of Research Project	The focus of this project was to investigate motor vehicle drivers' perceptions of safety and their behaviors at highway-rail grade crossings (HRGCs) to obtain insights for improving safety at these locations. During 2012, the Federal Railroad Administration (FRA) reported 1,970 crashes at HRGCs in the U.S. that involved 272 fatalities and 951 injuries. Therefore, there is a need for improving public safety at HRGCs. Motor vehicle drivers are expected to yield the right-of-way to oncoming trains since trains cannot stop on short notice. Therefore, almost all train-motor vehicle crashes at HRGCs are due to encroachments by motor vehicle drivers. Such crashes are due to a variety of reasons on part of motor vehicle drivers including misunderstandings of train warning signs, aggressive/distracted driving, or willful neglect of crossing signs, signals, and gates. However, drivers' perceptions of safety at HRGCs and behaviors are not well-

	understood and there is a need for obtaining insights into their behaviors at HRGCs. In this project, the researchers investigated motor vehicle drivers' characteristics, their perceptions of safety at crossings, understanding and comprehension of traffic signs/signals at crossings, and their self-reported unsafe maneuvers at HRGCs in different Nebraska cities. A three-stage mail contact survey design was used that included an initial mail notification to households in Nebraska, a survey questionnaire mailing, and a postcard reminder about mailing back the completed questionnaire. The researchers analyzed collected survey data using statistical summaries and models and revealed drivers' characteristics involved in unsafe maneuvers at HRGCs. The study found that drivers generally had good knowledge of safely driving negotiating HRGCs. However, some drivers lacked knowledge of certain safety aspects, such as violations under ascending gates, proper actions when emergencies occur, and the correct interpretation of some traffic signs at HRGCs. Drivers' levels of knowledge was associated with factors such as outreach of safety education programs, frequency of using HRGCs, years of driving experience, and the drivers' education levels. The research also found that drivers with negative/indifferent attitude towards safety at HRGCs, less knowledge of driving at HRGCs, higher education levels, higher income, frequent users of HRGCs and younger and female drivers were more likely to involve themselves in inattentive driving at HRGCs. Therefore, future educational programs advocating attentive driving could be targeted to these groups of drivers.
Describe Implementation of Research Outcomes (or why not implemented) Place Any Photos Here	Based on the results of the surveys, several recommendations were made. Educational programs for adult drivers need to be developed before they can be implemented. These programs should focus on improving safety at HRGCs, and they should be targeted to drivers that need them the most, such as drivers with less driving experience, with higher intent of violation, with less experience using HRGCs, and with relatively lower education levels.
Impacts/Benefits of Implementation (actual, not anticipated)	The recommended educational programs have not been developed or implemented yet. However, the work performed under this project has led to the following doctoral dissertation: • Zhao, S., "An investigation of Motor Vehicle Driver Inattention and its Effects at Highway-Rail Grade Crossings," Doctoral

	Dissertation, Department of Civil Engineering, University of Nebraska-Lincoln, August 2016. Moreover, a detailed report that summarizes all the work performed under this project is made available and can be downloaded from the UTCRS website using the link provided below.
Web Links • Reports • Project website	http://www.utrgv.edu/railwaysafety/_files/documents/reports/Drivers- Perceptions-HRGC-Safety_Project_Final_Report_021017.pdf http://www.utrgv.edu/railwaysafety/research/operations/drivers-perceptions-of-hrgc/index.htm

UNIVERSITY TRANSPORTATION CENTER FOR RAILWAY SAFETY

Exhibit F - UTCRS

UTC Project Information	
Project Title	Safety Modeling of Highway Railway Grade Crossings using Intelligent Transportation System Data
University	University of Nebraska-Lincoln (UNL)
Principal Investigator	Laurence Rilett, Ph.D., P.E., Civil Engineering (PI)
PI Contact Information	262D Whittier Research Center P.O. Box 830851 Lincoln, NE 68583-0851 Office (402) 472-1993 lrillet2@unl.edu
Funding Source(s) and Amounts Provided (by each agency or organization)	Federal Funds (USDOT UTC Program): $85,000 Cost Share Funds (UNL): $42,5000
Total Project Cost	$127,500
Agency ID or Contract Number	DTRT13-G-UTC59
Start and End Dates	November 2013 – December 2016
Brief Description of Research Project	Drivers face a number of decisions as they approach at a-grade highway railway grade crossings (HRGCs) including what approach speed is appropriate and whether to stop at the crossing. In turn, a large number of factors affect these decisions including presence of other vehicles and their location, presence of a train(s) and their location/speed, presence of traffic signals and their status, traffic signal timing, etc. If HRGC's are to be made safer, it is critical to understand the relationship between these factors and the driver's decision on whether to proceed across the HRGC or to stop. Most train safety studies collect this type of information manually which can be time consuming and expensive. This project will first develop an automatic data collection system that will obtain, process and store all relevant information including vehicle approach speed and location, train approach speed and location, traffic signal status, warning system information, weather information, and driver violations at the HRGC. The system will be tested in an urban

	environment and will form part of a long-term HRGC test bed in Lincoln, Nebraska. A portable data-collection system prototype will be used to collect data at various rural intersections. The data will then be used to develop a predictive model of driver violation as a function of the relevant factors. The goal of the research is to understand the complex behavior of drivers at HRGCs and to recommend effective countermeasures that will increase the safety of our nation's HRGCs.
Describe Implementation of Research Outcomes (or why not implemented) Place Any Photos Here	Though this research study is location specific, the provided methodology can easily be expanded to a wide range of traffic locations and situations. This is important in order to do the violation-need study such as the determination of optimal clearance interval or the improvement of HRGC geometry. The results of the study have not been used for further implementation because the methodology needs to be adapted for specific locations.
Impacts/Benefits of Implementation (actual, not anticipated)	The proposed research method has not been implemented yet. However, work on this project has resulted in one paper presentation at the Transportation Research Board 96th Annual Meeting, and a doctoral dissertation in progress, which is expected to be defended in August 2017. The information on the paper that was presented at the TRB Annual Meeting is provided hereafter: • Zhao, Li and Rilett, L., "Dynamic Model of Driver Approaching Behaviors at Highway-Rail Grade Crossings," Transportation Research Board 96th Annual Meeting, Washington, D.C., January 10, 2017. A detailed report summarizing all of the work performed under this project is also made available and can be downloaded from the UTCRS website at the link provided below.
Web Links • Reports • Project website	http://www.utrgv.edu/railwaysafety/_files/documents/reports/Modeling-of-HRGC-Using-ITS_Project_Final_Report_021017.pdf http://www.utrgv.edu/railwaysafety/research/operations/modeling-of-hrgc-using-its/index.htm

Exhibit F - UTCRS

UTC Project Information	
Project Title	Improving Safety at Rural Highway-Rail Grade Crossings by Utilizing Light Detection and Ranging (LiDAR) Technology
University	University of Nebraska-Lincoln (UNL)
Principal Investigator	Aemal Khattak, Ph.D., Civil Engineering (PI)
PI Contact Information	262D Whittier Research Center P.O. Box 830851 Lincoln, NE 68583-0851 Office (402) 472-8126 akhattak2@unl.edu
Funding Source(s) and Amounts Provided (by each agency or organization)	Federal Funds (USDOT UTC Program): $75,284 Cost Share Funds (UNL): $37,642
Total Project Cost	$112,926
Agency ID or Contract Number	DTRT13-G-UTC59
Start and End Dates	November 2013 – December 2015
Brief Description of Research Project	The objective of this research is to test and validate the feasibility of a computer- based tool that safety analysts can use to quickly assess rural highway-rail grade crossings for large truck traffic in case of an emergency or route closure situation. The suitability of many rural highway-rail grade crossings for use by large trucks with trailers is a concern because of the possibility of trucks getting stuck on the rail tracks when excessive grade difference exists between the rails and approach surface of the crossing highway. While trucks usually ply on designated routes, emergencies and highway closures may necessitate re- routing of trucks to rural highways with grade crossings that may not have the safe geometry needed for large trucks with trailers. Therefore, it would be useful to have a computer-based tool and relevant data by which analysts could quickly assess crossing suitability without the need for field visits.

	The availability of Light Detection and Ranging (LiDAR) data for most of NE makes the possibility of developing a computer-based tool that allows analysts to assess the suitability of highway-rail crossings for large vehicles a possibility. LiDAR data are usually collected using an appropriately-equipped airplane that flies and collects the locations of millions of points on the Earth's surface. Using geographic information systems (GIS) software, the point cloud can be converted into a terrain model replicating the surface profile. LiDAR data are available for most of Nebraska and in many cases free of cost. This research will develop a computer-based tool utilizing LiDAR data that will allow users to assess the suitability of rural highway-rail grade crossings for use by large trucks. Field validation of the results from the tool will be carried out as part of this research.
Describe Implementation of Research Outcomes (or why not implemented) Place Any Photos Here	**Data Analysis** Geo-referenced points of 160-ft ranges for crossing roads and a 2 meter resolution LiDAR elevation raster were integrated in the study area orthophoto using ArcGIS. An autonomous relative accuracy test of the data was conducted to see how accurately the data represented elevation of the study area. To conduct the assessment, LiDAR elevation data pertaining to the geo-referenced points in the three rail grade crossings were obtained from the GIS database and verified against field observations obtained using a geo-positioning system and a theodolite. The two corresponding groups of data were compared for relative accuracy. **Figure 4.1** shows the aerial photos of the rail grade crossing geometry and vertical elevation profiles between LiDAR data and field-measured data. The geo-referenced points were obtained along the arrows shown in the figure. In a range of 160-ft, point spacing for each was 2-ft resulting in 81 elevation points at each site. For the three sites, there were 243 elevation sample points for both LiDAR and field measured elevation data. A list of the total LiDAR and field elevation geo-referenced points appears in Appendix B. RMSE for each pair of all 243 points were only 0.30-ft, so the authors decided to proceed with further analysis.

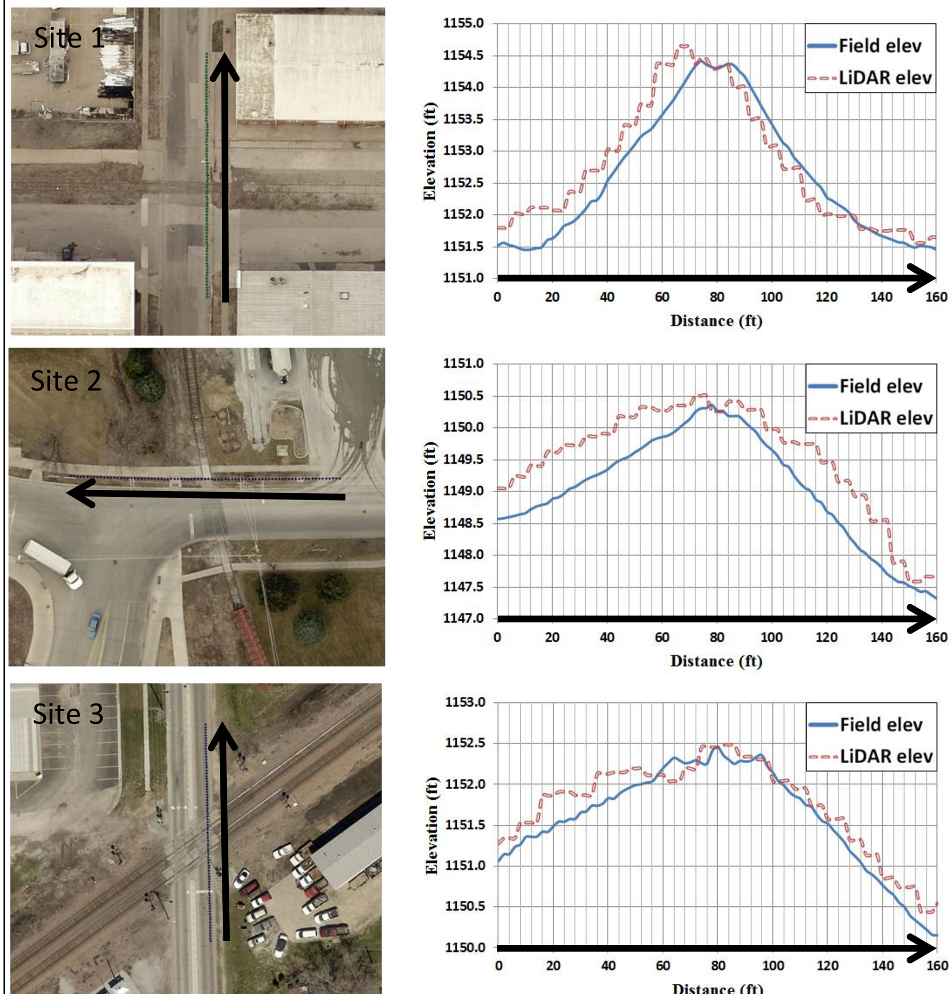


Figure 4.1 Comparison of vertical elevation profiles for LiDAR and field-measured data

4.1 Assessment of Crossing Suitability

Several design vehicles and their dimensions were utilized to assess crossing suitability. Reviewed literature provided information on the chosen design vehicles. Specifically, the selected vehicles were rear-loaded garbage trucks, aerial fire trucks, pumper fire trucks, school buses, lowboy trailers, and car carrier trailers; **Table 4.1** presents dimensions of these vehicles.

Table 4.1 Selected design vehicle dimensions
[Source: French et al. (2002)]

Design Vehicle	Wheel Base [ft]	Front Overhang [ft]	Rear Overhang [ft]	Ground Clearance (in)		
				Wheel Base	Front Overhang	Rear Overhang
Rear-Load Garbage Truck	20	-	10.5	12	-	14
Aerial Fire Truck	20	7	12	9	11	10
Pumper Fire Truck	22	8	10	7	8	10
School Bus	23	-	13	7	-	11
Lowboy Trailers < 53 feet	38	-	-	5	-	-
Car Carrier Trailer	40	-	14	4	-	6

Note: "-" indicates no hang-up problems due to this part of the vehicle

Crossing suitability analysis was conducted using an imaginary box placed under the target vehicle such that the wheelbase and vehicle ground clearance were the two sides of a rectangular box, as shown in **Figure 4.2**. For design vehicles having critical values in their front and rear overhang parts, the box was also placed under the vehicle in that overhang length and vehicle ground clearance were the two sides of the box. The rule for safe passage across a humped highway-rail grade crossing was that the top side of the rectangular box should not touch any part of the rail crossing surface. If the straight line representing the top side of the rectangular box intersects with the crossing surface, the vehicle theoretically gets lodged on the rail crossing. Line-of-sight analysis capabilities of 3D Analyst in ArcGIS was used to identify if the straight line was obstructed. This analysis shows a graphic line between two points, and obstructions, if any, are noted. If obstructed, the 3D Analyst provides the location of the point of obstruction. Ground clearance of the designated design vehicles was represented in the line-of-sight analysis by setting the heights of observer and target equal to the ground clearance of the design vehicle.

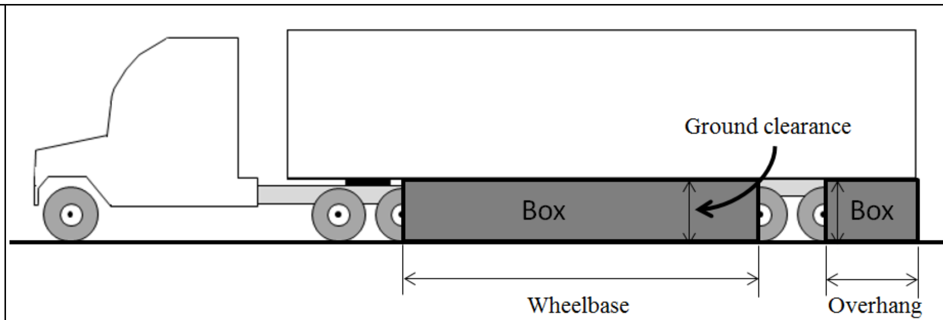


Figure 4.2 Semi-trailer with imaginary box under the trailer

Small incremental placements of the rectangular box (representing a certain wheelbase and ground clearance or an overhang length and ground clearance) in GIS across a rail crossing allowed identification of a selected vehicle's crossing suitability at that crossing.

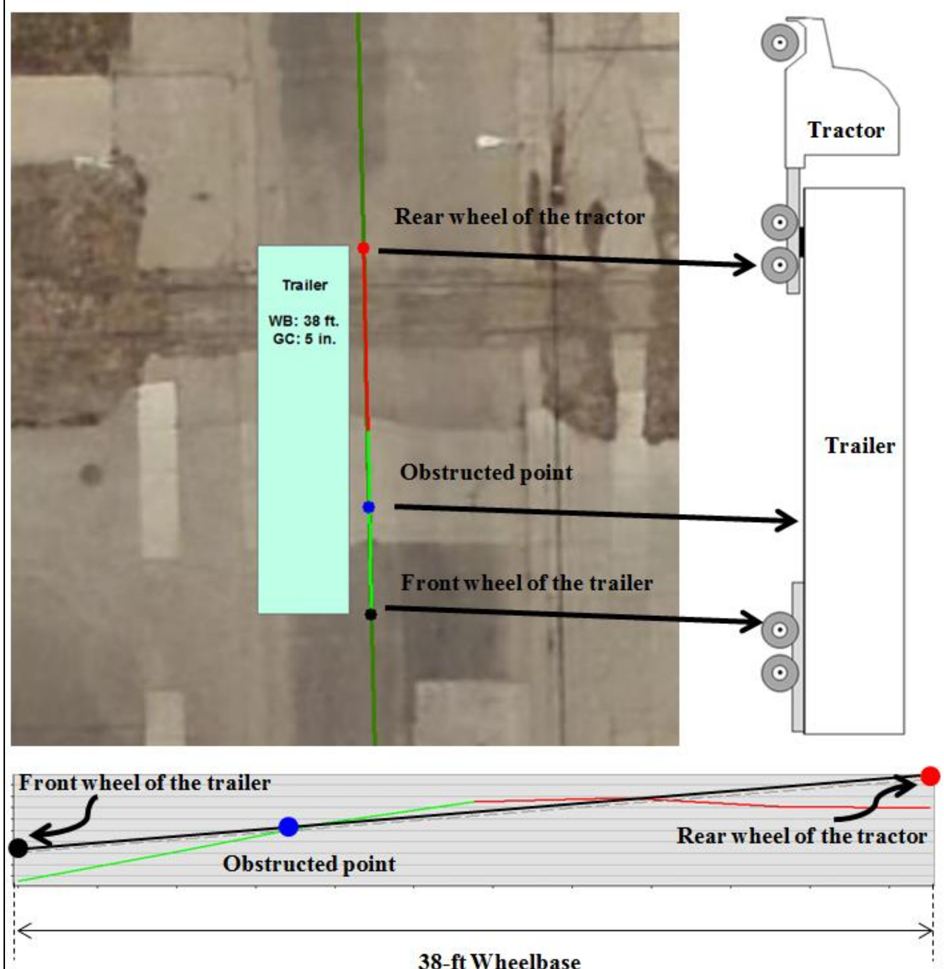


Figure 4.3 Identification of crossing suitability of a trailer with 38-ft wheelbase and 5 inches ground clearance at Site 1

Figure 4.3 presents the crossing suitability of a trailer having a 38-ft wheelbase and a 5 inch ground clearance using the line-of-sight analysis at Site 1. The imaginary trailer was moved in 2-ft increments along the roadway centerline until the tail part of the trailer completely passed the crossing to identify any obstructions. The observer point in the analysis was the front wheel of the trailer, and the target point was the rear wheel of the tractor. The result showed that a trailer would lodge or scratch the pavement at this site due to the identification of an obstructed point in the wheelbase. In the vertical profile chart, as shown in **Figure 4.3**, the straight line between the two wheels is obstructed by the surface of the highway-rail grade crossing, showing a potentially unsafe situation. In a similar manner, line-of-sight analysis was conducted for vehicles of different dimensions. It was noted that some design vehicles had front and rear overhang parts, which were taken into account during the analysis. For example, a rear-loaded garbage truck has a long rear overhang part for waste collection, which may drag on the pavement or cause the vehicle to become lodged on a crossing.

Table 4.2 Result of crossing suitability of selected design vehicles

Design Vehicles	Site 1			Site 2			Site 3		
	Wheel Base	Front overhang	Rear overhang	Wheel Base	Front overhang	Rear overhang	Wheel Base	Front overhang	Rear overhang
Rear-Load Garbage Truck	No hang-up	NA	No hang-up	No hang-up	NA	No hang-up	No hang-up	NA	No hang-up
Aerial Fire Truck	No hang-up	No hang-up	No hang-up	No hang-up	No hang-up	No hang-up	No hang-up	No hang-up	No hang-up
Pumper Fire Truck	No hang-up	No hang-up	No hang-up	No hang-up	No hang-up	No hang-up	No hang-up	No hang-up	No hang-up
School Bus	No hang-up	NA	No hang-up	No hang-up	NA	No hang-up	No hang-up	NA	No hang-up
Lowboy Trailers <53 feet	Hang-up	NA	NA	No hang-up	NA	NA	No hang-up	NA	NA
Car Carrier Trailer	Hang-up	NA	No hang-up	Hang-up	NA	No hang-up	No hang-up	NA	No hang-up

NA: Not Applicable

Table 4.2 presents the results of crossing suitability analysis for the three highway-rail grade crossing sites with different design vehicle dimensions. Vehicle hang-up problems were identified at Site 1 for a lowboy trailer and a car carrier trailer that lodged at both Site 1 and Site

2. The front and rear parts of the considered design vehicles did not present issues at any of the sites based on this analysis.

4.2 Field Validation of Crossing Suitability Results

The GIS-derived crossing suitability assessment results were validated in the field using a level line laser instrument, a geo-positioning surveying tool, and level rods. When a line laser was set at a certain distance from the railway centerline, the wheelbase distance of design vehicles were used to set a level rod from the line laser instrument. The height of the line laser instrument was set to be the ground clearance of the vehicle. Then it was observed if the laser beam reached the level rod at the same height of ground clearance without any obstruction from the crossing surface. If the straight line between the level line laser and level rod was uninterrupted, it implied a safe passage situation for the design vehicle (i.e., no hang- up issue). If the straight line between the level line laser and level rod was interrupted then the obstruction location was noted for later comparison with the crossing suitability results from the GIS. **Figures 4.4** and **4.5** illustrate field validation with the line laser instrument. A retro reflective lens was also used in a replacement of the level rod under the bright sunlight since laser beams were more clearly viewed by using it. Field validation results showed that all hang-up spots identified from the field validation process corresponded with the line-of-sight analysis results from the GIS, indicating that the adopted methodology successfully identified vulnerable rail grade crossings for the vehicle hang-up issue.

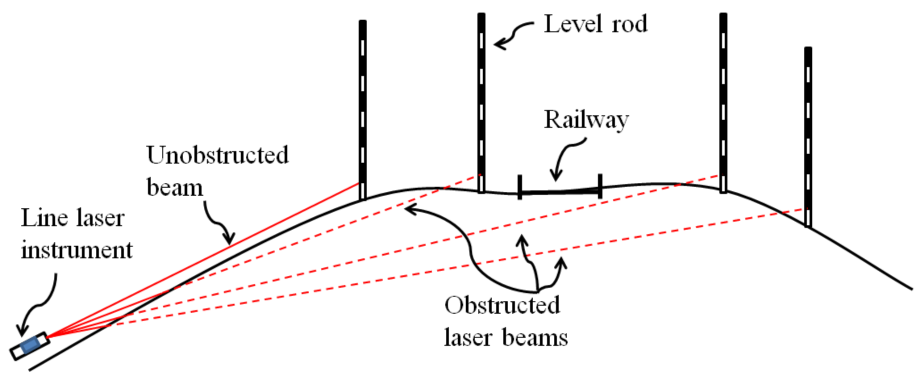


Figure 4.4 Illustration of the field validation of GIS-derived results

	 **Figure 4.5** Field validation of crossing suitability using a line laser and a retro-reflective lens
Impacts/Benefits of Implementation (actual, not anticipated)	The objective of the research was to test and validate the feasibility of assessing humped highway-rail grade crossings for safe passage of vehicles with low ground clearance using LiDAR data. From amongst the selected design vehicles, the lowboy trailer was found susceptible to lodging at site 1 while the car carrier trailer was susceptible to lodging at sites 1 and 2. The passage of the other design vehicles (a rear-loaded garbage truck, two types of fire trucks, and a school bus) was not an issue at any of the three highway-rail grade crossing sites. Validation of the GIS-derived results in the field showed that all the identified blockage spots were correctly identified. The conclusion from the conducted research was that LiDAR data can be used for identifying potential hang-up issues at rail grade crossings. This proposed method is efficient and safer because it avoids making measurements in the field where highway and train traffic may pose hazards to the safety of personnel. However, it is acknowledged that current updates to LiDAR data are infrequent and may not keep up with changes in the highway/rail networks. Therefore, any changes at or near highway-rail grade crossings after LiDAR data collection will likely require field assessment. This research only analyzed three highway-rail grade crossings; in future studies, more sites may be evaluated so the findings are more generalizable.

	Moreover, work on this project has resulted in one paper presentation at the Transportation Research Board 96th Annual Meeting: • Kang, Y. and Khattak, A., "A Cluster-Based Approach to Analyze Crash Injury Severity at Highway-Rail Grade Crossings," *Proceedings of the Transportation Research Board 96th Annual Meeting*, Washington, D.C., January 9, 2017. Additionally, a detailed report that summarizes all the work performed under this project is made available and can be downloaded from the UTCRS website using the link provided below.
Web Links • Reports • Project website	http://www.utrgv.edu/railwaysafety/_files/documents/reports/LiDAR_Project_Final_Report_022816.pdf http://www.utrgv.edu/railwaysafety/research/operations/ improving-safety-at-hrgc-by-using-lidar-technology/index.htm