Experimental Determination of Crack Growth in Rails Subjected to Long-Term Cyclic Fatigue Loading

Exhibit D

Recipient/Grant (Contract) Number: University of Texas Rio Grande Valley (UTRGV)/Grant No. 69A3552348340

Center Name: University Transportation Center for Railway Safety (UTCRS)

Research Priority: Promoting Safety

Principal Investigator(s): Dr. David H. Allen (PI, Texas A&M University (TAMU)) and Mr. Garrett Dorsett (Co-PI, TAMU)

Project Partners: MxV Rail

Research Project Funding: $55,243 (Federal), $27,622 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2025 to 08/31/2026

Project Description: It is well known that one of the most significant causes of train derailments within the U.S. is due to rail fracture. Despite this fact, a reliable model for predicting fatigue fracture in rails has not yet been deployed within the U.S. We have recently been developing a multiscale computational algorithm for predicting crack evolution in ductile solids subjected to long-term cyclic loading. With funding provided by MxV, we have also recently completed cyclic crack growth experiments on seven bi-axially loaded rails with internal cracks that had previously been in service. Within our companion UTC proposals, we are developing the ability to: a) characterize fracture parameters for deploying our advanced fracture mechanics model; b) utilize these parameters to predict crack growth due to cyclic fatigue in rails; and c) utilize our experimental results obtained over the previous decade of testing to validate our computational predictive methodology. In this UTCRS project, we will continue to perform intricate experiments on rails with internal cracks as a means of: 1) obtaining material properties, as described in our companion proposal Determination of Rail Fracture Properties, and 2) validating our advanced computational model under development in our companion proposal entitled Computational Model for Predicting Fracture in Rails Subjected to Long-Term Cyclic Fatigue Loading. Should this model development prove to be useful, it is our ultimate intention to utilize this new advanced technology as a tool for determining when rails with critical internal flaws should immediately be removed from service, or alternatively, how long rails in which subcritical flaws have been detected can be safely retained in service.

US DOT Priorities: This research aligns with the following U.S. DoT goals: safety, economic strength and global competitiveness, and transformation.

Outputs: This research will result in the following during the succeeding contractual year:

1. Refinement of our new advanced protocol for laboratory testing of previously in-service rails with defects;
2. The identification of proper material properties necessary to deploy our advanced computational model for predicting fracture in rails subjected to cyclic loading;
3. The continued improvement of our ability to accurately predict how long pre-damaged in-service rails can remain in service as functions of experimentally observed crack size, location, and orientation within rail heads; and
4. The dissemination of our computational model for predicting rail fracture to the U.S. railway community both via our research relationship with MxV Rail and our publications in technical journals.

Outcomes/Impacts: The broader impact of this research is that it will significantly impact railway safety via the development of more scientifically based track failure models that will significantly mitigate the probability of future environmentally and socially impactful train derailment incidents.

Final Research Report: Upon completion of the project, a URL link to the final report will be provided.

Computational Model for Predicting Fracture in Rails Subjected to Long-Term Cyclic Fatigue Loading

Deliverables and Reporting Requirements for UTC Grants Awarded in 2023 (June 2023)

Exhibit D

Recipient/Grant (Contract) Number: University of Texas Rio Grande Valley (UTRGV)/Grant No. 69A3552348340

Center Name: University Transportation Center for Railway Safety (UTCRS)

Research Priority: Promoting Safety

Principal Investigator(s): Dr. David H. Allen (PI, Texas A&M University (TAMU)), Dr. Yong-Rak Kim (Co-PI, TAMU)

Project Partners: MxV Rail

Research Project Funding: $192,592 (Federal), $96,296 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2025 to 08/31/2026

Project Description: It is well known that one of the most significant causes of train derailments within the U.S. is due to rail fracture. Despite this fact, a reliable model for predicting fatigue fracture in rails has not yet been deployed within the U.S. We have recently been developing an advanced computational algorithm for predicting crack evolution in ductile solids subjected to long-term cyclic loading. In this UTCRS project, we will continue to adapt this model to the prediction of crack growth in rails. Concomitantly, with funding provided by MxV Rail, we have recently completed a decade-long series of experiments designed to provide data usable for the purpose of developing just such a model. We, therefore, possess the ability to both predict crack growth due to cyclic fatigue in rails, as well as to utilize our previously obtained experimental results to validate our predictive methodology. Hence, we have begun the following rather challenging task of: 1) modifying our computational model for predicting crack growth for application to cyclic fatigue in rails; 2) developing an experimental protocol for obtaining the material properties required to deploy our computational fracture model (described in our companion project entitled Experimental Determination of Crack Growth in Rails Subjected to Long-Term Cyclic Fatigue Loading); 3) demonstrate the effectiveness of our model for predicting the effects of long-term cyclic loading on rail fracture; and 4) develop a procedure based on our model for railway engineers to utilize to determine when rails should be inspected and potentially removed from service for cause, thereby increasing rail safety. This project will be carried out with direct interaction and supervision by MxV Rail engineers.

US DOT Priorities: This research aligns with the following U.S. DoT goals: safety, economic strength and global competitiveness, and transformation.

Outputs: Our research will result in the following during the succeeding contractual year:

1. The continued modification of our computational multi-scale model for rail fracture;
2. The inclusion of newly obtained experimental fracture properties within our model (see our companion proposals on both experimental testing and the determination of rail fracture properties);
3. The validation of our rail fracture model versus our previously obtained rail fracture experimental data; and
4. The dissemination of our computational model for predicting rail fracture to MxV Rail and the rail industry community.

Outcomes/Impacts: The broader impact of this research is that it will significantly enhance railway safety via the development of more scientifically based track failure models that will markedly mitigate the probability of future environmentally and socially impactful train derailment incidents.

Final Research Report: Upon completion of the project, a URL link to the final report will be provided.

Advanced Model for Predicting Buckling in Rails

Exhibit D

Recipient/Grant (Contract) Number: University of Texas Rio Grande Valley (UTRGV)/Grant No. 69A3552348340

Center Name: University Transportation Center for Railway Safety (UTCRS)

Research Priority: Promoting Safety

Principal Investigator(s): Dr. David H. Allen (PI, Texas A&M University (TAMU))

Project Partners: MxV Rail

Research Project Funding: $91,402 (Federal), $45,701 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2025 to 08/31/2026

Project Description: It is well-known that track buckling is one of the most commonplace causes of train derailments. Accordingly, with partial funding provided by our previous USDOT UTC and the Technology Transportation Center, Inc. (TTCI, now MxV Rail), we are continuing to develop a track buckling model for deployment by MxV Rail as a tool for predicting track buckling. A significant advancement over currently deployed track buckling models, our technology includes an open-source nonlinear finite element algorithm that is user-friendly. Briefly, our track buckling model accounts for the effects of the following on track buckling: rail neutral temperature (RNT), temperature change, lateral and longitudinal track walk; both lateral and longitudinal crosstie-aggregate interfacial friction; track modulus; nonlinear track liftoff; and broken spikes.

In the most recent contractual year, we have extended the model to include the following: nonlinear lateral friction, longitudinal friction, longitudinal track walk, and longitudinally varying track properties. Most importantly, we have extended the model to include displacement control, hence, giving us the ability to predict the rail configuration in the post-buckled state, thereby rendering our model to be the first rail specific algorithm with this capability.

During the previous year, we met with MxV personnel at least once per month, and we have both ported the model over to them for their personal use and supplied them with expert advice on how to run the algorithm themselves. A TAMU doctoral student spent two months at MxV Rail facilities the previous summer guiding their personnel on the use of our buckling model.

US DOT Priorities: This research aligns with the following U.S. DoT goals: safety, economic strength and global competitiveness, and transformation.

Outputs: The research will result in the following during the upcoming contractual year:

1. Further predictions of the effects of longitudinal and lateral nonlinear friction on track buckling;
2. Continued predictions of the range of buckling loads caused by variations in experimentally determined values of track modulus and ballast-crosstie coefficients of friction; and
3. Under the guidance of MxV Rail engineers, the development of a more simplified user-friendly version of the buckling algorithm, thereby rendering it readily accessible to track engineers.

Outcomes/Impacts: The broader impact of this research is that it will significantly impact railway safety via the development of more scientifically based track failure models that will markedly mitigate the probability of future environmentally and socially impactful train derailment incidents.

Final Research Report: Upon completion of the project, a URL link to the final report will be provided.

Experimental Determination of Rail Fracture Properties

Exhibit D

Recipient/Grant (Contract) Number: University of Texas Rio Grande Valley (UTRGV)/Grant No. 69A3552348340

Center Name: University Transportation Center for Railway Safety (UTCRS)

Research Priority: Promoting Safety

Principal Investigator(s): Dr. Yong-Rak Kim (PI, Texas A&M University (TAMU)), Dr. David H. Allen (Co-PI, TAMU)

Project Partners: MxV Rail

Research Project Funding: $110,763 (Federal), $55,382 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2025 to 08/31/2026

Project Description: There are approximately 1,100 train derailments per year in the U.S., and rail fracture is responsible for 7% of these derailments. Fatigue cracking is a widespread rail fracture issue and a significant safety concern accompanied by critical rail maintenance costs. Despite this fact, a reliable model for predicting fatigue fracture in rails has not yet been deployed within the U.S. In this UTCRS project, we have developed an advanced computational algorithm for predicting crack evolution in rails subjected to cyclic fatigue loading. Our fracture model demonstrates the feasibility and scientific rigor over the traditional phenomenological approaches, while several challenges remain for its successful practical implementation. One of the core challenges is to identify fracture properties in the model when rails are subjected to long-term cyclic fatigue loadings. This project aims to determine the fracture properties of railheads subjected to long-term cyclic fatigue loading. Toward that end, we will use our nonlinear cohesive zone (NCZ) fracture model implemented within the finite element computational algorithm and experimental results from the railhead fatigue testing which is currently under development and will be continued in 2025-2026 (as described in our companion UTCRS proposal entitled Experimental Determination of Crack Growth in Rails Subjected to Long-Term Cyclic Fatigue Loading). Successful identification of rail fracture properties (i.e., fundamental material properties) through this project will serve as a core piece for the development of TAMU's rail fracture modeling framework which will significantly impact the current railway safety and asset management program. This project will be carried out with direct interaction and supervision by MxV Rail personnel.

US DOT Priorities: This research aligns with the following U.S. DoT goals: safety, economic strength and global competitiveness, and transformation.

Outputs: The Expected outcomes from this project are:

(1) rail fracture properties that are determined through model calibration with rail fatigue testing;
(2) model simulation results compared with experimental rail fatigue testing results;
(3) a final report summarizing all research activities and findings/outcomes;
(4) presentations at major conferences; and
(5) journal publications and/or conference papers.

Outcomes/Impacts: The broader impact of this research is that it will significantly impact railway safety via the development of more scientifically based track failure models that will markedly mitigate the probability of future environmentally and socially impactful train derailment incidents.

Final Research Report: Upon completion of the project, a URL link to the final report will be provided.

Evaluating Ballast Performance with Freeze/Thaw Cycles

Exhibit D

Recipient/Grant (Contract) Number: University of Texas Rio Grande Valley (UTRGV)/Grant No. 69A3552348340

Center Name: University Transportation Center for Railway Safety (UTCRS)

Research Priority: Promoting Safety

Principal Investigator(s): Dr. Yu Qian (PI, University of South Carolina (USC)), Dr. Dimitris Rizos (Co-PI, USC)

Project Partners: N/A

Research Project Funding: $70,410 (Federal), $32,771 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2025 to 08/31/2026

Project Description: In seasonally cold regions, railroad tracks are subjected to ice formation under sub-freezing conditions and ice thawing under above-freezing conditions due to significant seasonal temperature fluctuations, posing challenges for the maintenance of ballasted railway tracks and operation safety. Currently, little attention has been given to the impact of ice formation and thawing on the permanent deformation of railroad ballast and incidents due to track stiffness variation have not been reported. This proposed research project will investigate the effect of ice formation and thawing on the permanent deformation of ballast through large-scale triaxial cyclic testing, utilizing a newly developed freezing system to simulate frozen conditions. The results will demonstrate the potential track support variation when ballast is subject to freeze-thaw cycles, under the same loading cycles. The rate of permanent deformation will be related to track settlement and help predict track geometry degradation and optimize track maintenance for enhanced track safety.

US DOT Priorities: This research aligns with the U.S. DoT goal of safety.

Outputs: The expected products include:

1. A detailed analysis of the material behavior of field collected fouled ballast.
2. Test results of fouled ballast under different weather conditions from large-scale triaxial test in terms of permanent deformation and settlement rate.
3. Ballast resilient modulus at different moisture and temperature.
4. A report including all test results and guideline of potential reduction of ballast resilience under different temperature fluctuations between sub-freezing and above-freezing conditions.
5. One or more conference or journal publications.

Outcomes/Impacts: The broader impact of this project is to implement robust measures to improve and extend ballast service life and assist in making better ballast maintenance strategy that can yield significant benefits across public safety, economic performance, and environmental sustainability. By better assessing ballast performance, we can reduce track safety threat, optimize ballast maintenance schedule, reduce ballast maintenance cost, prolong track life, and improve track resiliency. Economically, these advancements can minimize costly service disruptions and maintenance requirements and mitigate track performance issues due to ballast degradation under different weather conditions, thereby enhancing the efficiency of both freight and passenger operations and improve railroad safety. This also strengthens supply chain reliability, promoting a safer, more efficient rail system.

Final Research Report: Upon completion of the project, a URL link to the final report will be provided.

Rapid Detection of Track Changes from In-Motion Data Acquisition Records: Lab Setup and Field Implementation - Year 3

Exhibit D

Recipient/Grant (Contract) Number: University of Texas Rio Grande Valley (UTRGV)/Grant No. 69A3552348340

Center Name: University Transportation Center for Railway Safety (UTCRS)

Research Priority: Promoting Safety

Principal Investigator(s): Dimitris Rizos (PI, University of South Carolina (USC)), Reza Naseri (Co-PI, USC), Brennan Gedney (Co-PI, USC)

Project Partners: N/A

Research Project Funding: $110,493 (Federal), $52,764 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2025 to 08/31/2026

Project Description: Track stiffness is a critical parameter influencing infrastructure integrity, safety, and maintenance efficiency. Track stiffness variations over time and space lead to uneven load distribution, track degradation, and increased risk of failure, necessitating continuous monitoring and timely intervention. Current technologies determine stiffness under loaded or unloaded conditions at discrete locations, or through continuous measurements. They are either costly, labor-intensive, or limited in spatial and temporal resolution. The proposed work is a four-year effort to develop an in-motion system that detects track stiffness and stiffness changes in real-time that is free of the shortcomings of existing techniques. The proposed system is an acceleration-based system that uses hybrid signal processing techniques and machine learning for classification. The system consists of three modules: (1) Data acquisition using onboard vibration sensors; (2) Hybrid signal processing on the edge for feature identification and data compression; and (3) Classification and decision support, utilizing machine learning algorithms for characterization of track conditions in predictive maintenance. This proposal is for Year 3 of our current UTCRS sponsored effort. Year 1 focused on the development of a track stiffness monitoring concept and produced a feasibility study that led to Year 2 work on method development, and validation through simulations and laboratory small-scale testing. Spurred by the findings of Years 1&2, this proposal focuses on the development of an experimental prototype system and its validation through high-fidelity laboratory testing. In addition, we propose to develop a digital twin of the experimental prototype to facilitate extensive validation, calibration, and sensitivity studies to enhance accuracy and scalability. The project will enhance track safety, reduce maintenance costs, and improve railway infrastructure reliability by enabling continuous, cost-effective, and scalable monitoring. The research directly aligns with UTCRS's strategic goals by advancing infrastructure monitoring technologies and contributes to USDOT's objectives in safety and economic competitiveness.

US DOT Priorities: This research aligns with the U.S. DoT strategic goals in safety, economic strength and global competitiveness.

Outputs: The project develops an experimental prototype of the in-motion track stiffness monitoring system validated through laboratory tests on the high-fidelity 1:7 scale track rig, and its digital twin, as well as preliminary field data. Key outcomes include:

1) Description of the in-motion stiffness detection system, the scientific fundamentals, methods and implementation.

2) Description of the 1:7 scale experimental track rig, and its digital twin as used in controlled testing and calibration.
3) Results of the laboratory investigations and the digital twin parametric studies.
4) Preliminary field-testing reports comparing system performance with conventional methods.
5) Journal and conference publications, and industry presentations to support knowledge dissemination and industry adoption.

Outcomes/Impacts: This research revolutionizes the current practice in vehicle-track interaction by presenting a data-driven technique to detect changes over space and time from onboard vibration records in real time. The proposed system may be integrated with existing automated track geometry inspection technologies at a minimal incremental cost. The outcome will enhance railway safety, infrastructure reliability, and cost-effective maintenance by enabling real-time in-motion track stiffness monitoring. It facilitates predictive maintenance, reducing track failures and costly repairs, while promoting sustainability through optimized maintenance and extended track lifespan. Edge computing and machine learning will advance smart infrastructure monitoring, benefiting both research and industry.

Final Research Report: Upon completion of the project, a URL link to the final report will be provided.

Modeling Special Cases of Longitudinal Resistance in Continuously Welded Rail (CWR)

Exhibit D

Recipient/Grant (Contract) Number: University of Texas Rio Grande Valley (UTRGV)/Grant No. 69A3552348340

Center Name: University Transportation Center for Railway Safety (UTCRS)

Research Priority: Promoting Safety

Principal Investigator(s): Eleazar Marquez (PI, UTRGV), Arturo Fuentes (Co-PI, UTRGV), Constantine Tarawneh (Co-PI, UTRGV)

Project Partners: David Allen (Collaborator, Texas A&M University), Stephen Wilk (Collaborator, MxV Rail)

Research Project Funding: $87,451 (Federal), $33,186 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2025 to 08/31/2026

Project Description: Continuously welded rail (CWR) is the standard for North American freight railroads due to its advantages in ride quality, fatigue life, and reduced maintenance costs, despite concerns about rail buckling and breaks. Longitudinal rail resistance is a critical parameter for re-establishing rail neutral temperature (RNT) after rail breaks and for mitigating potential rail failures caused by vehicle loading, temperature changes, and maintenance activities. This proposed research builds upon a previous year project and continues the effort to refine and enhance the Finite Element (FE) modeling of rail longitudinal resistance. Specifically, it aims to improve the representation of realistic rail and anchor conditions by integrating new experimental data into the FE models. The research will develop efficient 2D and 3D FE models in ABAQUS that incorporate rail-to-tie friction, anchor slip forces, and tie-to-ballast restraint, using both experimental results (e.g., anchor slip behavior under varying load conditions) and historical data (e.g., rail-sleeper friction and sleeper-ballast resistance). The models will accommodate various rail profiles, tie materials, and geometric configurations, and will be applicable to a wide range of track conditions including frozen ballast, frozen structures, turnouts, crossings, and loading scenarios from vehicles and maintenance activities. The proposed project will be executed through four key interconnected areas of research: (1) Effects of sleeper-ballast on models larger than 4-ft in length using FE modeling in ABAQUS, (2) experimental testing in the laboratory for anchor slippage with various anchor types, (3) sensitivity analysis, and (4) model analysis with various track conditions.

US DOT Priorities: This research aligns with the following U.S. DoT goals: safety, economic strength and global competitiveness, and workforce development.

Outputs: This project is expected to produce practical tools, models, and documentation that will support improved understanding and application of rail longitudinal resistance under a variety of real-world conditions. Key deliverables include:

1. Evaluation charts of rail longitudinal resistance, accounting for various rail designs, special track conditions, and external longitudinal and vertical loading scenarios.
2. User-friendly 3D finite element (FE) models that can be readily utilized by railway engineers for practical applications.
3. Dissemination of the project outcomes through multiple channels, including:
   - A final report detailing research procedures, methodologies, and findings.
   - Peer-reviewed journal publications to enhance the credibility and visibility of the work.

- Conference presentations (e.g., 2026 InnovaRail Conference) to engage with the broader research and industry community.
- A master's thesis thoroughly documenting the research and its contributions.

Outcomes/Impacts: The research objective of this proposed project is to develop efficient rail longitudinal resistance FE models that include efficient representation of rail-to-tie friction, anchor slipping force, and tie-to-ballast restraint, to propose rail longitudinal resistance charts considering various rail sizes, multiple material and geometric tie properties, and a wide range of track conditions, such frozen ballast, frozen structures, turnouts, crossings, vehicle forces, and maintenance disturbance. The theoretical research of developing FE rail longitudinal resistance models that include efficient representation of rail-to-tie and tie-to-ballast interactions can have multiple practical applications, including (1) providing improved RNT re-establishment guidance under special track conditions, and (2) evaluating changes in RNT from vehicle and maintenance-induced longitudinal rail movement. However, the research will have impacts beyond this specific engineering problem. Industry Impact: The results could lead to recommendations for industry best practices; for example, a recommendation for proper rail longitudinal resistance for various CWR segments considering multiple special conditions, to assist in the determination of RNT pre-failure or after break. Educational Impact: The project will be carried out by undergraduate and graduate students working under the supervision of the PIs. We anticipate that most of the students will have the chance to work with MxV Rail engineers and spend some time during the summer at MxV Rail facilities. The students will gain invaluable experience in designing and fabricating the laboratory test setup and in conducting tests according to AAR standards. We anticipate that one graduate student and one undergraduate student will participate in the various aspects of the project.

Final Research Report: Upon completion of the project, a URL link to the final report will be provided.

Temperature-Induced Cyclic Loading Effects on Rail Anchor Slip Force

Exhibit D

Recipient/Grant (Contract) Number: University of Texas Rio Grande Valley (UTRGV)/Grant No. 69A3552348340

Center Name: University Transportation Center for Railway Safety (UTCRS)

Research Priority: Promoting Safety

Principal Investigator(s): Mustapha Rahmaninezhad (PI, UTRGV), Constantine Tarawneh (Co-PI)

Project Partners: MxV Rail, BNSF Railway

Research Project Funding: $130,966 (Federal), $59,457 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2025 to 08/31/2026

Project Description: Recently, continuous welded rail (CWR) systems have been widely adopted due to their enhanced ride quality, reduced maintenance requirements, and extended service life for both rails and rolling stock. However, the elimination of joints in CWR introduces challenges, particularly in managing thermal expansion, which can lead to track buckling. A critical factor in maintaining track stability is the Rail Neutral Temperature (RNT) – the temperature at which rails are free of thermal stress. Anchors, which resist longitudinal rail movement, play a key role in managing RNT and ensuring track integrity. While previous studies have largely focused on the static behavior of rail anchors, this research emphasizes the importance of cyclic longitudinal loading, which can simulate daily and seasonal temperature fluctuations. Unlike static loading, cyclic longitudinal loading on the rail-anchor under different temperatures can potentially lead to gradual degradation in anchor performance, slip initiation, or cumulative displacement over time. These effects may be more critical to track stability than static forces alone, especially under service operating conditions. This study will conduct full-scale laboratory testing to investigate the impact of cyclic temperature-induced longitudinal loading on slip force performance for various rail anchor types. By simulating temperature cycles and measuring anchor slip under controlled conditions – including different anchor geometries, installation tightness, and environmental parameters – this research aims to provide an understanding of the long-term reliability of rail anchoring systems under thermal cycling. Also, this study addresses the need to construct a 15-foot full-scale track segment on ballast and wood ties to replicate in-field conditions for the future studies to be performed for this project.

US DOT Priorities: This research aligns with the following U.S. DoT goals: safety, economic strength and global competitiveness, and workforce development.

Outputs: The expected products and deliverables include:

1. Modification and Setup of the Self-Reacting Loading System (if needed) - Adaptation of the existing loading platform to accommodate cyclic, displacement-controlled testing of a single rail supported by steel ties.
2. Quantified Rail Anchor Slip Forces - Experimental data on slip forces for various steel anchor types under different temperature conditions, evaluating cyclic thermal effects.
3. Final Report - Documentation of all experimental procedures, data analysis, and key findings related to anchor performance and temperature-induced cyclic loading effects.
4. Industry Dissemination - Final report shared with MxV Rail, BNSF Railway, Class I railroads, the Association of American Railroads, and the Texas A&M University Center for Railway Research, and also available to the general public through the UTCRS website.

Outcomes/Impacts: While the core outcome of this research is to characterize and quantify rail anchor slip forces under simulated service and temperature conditions, its broader impacts extend well beyond this objective.

Industry Impact: The findings will support the development of best practices guidelines for rail anchor selection and application under varying environmental temperatures. These insights can help improve track stability, reduce derailment risks, and enhance long-term infrastructure resilience through optimized anchor performance.

Educational Impact: This project provides hands-on research opportunities for both undergraduate and graduate students under the guidance of the PIs. Students will gain practical experience in lab testing, data analysis, and system fabrication, while also interacting with MxV Rail and BNSF Railway engineers. Planned activities include a student workshop and potential summer visits to industry facilities. At least two undergraduate students and one graduate student are expected to participate in the various phases of the project.

Final Research Report: Upon completion of the project, a URL link to the final report will be provided.

Non-Contact Energy Harvesting for Rural Grade Crossings - Year 3

Exhibit D

Recipient/Grant (Contract) Number: University of Texas Rio Grande Valley (UTRGV)/Grant No. 69A3552348340

Center Name: University Transportation Center for Railway Safety (UTCRS)

Research Priority: Promoting Safety

Principal Investigator(s): Joseph Turner (PI, University of Nebraska-Lincoln (UNL)), Carl Nelson (Co-PI, UNL)

Project Partners: Mohsen Amjadian (Collaborator, UTRGV)

Research Project Funding: $66,556 (Federal), $61,445 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2025 to 08/31/2026

Project Description: The network of US railroads often spans remote parts of the country that are sparsely populated. In these areas, rail grade crossings are much less likely to have warning lights or crossing gates primarily due to the lack of electricity. Such unprotected or passive crossings have the majority of the grade crossing fatalities and accidents. To reduce rail accidents, enhanced warning systems are needed at as many passive crossings as possible. We propose to create a new energy harvesting approach based on the motion of the wheels to generate sufficient power for an LED-based grade crossing warning system. Recent advances to create small and powerful magnets allows for the design of a non-contact power generation approach that is activated with each passing wheel. The feasibility of this approach has been demonstrated and an initial prototype will provide data for optimization of the energy harvesting capabilities.

US DOT Priorities: This research aligns with the following U.S. DoT goals: safety, economic strength and global competitiveness, and transformation.

Outputs: There are several expected results and products for this project. These include:

1. Results from this project have been accepted for presentation at the International Heavy Haul Association (IHHA) Conference. The 13th IHHA Conference will be held November 17-21, 2025, in Colorado Springs, Colorado, in conjunction with the 14th World Congress on Railway Research (WCRR),
2. Data from the initial field tests,
3. One or more patent disclosures,
4. Additional conference presentations and journal publications, and
5. One Ph.D. dissertation within two years.

Outcomes/Impacts: The broader impacts of this project include:

1. Education of a graduate student who will be trained to work in the railroad industry,
2. Collection of experimental field data to show the capabilities of the device for energy harvesting,
3. Creation of computational models that show the scalability of the approach for multiple devices within a compact enclosure,
4. Dissemination of presentations, reports, and journal publications that demonstrate the approach, and
5. One or more patent disclosures.

Final Research Report: Upon completion of the project, a URL link to the final report will be provided.

Ultrasonic Inspection of Reconditioned Railroad Bearing Components - Year 3

Exhibit D

Recipient/Grant (Contract) Number: University of Texas Rio Grande Valley (UTRGV)/Grant No. 69A3552348340

Center Name: University Transportation Center for Railway Safety (UTCRS)

Research Priority: Promoting Safety

Principal Investigator(s): Joseph Turner (PI, University of Nebraska-Lincoln (UNL)), Constantine Tarawneh (Collaborator, UTRGV)

Project Partners: Anish Poudel and Matt Wenger (MxV Rail)

Research Project Funding: $83,444 (Federal), $13,100 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2025 to 08/31/2026

Project Description: Freight rail bearings are often subjected to heavy loads such that the performance of each bearing plays a crucial role in the safe operation of the entire train. Even bearings that are properly maintained may still fail due to rolling contact fatigue (RCF) if local regions within the bearing race do not meet established effective case depth (ECD) standards. In addition, little is known about potential changes that may occur within the highest stress region after extensive service life. Ultrasonic grain scattering shows sensitivity to both microstructure and residual stresses such that nondestructive measurement methods based on diffuse ultrasonic backscatter have shown a high correlation with the overall status of the raceway. Results from the first year showed clear differences between new and reconditioned bearing cups in terms of their ultrasonic signatures. This work will be expanded to include spatial maps of raceways to identify locations that are outside the statistical bounds expected for a given part. Those locations will be identified and those parts will be tested in simulated service life testing at UTRGV for comparison with the predictions.

US DOT Priorities: This research aligns with the following U.S. DoT goals: safety, economic strength and global competitiveness.

Outputs: During this project, several results are expected. These include:

1. Laboratory ultrasonic experiments will be performed on bearing components at various stages of service life.
2. Statistical analysis of the ultrasonic data will be performed to identify differences present within parts and between different categories of parts (e.g., new, used, spalled, repaired).
3. Statistical results will be used to identify outliers and anomalies within each part and with respect to the ensemble of parts.
4. A select number of bearing components will be subjected to laboratory service life testing to quantify the inspection approach.
5. Results from this project have been accepted for presentation at the International Heavy Haul Association (IHHA) Conference. The 13th IHHA Conference will be held November 17-21, 2025, in Colorado Springs, Colorado in conjunction with the 14th World Congress on Railway Research (WCRR).
6. Additional products include conference presentations, reports, journal articles, and patent disclosures. Building on previous research, two conference presentations and one journal article should be possible during the year.

Outcomes/Impacts: The broader impacts of this project include:

1. Training of a graduate student with specific knowledge of bearing testing and details specific to the railroad industry,
2. Training of a graduate student for at least two different nondestructive evaluation techniques,
3. Collection of experimental data on railroad bearing components to quantify potential spall locations,
4. Details regarding statistical methods and their application to ultrasonic measurements on railroad bearing components, and
5. Dissemination of presentations, reports, and journal publications that demonstrate the approach.

Final Research Report: Upon completion of the project, a URL link to the final report will be provided.

Effect of Long-Term Inactivity on Railcar Bearing Lubricant and Seal Function

Exhibit D

Recipient/Grant (Contract) Number: University of Texas Rio Grande Valley (UTRGV)/Grant No. 69A3552348340

Center Name: University Transportation Center for Railway Safety (UTCRS)

Research Priority: Promoting Safety

Principal Investigator(s): Constantine Tarawneh (PI, UTRGV), Robert Jones (Co-PI, UTRGV), Jose Jaime Taha (Co-PI, UTRGV); Collaborators: Kim Bowling (CSX Transportation), and Joey Rhine (NTSB)

Project Partners: CSX Transportation, National Transportation Safety Board (NTSB), MxV Rail

Research Project Funding: $109,786 (Federal), $44,465 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2025 to 08/31/2026

Project Description: Prior work on the effects of prolonged inactivity on rail bearing performance focused on possible effects of extended idle periods on lubricant condition and performance. Those studies utilized bearings which had been idle for three years. Normal changes in lubricant antioxidants and consistency were observed but changes did not fall outside the necessary condition for safe operation of the bearing. A controlled study of long-term idleness on lubricant characteristics began as part of that study and we propose extending that work for another year. In the testing of the idle bearings received from CSX, two seal-related conditions were observed which would have some impact on long term performance. One bearing showed evidence of water intrusion as evidenced both by corrosion on the bearing raceway and behavior of samples in thermal analysis. In addition, several bearings subjected to service testing developed lubricant leaks from the metallic joint between the seal and bearing cup which is a press fit. In almost two decades of bearing life testing, we have never seen a leak at that location, even in bearings which had been reassembled multiple times. The proposed work would have one continuing effort and one new line of investigation. (1) The effects of extended inactivity on lubricants stored in a bearing simulator and continuously exposed to the South Texas elements would continue for another year. (2) Evaluation of effects of extended periods under load without rotation on the metal-metal interface between the bearing seal and the bearing cup.

US DOT Priorities: This research aligns with the following U.S. DoT goals: safety, economic strength and global competitiveness, and transformation.

Outputs: The expected products and deliverables include:

a. Results of TGA and DSC analysis of lubricants before and at various aging times.
b. Results of Tribological evaluations: COF, WSD, friction torque.
c. Results of Rheological evaluations: viscosity.
d. Scans and CMM reports of leaking seal rings.
e. Scans and CMM reports of tested seal rings.
f. Vibration and temperature data of thermally aged bearings during testing.
g. Final report with findings.
h. One or more conference or journal publications. At a minimum, we will submit a paper to the 2026 INNOVARail Conference after results are available.

Outcomes/Impacts: The primary impact of the research is answering the question of what effects long periods of inactivity have on lubricant properties and bearing seal performance, reliability, and service life. However, the research will have impacts beyond this specific question. Industry Impact: The results could lead to recommendations for industry best practices; for example, a recommendation to move inactive railcars by a short distance at given intervals, or a recommendation to take weighted inactive time into account when predicting bearing mileage. Educational Impact: The UTCRS portions of the project will be carried out by students working under the supervision of the PIs. The students will gain invaluable experience in operating lubricant test equipment, bearing test equipment and in conducting tests according to AAR and ASTM standards. We anticipate that at least four undergraduate and graduate students will participate in the various aspects of the project.

Final Research Report: Upon completion of the project, a URL link to the final report will be provided.

Laboratory and Field Testing of an Impact-Driven Multi-Resonant Energy Harvester for Electrical Power Generation in Rail-Track Systems - Phase II, Year 2

Exhibit D

Recipient/Grant (Contract) Number: University of Texas Rio Grande Valley (UTRGV)/Grant No. 69A3552348340

Center Name: University Transportation Center for Railway Safety (UTCRS)

Research Priority: Promoting Safety

Principal Investigator(s): Dr. Mohsen Amjadian (PI, UTRGV) and Dr. Constantine Tarawneh (Co-PI, UTRGV)

Project Partners: National Transportation Safety Board (NTSB), Rio Valley Switching Company (RVSC)

Research Project Funding: $56,251 (Federal), $58,005 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2025 to 08/31/2026

Project Description: Reliable power sources are often unavailable across much of the rail network, hindering the deployment of essential sensors and condition monitoring systems needed for real-time infrastructure assessment and safety. This research builds upon the first year of Phase 2, where the theoretical foundation and initial design of a Multi-Resonant Impact-Driven Energy Harvester (MRIDEH) were developed. The harvester employs an impact-driven mechanism and multiple resonators tuned to the dominant vibration frequencies of the rail track system under a moving train load to enhance electromechanical coupling and broaden its operational bandwidth. While the earlier phase focused on analytical modeling and theoretical investigations, the current work transitions the concept into a functional prototype through design refinement, fabrication, and experimental validation. The proposed research will focus on (1) optimizing the harvester's design parameters to maximize power output through systematic parametric studies, (2) fabricating a prototype incorporating the optimized design, (3) conducting comprehensive laboratory testing, including integration with an energy storage circuit for power management evaluation, and (4) conducting field tests under actual rail traffic conditions to assess performance and feasibility. The outcomes of this work will provide essential experimental evidence to confirm the practical performance of the MRIDEH system. This validation will demonstrate its ability to generate reliable electrical power from train-induced vibrations, supporting its use as a self-sustaining energy source. The findings will help advance the development of a scalable and low-cost solution that can be deployed across various segments of the rail network to power sensors and monitoring devices which are critical for improving the safety, reliability, and efficiency of rail operations by collecting real-time data on train movements and track conditions.

US DOT Priorities: This research aligns with the following U.S. DoT goals: safety, workforce development, and transformation.

Outputs: The project is expected to deliver the following:

1. Detailed design documents and assembly guides for the proof-of-concept energy harvester prototype, provided in AutoCAD, SolidWorks, and Adobe formats. (File Formats: DWG, SLDPRT, PDF)
2. Extensive laboratory and field raw data capturing time history of acceleration, voltage, and electric power output of the energy harvester. (File Formats: TXT, CSV)
3. A fully operational fabricated proof-of-concept prototype based on an optimized design, which will undergo rigorous testing both in the laboratory and the field with its harvesting circuit and booster to store electrical power.

4. A detailed report (or publication) summarizing the findings from both lab and field tests, prepared to meet the specifications of the USDOT and UTCRS.
5. The dissemination of research findings through one or more conference presentations or journal publications. Specifically, the PI will present the results at national conferences, focusing on advancements in energy harvesting systems.

Outcomes/Impacts: This proposal addresses critical societal challenges by advancing scientific knowledge and contributing to meaningful improvements in the safety, efficiency, and sustainability of the U.S. rail network. It focuses on developing a cost-effective and scalable energy harvesting system designed to provide reliable electrical power for sensors and monitoring equipment used in rail infrastructure. These systems are essential for tracking train movement, detecting track conditions, and supporting predictive maintenance, especially in areas where access to conventional or solar power sources is limited, such as tunnels, shaded tracks, and remote locations. By enabling self-powered sensing systems, the proposed research supports the deployment of smart technologies that improve safety and operational awareness across the rail system. The outcomes of this work will lay the foundation for broader applications of vibration-based energy harvesting across various types of transportation infrastructure. This project also strongly supports STEM education by creating hands-on learning opportunities, particularly for local students at UTRGV. It will involve graduate students in research that spans mechanical-electrical modeling, design optimization, and field testing, equipping them with interdisciplinary skills that are critical for careers in advanced transportation infrastructure technologies. Moreover, the project fosters collaboration between academia and industry, helping to translate research outcomes into real-world applications. Industry engagement will be strengthened through workshops, webinars, and conference publications (e.g., ASCE EMI and SPIE Smart Structures), ensuring knowledge dissemination and stakeholder involvement.

Final Research Report: Upon completion of the project, a URL link to the final report will be provided.

Comparison of Onboard Condition Monitoring System Mounting Location for Freight Railcar Bearing Defect Detection Using Vibration Signatures

Exhibit D

Recipient/Grant (Contract) Number: University of Texas Rio Grande Valley (UTRGV)/Grant No. 69A3552348340

Center Name: University Transportation Center for Railway Safety (UTCRS)

Research Priority: Promoting Safety

Principal Investigator(s): Heinrich Foltz (PI, UTRGV), Joseph Montalvo (Co-PI, UTRGV), Constantine Tarawneh (Co-PI, UTRGV)

Project Partners: Hum Industrial Technologies, Inc., MxV Rail

Research Project Funding: $117,763 (Federal), $78,871 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2025 to 08/31/2026

Project Description: Prior research at UTCRS has demonstrated that onboard sensor technology can make early and accurate detections of defect initiation in railcar bearings and wheels. Vibration thresholds were developed using the extensive history of acceleration data gathered from an accelerometer mounted at the preferred Smart Adapter (SA) location on the bearing adapter. This location is not available on many adapter types. Data acquired at alternate locations on the adapter indicates that there are systematic differences in recorded vibration waveforms that are significant enough to require compensation in order to find equivalent threshold levels. We propose a study using multiple, simultaneously sampled accelerometers on adapters at several different locations of the adapter surface, to determine the required compensation functions. This large-scale study will be conducted at the UTCRS lab but will be supplemented with field data expected to be gathered at the MxV Rail Fast Loop facility. The test will directly acquire data from (a) the SA location, (b) face-mounted top dead center (TDC) location, (c) and face-mounted at a location 45° off top-dead center (Mote). It will also be compared with statistical data from commercial vibration sensors with alternate mountings. The lab testing will take place concurrently with other previously committed experiments on a combination of healthy bearings and bearings with known early-stage and progressing defects. The outcomes of this project would include quantitative, calibrated comparisons of vibration signatures from the SA location to the alternate as well as potential improvements to existing thresholds and algorithms.

US DOT Priorities: This research aligns with the following U.S. DoT goals: safety, economic strength and global competitiveness, and transformation.

Outputs: The expected products and deliverables include:

1. A database that includes full vibration waveforms for bearings at different mounting locations.
2. Recommended correction functions for converting previously acquired vibration data to match the new optimal location, or vice versa.
3. Publications and reports presented at national venues and uploaded to the UTCRS website.

Outcomes/Impacts: Industry Impact: The results could lead to recommendations for industry best practices, in particular, deployment of onboard sensing. Even if onboard sensing is not deployed, industry will have increased knowledge of what level and types of bearing and wheel damage fall below the current thresholds of wayside instruments, which could lead to modified thresholds or trend analysis. Educational Impact: The UTCRS portions of the project will be carried out by students working under the supervision of the PIs, who will receive training and gain experience in rail sensor applications, calibration, and bearing test procedures. We anticipate that at least three students will participate.

Final Research Report: Upon completion of the project, a URL link to the final report will be provided.

Multi-modal AI Agents for Railway Safety

Exhibit D

Recipient/Grant (Contract) Number: University of Texas Rio Grande Valley (UTRGV)/Grant No. 69A3552348340

Center Name: University Transportation Center for Railway Safety (UTCRS)

Research Priority: Promoting Safety

Principal Investigator(s): Evangelos Papalexakis (PI, University of California-Riverside (UCR)), Jia Chen (Co-PI, UCR), Yue Dong (Co-PI, UCR), Ping Xu (Collaborator, UTRGV)

Project Partners: N/A

Research Project Funding: $100,000 (Federal), $50,000 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2025 to 08/31/2026

Project Description: Artificial Intelligent agents, powered by foundation models, such as ChatGPT, have transformed every aspect of everyday life, in personal and professional settings, and have also started making substantial progress in specializing and producing results in various scientific and engineering domains. In this project, continuing the effort we started in Year 2 which entailed the development of a prototype for a large language foundation model for railway safety, we will work towards developing a multi-modal AI agent for railway safety, which will be able to seamlessly integrate structured and unstructured text (such as accident reports and policy documents) with image data pertaining to a railway crossing and perform a number of tasks such as analyzing, comparing, and contrasting different railway crossings with respect to their risk factors and/or accident history, and come up with safety recommendations specifically tailored to a crossing. The proposed AI agent will combine rich domain expertise and the ability to sift through and analyze vast amounts of data that no human operator or policy maker may realistically be able to, thus empowering large scale data-driven railway safety.

US DOT Priorities: This research aligns with the following U.S. DoT goals: safety, economic strength, workforce training, and transformation.

Outputs: We expect to have the following results by the end of the project period:

(1) Research publications, targeted to top-tier data science, machine learning, and artificial intelligence venues.
(2) Publicly available source code for the methods developed. Typically, each publication will be accompanied by a link to publicly available source code on a widely used repository such as GitHub.

Outcomes/Impacts: The project's broader impacts are multi-pronged: (1) From a social good point of view, our proposed work has the potential to improve railway safety; (2) From the point of view of human resources and sustainability, the project has the potential to improve the way in which railway safety professionals operate, in government and industry. Success in our project will enable them to heavily rely on our AI foundation models in order to come up with summaries of existing knowledge or policy recommendations, a fact which can transform their work and productivity; and (3) the project will provide educational opportunities to graduate and undergraduate students to be involved in cutting-edge AI and machine learning research.

Final Research Report: Upon completion of the project, a URL link to the final report will be provided.

Non-Motorist Safety at Highway-Rail Grade Crossings: Developing a Crash Prediction Model with Integrated Non-Motorist Exposure - Year 3

Exhibit D

Recipient/Grant (Contract) Number: University of Texas Rio Grande Valley (UTRGV)/Grant No. 69A3552348340

Center Name: University Transportation Center for Railway Safety (UTCRS)

Research Priority: Promoting Safety

Principal Investigator(s): Aemal Khattak (PI, University of Nebraska-Lincoln (UNL)), M. Naveed Aman (Co-PI, UNL)

Project Partners: N/A

Research Project Funding: $130,000 (Federal), $65,445 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2025 to 08/31/2026

Project Description: The proposed research objective is to address the safety of non-motorists at highway-rail grade crossings (HRGCs). In Phase III (Year 3), the research team will focus on a survey of pedestrians and bicyclists in Federal Region VII (NE, IA, KS, and MO) to investigate their characteristics, perceptions of safety at crossings, understanding and comprehension of traffic signs/signals at crossings, and their self-reported unsafe movements at HRGCs. The focus on this region ensures a representation of the Midwest, where the extensive rail network creates safety issues for non-motorists. Incidents involving non-motorist users at HRGCs are often underreported or overlooked, yet statistics reveal that they significantly contribute to overall fatalities and injuries at these locations. Pedestrians and bicyclists at HRGCs are particularly vulnerable due to the lack of adequate protective barriers or warning devices. In 2022, the Federal Railroad Administration (FRA) recorded 2,202 crashes at HRGCs, leading to 269 fatalities and 827 injuries nationwide. Furthermore, during the same year, there were 1,157 reported incidents of pedestrian rail trespassing, resulting in 606 fatalities and 551 injuries. These numbers emphasize the need for a comprehensive understanding of the risks associated with non-motorized users at HRGCs and identification of crossings where non-motorized users may be susceptible to crashes. This research will contribute to a deeper understanding of safety hazards associated with HRGCs and lead to the development of autonomous mitigation technologies for rail crossings.

US DOT Priorities: The proposed research is directly related to the USDOT strategic goal of making the transportation system safer for all people and to advance a future without transportation-related serious injuries and fatalities.

Outputs: Expected results include behavioral insights, perceived safety and risk factors, distraction and awareness levels, and state-specific trends in non-motorist behaviors. These measures will allow identification of gaps in safety measures and provide information for development of autonomous safety-enhancement technologies. Products from the research include a comprehensive survey report, data visualizations and infographics, presentations at appropriate venues, and peer-reviewed academic papers.

Outcomes/Impacts: The findings from this survey will extend beyond the immediate research objectives, influencing transportation safety, policymaking, infrastructure planning, and public awareness. The broader impacts include enhancing rail crossing safety for non-motorists, informing transportation policies and planning, raising public awareness, and advancing research in transportation safety.

Final Research Report: Upon completion of the project, a URL link to the final report will be provided.

Design of Dynamic Train Crossing Estimation and Real-Time Traffic Control Systems for Grade Crossing Safety

Exhibit D

Recipient/Grant (Contract) Number: University of Texas Rio Grande Valley (UTRGV)/Grant No. 69A3552348340

Center Name: University Transportation Center for Railway Safety (UTCRS)

Research Priority: Promoting Safety

Principal Investigator(s): Chen, Yuche (PI, University of South Carolina (USC)); Qian, Yu (Co-PI, USC); Dimitris Rizos (Co-PI, USC)

Project Partners: N/A

Research Project Funding: $54,485 (Federal), $32,031 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2025 to 08/31/2026

Project Description: This research project aims to enhance safety and traffic flow efficiency at rail grade crossings by developing a real-time traffic operation control system that dynamically coordinates traffic signals with train movements. A key innovation is the design of dynamically updated train crossing windows for all at-grade crossings within a region. By leveraging available real-time train tracking data, including location, speed, and projected arrival times at crossings, the system will continuously predict and update crossing windows. These predictions will be integrated into adaptive traffic signal control algorithms, ensuring efficient vehicle movement while reducing delays and potential conflicts at crossings. The proposed system will consist of three core components: (1) a real-time train movement prediction model using GPS, trackside sensors, and historical train operation data; (2) a dynamic train crossing window estimation module that calculates and updates available crossing opportunities for all grade crossings in the region based on evolving train movement data; and (3) an intelligent traffic signal coordination system that adjusts traffic lights in real time to optimize vehicle throughput while ensuring safety at rail crossings. This approach will minimize unnecessary traffic stops, reduce congestion, and improve safety by providing a network-wide, adaptive traffic management solution. The findings of this research will contribute to the advancement of intelligent transportation systems, offering practical applications for traffic agencies and rail operators in improving grade crossing safety and efficiency.

US DOT Priorities: This research aligns with the U.S. DoT goals of safety and transformation.

Outputs: The expected products include:

a. A dynamic train crossing window estimation system for real-time updates across all grade crossings.
b. An adaptive traffic signal coordination tool optimizing vehicle flow using real-time train data and predictive analytics.
c. A final report for U.S. DoT and UTCRS, detailing findings, methodology, and implementation recommendations.
d. Technology transfer, including collaborations for field testing.

Outcomes/Impacts: This research and student training will have broad impacts beyond its findings. Research Activities: Developing a real-time traffic control system will enhance safety, reduce delays, and improve traffic flow at grade crossings. AI-driven signal optimization advances intelligent transportation and data-driven decision-making. Findings shared through publications and conferences will influence industry best practices. Adaptive control strategies also support sustainability by minimizing idling. Educational Activities: Engaging students strengthens the transportation engineering workforce. Overall, the project contributes to public safety, intelligent systems, knowledge transfer, and workforce development.

Final Research Report: Upon completion of the project, a URL link to the final report will be provided.

Intelligent Aerial Drones for Railroad Track Traversability Assessment, Intrusion Detection and Integrity Evaluation

Exhibit D

Recipient/Grant (Contract) Number: University of Texas Rio Grande Valley (UTRGV)/Grant No. 69A3552348340

Center Name: University Transportation Center for Railway Safety (UTCRS)

Research Priority: Promoting Safety

Principal Investigator(s): Dr. Nikolaos Vitzilaios (PI, University of South Carolina (USC)), Dr. Dimitris Rizos (Co-PI, USC), Dr. Yu Qian (Co-PI, USC)

Project Partners: N/A

Research Project Funding: $64,612 (Federal), $32,549 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2025 to 08/31/2026

Project Description: Aerial drones have been increasingly used in railroad operations as they offer an effective low-cost solution that can be easily deployed and efficiently support the human efforts in inspection and monitoring activities. This proposal outlines the development of an advanced system leveraging intelligent aerial drones for comprehensive railroad track monitoring and evaluation. The project serves as the integration phase (phase 3) of two UTCRS projects that in the previous two phases developed related technology: (i) a project on the development of Intelligent Aerial Drones for Traversability Assessment of Railroad Tracks, and (ii) a project on the development of AI-enabled system for Track Intrusion Detection and Track Integrity Evaluation. Through this integration, an intelligent aerial drone will be developed able to carry equipment for the autonomous inspection of railroad tracks with the following capabilities: (i) Visual-based identification and autonomous following of the track; the system will be able to work even in GPS-degraded environments (tunnels, dense forests); (ii) Collision avoidance capability where the drone senses and avoids obstacles; (iii) Track centering capability where the drone follows the same line regardless of the number of tracks in the field of view; (iv) Identification and mapping of any obstacles identified blocking the line; (v) Intrusion\Trespassing detection; and (vi) AI-based Detection, Classification, Tracking, and Situational Evaluation. This innovative solution promises to improve operational efficiency, safety, and cost-effectiveness in the management of railroad networks, while minimizing downtime and enhancing system reliability.

US DOT Priorities: This research aligns with the following U.S. DoT goals: safety, economic strength and global competitiveness, transformation, and organizational excellence.

Outputs: The expected products include:

1. Algorithms for autonomous navigation and collision avoidance for drone systems flying over railroad tracks.
2. A prototype drone system with online processing capabilities.
3. A tailored image training library for future track intrusion or track integrity detection model development.
4. An AI model that is customized to detect, classify, and track abnormal objects at the railroad crossing areas or the broader area along the track segment.
5. A prototype integrated hardware system for edge computing.
6. One or more conference or journal publications.

Outcomes/Impacts: This project contributes to the development of modern drone-based inspection systems with these key impacts in the railroad sector: Improved Safety, Enhanced Efficiency, Timely Maintenance-Repair, Cost Savings, Enhanced Asset Management, Technological Advancements. The broader impact of this project implementing robust measures to mitigate trespassing and track intrusion at railroad crossings can yield significant benefits across public safety, economic performance, and environmental sustainability. By actively monitoring railroad crossings and nearby track segments, we can potentially reduce related accidents and fatalities, bolstering public confidence in rail transportation. Economically, these advancements can minimize costly service disruptions and maintenance requirements, and mitigate legal issues, thereby enhancing the efficiency of both freight and passenger operations. This also strengthens supply chain reliability, promoting a safer, more efficient rail system.

Final Research Report: Upon completion of the project, a URL link to the final report will be provided.

Quantifying Traffic at Highway-Rail Grade Crossings Using Artificial Intelligence

Exhibit D

Recipient/Grant (Contract) Number: University of Texas Rio Grande Valley (UTRGV)/Grant No. 69A3552348340

Center Name: University Transportation Center for Railway Safety (UTCRS)

Research Priority: Promoting Safety

Principal Investigator(s): Gasser Ali (PI, UTRGV), and Constantine Tarawneh (Co-PI, UTRGV)

Project Partners: National Transportation Safety Board (NTSB)

Research Project Funding: $73,575 (Federal), $25,934 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2025 to 08/31/2026

Project Description: Rail-highway grade crossings remain a critical safety concern, with 2,246 incidents, 266 fatalities, and 744 injuries in 2024 based on data from the US Department of Transportation (USDOT) and the Federal Railroad Administration (FRA). There is a need to explore new standards and technologies that increase safety at grade crossings and eliminate incidents. Updated reports and data from crossings are necessary to achieve that goal. However, the number of crossings in the US is vast. Although the FRA maintains a crossing inventory as a publicly available resource, which has invaluable data for operation and maintenance, many crossings have outdated information. Analysis of the data in the crossing inventory reveals that the average age of Annual Average Daily Traffic (AADT) in revisions submitted in 2024 is approximately 16.5 years old. Also, many crossings are missing that information completely. As such, there is a need to update traffic information at rail crossings. Manually counting and classifying vehicles to estimate daily traffic is tedious and labor intensive. This research intends to address the need for updated traffic information at grade crossings using Artificial Intelligence (AI). The proposed work will extend on previous research by the team by implementing advanced AI models, using Deep Learning (DL), which will automatically detect, classify, and track vehicles and pedestrians at grade crossings using video streams from cameras. The developed model will capitalize on crowd-sourced and publicly available videos for model training and validation. The model will be able to use affordable cameras to be a cost-effective solution. The AADT information produced from the model will support decision-makers to prioritize safety updates at rail crossings.

US DOT Priorities: This research aligns with the following U.S. DoT goals: safety, economic strength and global competitiveness, and transformation.

Outputs: The expected products include:

1. Developed model to identify and track vehicles and pedestrians at grade crossings and estimate AADT.
2. A dataset for further research with UTCRS participants and grade crossing research subgroup.
3. One or more conference or journal publications.
4. Prototype of a small portable system implementing the model. The system should be easily deployable and can generate a report with summary fundings over its installation duration.

Outcomes/Impacts: The primary impact of the research is providing a framework that contributes to improving safety at crossings. The research will have impacts beyond this specific goal. Industry Impact: The results would lead to recommendations to improve safety at crossings, and practical technologies to autonomously monitor crossings. Educational Impact: The UTCRS portions of the project will be carried out by two students working under the supervision of the PIs, and the project will indirectly support the development of many other students. The students will receive invaluable training in research methodologies and developing AI models.

Final Research Report: Upon completion of the project, a URL link to the final report will be provided.