Enhancing the TAMU Model for Predicting Buckling in Rails

Exhibit D

Research Project Requirement Template

Recipient/Grant (Contract) Number: University of Texas Rio Grande Valley (UTRGV), Texas A&M University (TAMU)/Grant No. 69A3552348340

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

Research Priority: Promoting Safety

Principal Investigator(s): Dr. David Allen (PI, TAMU), Dr. Yong-Rak Kim (Co-PI, TAMU)

Project Partners: MxV Rail, BNSF

Research Project Funding: $199,954.32 (Federal), $102,518.41 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2023 to 08/31/2024

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., we have begun developing a Beta-version track buckling model for deployment by U.S. Railroad Companies 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: both longitudinal and lateral track walk; rail neutral temperature (RNT); both lateral and longitudinal crosstie-aggregate interfacial friction; track modulus; nonlinear track liftoff; and broken spikes. In addition, it is sufficiently robust to be capable of accounting for additional environmental causes to be described herein and in a companion proposal. Given these advanced capabilities, track engineers will be able to dramatically improve track safety.

US DOT Priorities: This project aligns with the following USDOT strategic goals, as established in the USDOT Strategic Plan for FY2022-FY2026: **(a) Safety:** The project directly addresses a major safety concern, rail buckling. **(b) Economic Strength:** This tool will improve the accuracy and cost effectiveness of rail inspections and reduce the economic impacts of unplanned stoppages and derailments.

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

a. The validation of our developed advanced track buckling model.
b. The creation of a user-friendly track buckling predictive tool for use by on-site track engineers.
c. The experimental determination of track modulus and ballast-crosstie coefficients of friction for various track base constituents.

Outcomes/Impacts: The primary long-term impact of this project is improved rail safety and efficiency by providing railway engineers with accurate, user-friendly models enabling quantifiable decision making about track replacement.

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

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

Exhibit D

Research Project Requirement Template

Recipient/Grant (Contract) Number: University of Texas Rio Grande Valley (UTRGV), Texas A&M University (TAMU)/Grant No. 69A3552348340

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

Research Priority: Promoting Safety

Principal Investigator(s): Dr. David Allen (PI, TAMU), Dr. Yong-Rak Kim (Co-PI, TAMU)

Project Partners: MxV Rail

Research Project Funding: $175,927.31 (Federal), $88,058.15 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2023 to 08/31/2024

Project Description: It is well-known that one of the most significant causes of train derailments within the U.S. is 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 two-way coupled multiscale computational algorithm for predicting crack evolution in ductile solids subjected to long-term cyclic loading. In this UTCRS project, we will adapt this model to the prediction of crack growth in rails. Concomitantly, with funding provided by TTCI (Now MxV), we have for nearly a decade performed long-term laboratory cyclic crack growth experiments on rails. We possess the ability to both predict crack growth due to cyclic fatigue in rails and utilize our experimental results to validate our predictive methodology. It is therefore our intention to: (1) modify our multi-scale computational model to predict crack growth due to cyclic fatigue in rails; (2) validate our model against our own previously obtained experimental results; and (3) 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 enhancing rail safety.

US DOT Priorities: This project aligns with the following USDOT strategic goals, as established in the USDOT Strategic Plan for FY2022-FY2026: **(a) Safety:** The project directly addresses a major safety concern, rail fractures. **(b) Economic Strength:** The model produced will improve the accuracy and cost effectiveness of rail inspections and reduce the economic impacts of unplanned stoppages and derailments.

Outputs: Our research will result in the following at the end of a multi-year effort:

a. The modification of our computational multi-scale model for rail fracture.
b. The validation of our rail fracture model versus our previously obtained rail fracture experimental data.
c. The dissemination of our computational model for predicting rail fracture to the U.S. railway community.
d. An improved rail fracture model that is more user friendly.

Outcomes/Impacts: The primary long-term impact of this project is improved rail safety and efficiency by providing railway engineers with accurate, user-friendly models enabling quantifiable decision making about track replacement.

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

Autonomous Rail Surface Defect Detection

Exhibit D

Research Project Requirement Template

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

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

Research Priority: Promoting Safety

Principal Investigator(s): Dr. Yu Qian (PI, UofSC), Dr. Nikolaos Vitzilaios (Co-PI, UofSC)

Project Partners: N/A

Research Project Funding: $51,810 (Federal), $26,741 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2023 to 08/31/2024

Project Description: Rail surface defects are a major type of rail defect which progressively propagate with the accumulation of tonnage. It is reported that around 90% of railway accidents have rail surface defects, as either a direct or indirect factor. Historically, railway tracks are inspected by trained personnel. However, manual inspection has low efficiency and low accuracy because it is heavily dependent on the experience of the inspectors. Many automatic track inspection systems have been developed over time, usually mounted on an inspection car or a hi-rail vehicle with various types of sensors. Those systems are mainly based on laser, acoustic emission, LiDAR, ultrasonic wave, and ground penetration radar (GPR) technologies, which are effective in identifying rail internal defects, hollow timber ties, fouled ballast, and drainage problems. However, those systems have limited effectiveness in detecting and quantifying the rail surface defects. Visual inspection systems using the image processing algorithms and deep learning-based object detection methods have been introduced for the rail surface inspection over the past decade, which typically use images taken by cameras mounted on rail inspection vehicles. The models are usually developed based on images taken with a consistent angle and good contrast between the rail surface and the track. However, these approaches cannot handle arbitrary-oriented rail surface in images.

Recently, using UAV-based cameras has drawn great attention due to its convenience. More importantly, using UAVs to acquire rail surface images does not require track time and does not disturb normal train operations. The hardware cost is also much lower compared to the previous vehicle mounted systems. However, issues associated with consistency of image quality of track due to environmental and drone operations are the current barriers to taking full advantage of the UAV benefits. The objective of the proposed research is to develop an automatic rail surface defect detection system based on machine learning and convolution networks that is suitable for UAV implementation. This research addresses questions pertaining to the consistency and quality of images acquired by UAV-based cameras during flight and will focus on mitigating effects of: (i) vibrations and other operating/environmental conditions, (ii) variations of track width, location, and orientation, and (iii) shadows, rail reflectivity, and sunlight intensity. Furthermore, the proposed system will be integrated to the proposed Intelligent Aerial Drones for Traversability Assessment of Railroad Tracks project.

US DOT Priorities: This project aligns with the following USDOT strategic goals, as established in the USDOT Strategic Plan for FY2022-FY2026: **(a) Safety:** Enhanced rail inspection practices can improve rail operation safety and potentially reduce the incidence of train derailments and related accidents, ensuring safer travel for

both passengers and freight, which in turn boosts public confidence in rail transportation. **(b) Economic Strength:** Efficient track inspections can help detect maintenance needs earlier, thereby reducing costly repairs and minimizing service disruptions, leading to more reliable freight supply chains and passenger services.

Outputs: The expected products include:

a. A tailored image training library for future track inspection model development.
b. An Artificial Intelligence (AI) model that is customized to detect and quantify rail head surface defects from images taken by drones.
c. A prototype integrated edge computing system.
d. A report including performance validation results compared with other state-of-the-art models on rail head surface defect detection and quantification.
e. One or more conference or journal publications

Outcomes/Impacts: The broader impact of this project addressing the rail surface defect inspection challenge is multifaceted, significantly influencing public safety and economic efficiency. Enhanced rail inspection practices can improve rail operation safety and potentially reduce the incidence of train derailments and related accidents, ensuring safer travel for both passengers and freight, which in turn boosts public confidence in rail transportation. Economically, efficient track inspections can help detect maintenance needs earlier, thereby reducing costly repairs and minimizing service disruptions, leading to more reliable freight supply chains and passenger services.

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

Intelligent Aerial Drones for Traversability Assessment of Railroad Tracks

Exhibit D

Research Project Requirement Template

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

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

Research Priority: Promoting Safety

Principal Investigator(s): Dr. Nikolaos Vitzilaios (PI, UofSC), Dr. Dimitris Rizos (Co-PI, UofSC),

Project Partners: N/A

Research Project Funding: $59,153 (Federal), $30,684 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2023 to 08/31/2024

Project Description: Efficient railroad infrastructure monitoring and assessment is a critical issue for safe and sustainable operations. Apart from scheduled inspection and routine maintenance, there is a need for rapid assessment of the rail network after major events. For example, a storm can affect the traversability of a line (downed trees, rocks or flooding can block the line). Since it is impossible to continuously monitor the whole network before and after a major event, there is always the risk of an accident for a train crossing a blocked line, if the obstacle\damage ahead is realized too late. In this project, we aim to develop intelligent aerial drones capable of identifying and following railway lines, while assessing the traversability and providing an early warning whenever needed. The drone system can be carried and deployed by the locomotive, with the mission to fly ahead of the train within the railway right of way for a distance that is safe to provide this early warning (2-3 miles). The main characteristics of this system are: (i) Visual-based identification and autonomous following of the line; 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; and (iv) Identification and mapping of any obstacles blocking the rail line.

US DOT Priorities: This project aligns with the following USDOT strategic goals, as established in the USDOT Strategic Plan for FY2022-FY2026: **(a) Safety:** The developed drone-based traversability assessment system will make the transportation system safer for all people. The rapid assessment of track, especially after major events, will increase safety of operations and reduce serious accidents and fatalities that may be caused by obstacles on the track or damage induced by significant weather events. **(b) Economic Strength and Global Competitiveness:** This project aims to build a modern transportation system with economic strength and resilience in major events. A rapid assessment technology for targeted inspection of track will help minimize disruption and downtime of operations after a major event. This disruption may have significant economic effects considering the vast amount of rail network in the country and the financial loss accumulating over time if operations are not resumed due to delays in the inspection process. **(c) Transformation:** This project makes use of drone technology, building a system that addresses present challenges but also modernizes operations and builds the transportation system of the future. **(d) Organizational Excellence:** This project aims to provide the tools for an innovative inspection system that will improve the inspection process and strengthen rail organizational excellence.

Outputs: The overarching goal of this project is to develop an autonomous drone-based system able to track and follow railroad lines, identifying obstacles that affect the traversability. For this portion of the project (Phase 1), the expected results and products include:

a. A set of AI\ML algorithms able to identify track patterns in video images.
b. Demonstration of tracking a rail line on drone footage.
c. Demonstration of identifying obstacles on a rail line.
d. Footage from manual drone flights.
e. A list of the features that will need to be developed for the integration of the drone navigation systems, towards a fully autonomous operation.

Outcomes/Impacts: This project contributes to the development of modern drone-based inspection systems that will have the following key impacts in the railroad sector and beyond:

a. Improved Safety: By autonomously identifying obstacles on railroad tracks, drones can contribute to improving safety for trains, passengers, and railway workers. Obstacles such as fallen trees, debris, or unauthorized objects can pose serious risks if not detected promptly. Autonomous drones can provide real-time monitoring and alert railway operators about potential obstacles, enabling timely action to remove or mitigate the hazards.
b. Enhanced Efficiency: Autonomous drones equipped with obstacle detection capabilities can efficiently scan long stretches of railroad tracks and identify obstacles much faster than manual inspections. This increased efficiency enables quicker response times that minimize disruptions to train services.
c. Timely Maintenance and Repair: By detecting obstacles on railroad tracks, autonomous drones can aid in identifying areas that require maintenance or repair. Timely maintenance reduces the risk of accidents, ensures smooth train operations, and minimizes costly repairs that may arise from prolonged neglect.
d. Cost Savings: By automating the detection process, drones can perform regular inspections at scheduled intervals without requiring extensive human labor. This efficiency reduces the need for manual inspections and associated expenses, leading to potential cost savings in maintenance and workforce deployment.
e. Enhanced Asset Management: Autonomous drones can provide valuable data and insights that contribute to better asset management for rail infrastructure. By continuously monitoring and detecting obstacles, drones generate a wealth of data that can be analyzed to identify patterns, track trends, and optimize maintenance schedules. This data-driven approach enables more informed decision-making and improves resource allocation.
f. Technological Advancements: The development of autonomous drones for obstacle identification on railroad tracks fosters the advancement of obstacle detection algorithms, sensor technologies, and autonomous navigation systems. The knowledge gained from this use case can be transferred to other industries and applications, leading to broader innovations in robotics, automation, and transportation.

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

Rapid Detection of Track Changes from Onboard Data Acquisition Records

Exhibit D

Research Project Requirement Template

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

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

Research Priority: Promoting Safety

Principal Investigator(s): Dr. Dimitris Rizos (PI, UofSC), Dr. Yu Qian (Co-PI, UofSC)

Project Partners: N/A

Research Project Funding: $72,974 (Federal), $37,573 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2023 to 08/31/2024

Project Description: The objective of this research project is to develop a simple yet efficient track stiffness assessment system that can quickly estimate both the lateral and the vertical track stiffness and detect stiffness changes in space and time. The proposed system uses track geometry data and vehicle response data collected from instrumentation already onboard railroad inspection cars or locomotives (e.g. DOTX220, DOTX216). The acquired measurements are processed through the innovative Rapid Vehicle-Track Interaction (R-VTI) calculator developed by the PI to calculate the track stiffness while the vehicle is moving at its normal operation speed along the track. It is noted that the proposed system simply makes better use of existing data already being collected and does not require any additional instrumentation on the track. The proposed approach facilitates continuous track stiffness assessment along the network in space and time. In addition, it provides the real track stiffness values as vehicles move on top of the loaded track. The success of the proposed research will significantly improve railroad safety by effectively assessing the track stiffness and detecting stiffness changes from existing data being collected from the field without extra instrumentation burden to the railroads or the administration.

The proposed intelligent monitoring procedures apply to: (1) real-time monitoring and detection, (2) on-demand real-time monitoring of high-risk areas, and (3) accident investigation to identify possible contributing track conditions. These applications are facilitated by the fact that: (1) the vibration measurements are continuously acquired by onboard instrumentation, (2) R-VTI computes characteristic track responses (an indirect measure of track stiffness) that depend only on the track condition, and (3) the characteristic responses can be correlated to past responses for change detection.

US DOT Priorities: This project revolutionizes the current practice in vehicle-track interaction by solving the inverse problem to calculate the track dynamic stiffness and to detect changes over space and time, thus, addressing track infrastructure inspection for safer operations. It aligns directly with multiple USDOT strategic goals: **(a) Safety:** This project directly impacts safety of operations since it automates the quantification of the track stiffness and detects stiffness changes in real-time or near real-time for continuous track monitoring simultaneously with standard track geometry inspections, enabling performance-based maintenance that accounts for vulnerability, risk, and consequence. **(b) Economic Strength:** Service disruptions due to compromised track cause serious economic impact and loss of confidence in service reliability. Preventing track caused derailments minimizes the financial and societal impact, especially when hazmat is involved. **(c)**

Sustainability: The detection of factors that lead to track settlement and failures along the right of way enables predictive action for hazard mitigation, extending the life of track and structures. The proposed technology makes better use of the existing recourses and provides more useful information without the need for additional sensors and instrumentation on track, enabling performance-based maintenance. As a result, targeted maintenance operations that account for risk, vulnerability, and consequence lead to maximizing track life and minimizing the environmental impact. **(d) Transformation:** This project revolutionizes the current practice in vehicle-track interaction by solving the inverse problem to calculate the track dynamic stiffness and to detect changes over space and time. The proposed system can be integrated with existing automated track geometry inspection technologies without additional resources and becomes the backbone for developing performance-based maintenance practices.

Outputs: Specific outcomes stemming from this project's mission are centered around the need to improve the safety of track infrastructure and performance of track risk management, and will be captured in the following deliverables:

a. Report with technical details and documentation of the DSR of railcar and track parameters.
b. Journal or conference paper on the "Inverse Problem" algorithm and the extended R-VTI method.
c. Journal paper on track stiffness change detection method.
d. IP disclosure of the technology.

Outcomes/Impacts: This project aims to:
a. Revolutionize the current practice in vehicle-track interaction by solving the inverse problem to calculate the track dynamic stiffness and to detect changes over space and time.
b. Quantify the track stiffness directly based on the existing track geometry data, vehicle configurations, and vehicle dynamic responses data. The proposed technology makes better use of the existing recourses and provides more useful information without the need for additional sensors and instrumentation on track.
c. Automatically quantify the track stiffness and detect stiffness changes in real-time or near real-time for continuous track monitoring simultaneously with standard track geometry inspections.
d. Integrate with existing automated track geometry inspection technologies without additional resources.

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

Rail Anchor Slip Force Testing

Exhibit D

Research Project Requirement Template

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. Mustapha Rahmaninezhad (PI), Dr. Mohsen Amjadian (co-PI), Dr. Siang Zhou (co-PI), Dr. Arturo Fuentes (co-PI), Dr. Constantine Tarawneh (co-PI)

Project Partners: MxV Rail, BNSF

Research Project Funding: $114,814 (Federal), $71,316 (Non-Federal Cost Share)

Project Start and End Date: 09/01/2023 to 08/31/2024

Project Description: In recent decades, studies have focused on continuous welded rail (CWR) for its growing adoption as a replacement for jointed track. Key reasons include improved ride quality, increased rail and rolling stock fatigue life, and reduced track maintenance costs. However, the absence of joints introduces challenges such as thermal expansion-related track buckling in summer and tensile pull-apart failures in winter, often causing catastrophic derailments. Two significant safety-affecting failure modes are lateral stability loss (track buckling, shift, and radial breathing) and rail pull apart (rail break under high tensile forces). Buckled tracks in lateral and vertical planes can lead to vehicle derailments due to incompatibility with normal operating speeds. The lateral and longitudinal resistances play critical roles in ensuring the stability of a track and minimize the damage of the temperature stress in the rails. Several methods have been proposed to enhance both the lateral and longitudinal track resistances. These methods include (1) employing winged and framed ties, (2) modification on the shape of the tie bottom surface, (3) employing wider ties, and (4) using anchors. Installing rail anchors (clamps) between rails and ties can improve track stability by distributing the loads from rail into the ties, thereby improving longitudinal resistance. In this study, a series of full-scale railway track model tests will be conducted to examine the effect of rail anchors on the longitudinal resistance of tracks. Towards that goal, a series of full-scale model laboratory testing will be conducted to evaluate the longitudinal resistances of anchored rails with different anchor types, patterns, tightness, and conditions, and to investigate the life cycle of these rail anchors. A full-scale laboratory test setup will be designed and fabricated for this study. The acquired results will be used to identify conditions that can lead to a reduction in anchor slip resistance. This study will represent a preliminary step towards a comprehensive study on ballast bed anchored tracks.

US DOT Priorities: The proposed work in this project is aligned with three of the six USDOT strategic goals: **(a) Safety:** The project directly investigates a potential safety concern that has been identified by Class I railroads and MxV Rail engineers. **(b) Economic Strength:** Unscheduled stoppages and field repairs cause serious economic losses for rail companies and their customers, and other users of the track. **(c) Equity:** UTRGV is a minority serving institution with an established record of training students from underrepresented groups and placing them in professional positions in the transportation industry. This project will directly employ three undergraduate and one graduate student who will perform the experimental testing and data analysis. These students will also undergo professional training at MxV Rail facilities as part of them receiving relevant workforce development opportunities. **(d) Sustainability:** By characterizing the rail anchor slip forces, design enhancements

and field implementation of these anchors can be optimized which will extend the useful lifetime of rail track ties and mitigate the number of environmentally-significant derailments caused by rail buckling and rail pull apart failures.

Outputs: The expected products include:

a. Design and fabrication of a self-reacting loading system on a testing platform.
b. Rail anchor slip forces for several different rail anchor configurations and anchor types.
c. Final report documenting all the acquired results.
d. One or more conference or journal publications prepared by the students and PIs. At a minimum, an abstract and a manuscript of a paper will be submitted to the Geo-Congress 2025 and TRB 2025, respectively.

Outcomes/Impacts: The primary impact of the research is characterizing and quantifying the rail anchor slip forces for several simulated rail service conditions and whether removal and re-application of these rail anchors affects the slip resistance. 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 for proper use of rail anchors and optimized configurations as well as design optimizations or enhancements to increase slip resistance. **Educational Impact:** The project will be carried out by undergraduate and graduate students working under the supervision of the PIs. As a minority serving institution in a rapidly growing metropolitan area, we anticipate that most of the students will be from underrepresented groups, and that these 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 at least three undergraduates and one graduate 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.

Non-Contact Energy Harvesting for Rural Grade Crossings

Exhibit D

Research Project Requirement Template

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

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

Research Priority: Promoting Safety

Principal Investigator(s): Joseph Turner (PI, UNL), Carl Nelson (Co-PI, UNL), Mohsen Amjadian (Collaborator, UTRGV)

Project Partners: University of Texas Rio Grande Valley

Research Project Funding: $86,063 (Federal), $43,032 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2023 to 08/31/2024

Project Description: The network of U.S. 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 allow for the design of a non-contact power generation approach that is activated with each passing wheel. The goal will be to design and test multiple configurations in order to assess their potential for energy harvesting and to optimize them for grade crossing applications.

US DOT Priorities: This project aligns with the following USDOT strategic goals, as established in the USDOT Strategic Plan for FY2022-FY2026: **(a) Safety:** The project plans to address the safety of rural grade crossings which represent a large number of accidents. The ability to provide low-cost power near existing passive crossings would allow additional signaling to be added which will greatly enhance the visibility of the crossings to approaching vehicles. **(b) Economic Strength:** Accidents at rural grade crossings affect more than the economics of the railroads. The livability of rural populations is greatly impacted by safety issues and improvements to railroad crossings will provide a higher quality of life and stronger economies. **(c) Equity:** In the past decade, UNL has developed partnerships with minority serving institutions in order to grow the graduate enrollments of these groups. In particular, the UNL Mechanical and Materials Engineering Department has a cooperative PhD program with UTRGV which has enhanced underrepresented groups at UNL. This project will support one student who completed his MS degree at UTRGV to pursue his doctoral degree at UNL as part of expanding the pathways to doctoral studies for underrepresented Hispanic students.

Outputs: In the initial year of this project, expected results include:

a. Computational models will be developed to understand the impact of the various design choices on power generation,
b. Design implications for magnet arrays to modify the symmetry of the magnetic field will be quantified,

c. Laboratory experiments will be created for several of the designs,
d. Experimental data will be collected from the experiments to quantify the potential for maximum power generation, and
e. General concepts for implementation in the field will be initiated.

Relevant products would include conference presentations, reports, journal articles, and patent disclosures. We will strive for at least one presentation during the first year at the ASME-IEEE Joint Rail Conference in Spring 2024 or other related conferences.

Outcomes/Impacts: The long term outcome of this project will be improved safety at grade crossings that are currently passive. Availability of low-cost power at existing passive crossings will enable the addition of sensors and signaling. The project will also contribute to a diverse workforce in advanced rail safety technology, through the cooperative agreement with UTRGV.

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

Ultrasonic Inspection of Reconditioned Railroad Bearings

Exhibit D

Research Project Requirement Template

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

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

Research Priority: Promoting Safety

Principal Investigator(s): Jospeh Turner (PI, UNL), Constantine Tarawneh (Collaborator, UTRGV)

Project Partners: University of Texas Rio Grande Valley.

Research Project Funding: $60,741 (Federal), $26,442 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2023 to 08/31/2024

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 ECD. Thus, this project will exploit the relationship between ECD and ultrasonic scattering with respect to reconditioned bearings. Bearing components at several different usage states will be inspected with a goal to identify locations that may be more susceptible to early spalling. During later stages of this program, those parts will be tested using laboratory rolling contact fatigue tests for comparison with predictions.

US DOT Priorities: This project aligns with the following USDOT strategic goals, as established in the USDOT Strategic Plan for FY2022-FY2026: **(a) Safety:** The project impacts the structural performance of railroad bearings, which must maintain their integrity for overall rail safety. Bearings are major safety concerns such that enhanced inspection strategies are critical. **(b) Economic Strength:** Poor performing bearings may lead to slower train speeds, field repairs, and unnecessary stoppages that can affect profit margins for railroads and their customers. **(c) Equity:** In the past decade, UNL has developed partnerships with minority serving institutions in order to grow the graduate enrollments of these groups. In particular, the UNL Mechanical and Materials Engineering Department has a cooperative PhD program with UTRGV which has enhanced underrepresented groups at UNL. This project will support one student who completed their MS degree at UTRGV to pursue their doctoral degree at UNL. **(d) Sustainability:** The new inspection approaches to be developed will lead to longer life of bearings and higher performance metrics that will provide a more sustainable transportation footprint.

Outputs: In the initial year of this project, several results are expected. These include:

a. Laboratory ultrasonic experiments will be performed on bearing components at various stages of service life,

b. 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),
c. Statistical results will be explored with respect to identification of outliers and anomalies within each part and with respect to the ensemble of parts, and
d. Initial measurement protocols will be defined with respect to future research that will correlate outlier spatial positions with spall development.

Relevant products include conference presentations, reports, journal articles, and patent disclosures. Building on previous research, one conference presentation should be possible during the first year.

Outcomes/Impacts: This project will improve rail safety, efficiency, and sustainability by gaining insight into bearing defect mechanisms, and by developing improved inspection techniques. The project will also contribute to developing a diverse workforce with advanced knowledge in rail safety, through the cooperative doctoral program.

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

AI-Enabled Intelligent Vibration Sensor for Active Highway-Rail Grade Crossings

Exhibit D

Research Project Requirement Template

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: Rio Valley Switching Company

Research Project Funding: $51,836 (Federal), $34,866 (Non-Federal Cost Share)

Project Start and End Date: 09/01/2023 to 08/31/2024

Project Description: Highway-Rail Grade Crossings (HRGCs) have many safety challenges due to the potential collisions between oncoming trains and road users, including vehicles, bicycles, and pedestrians. The implementation of Positive Train Control (PTC) technology is regarded as a promising solution to reduce rail accidents. However, its effectiveness is hindered at HRGCs, especially in rural regions, where radio and GPS communication can be unreliable or lost (dark territory). To mitigate the risk of catastrophe, it is imperative for road users to detect trains early and maintain a safe distance allowing sufficient reaction time. This can be challenging especially in rural regions where it is difficult to supply enough power for advanced and heavy train detection sensors. This research seeks to develop an AI-enabled vibration sensing system capable of identifying and tracking approaching trains from a considerable distance upstream. This advancement enables road users to preemptively initiate responsive actions within a secure timeframe. The system's design is especially tailored for deployment in remote areas where there is limited access to electric power sources required for conventional vibration sensors.

US DOT Priorities: The proposed work in this project is aligned with three of the six USDOT strategic goals, which are listed hereafter: **(a) Safety:** By developing theoretical (analytical) and numerical models to assess the performance of vibration-based sensors for detection of trains from a considerable distance upstream and leveraging advanced signal processing and data analytic techniques to analyze the time series data. **(b) Equity:** By providing training opportunities to graduate and undergraduate students coming from underrepresented populations and diverse communities and equipping them with the necessary skills and knowledge for pursuing successful careers in the field of transportation. **(c) Transformation:** By developing translating developments from other engineering fields (e.g., computer and electrical) into vibration monitoring of railroad track system, conducting research to understand the needs and implications of smart sensing technologies in railroad engineering, and eventually transferring technology to stakeholders and industry partners.

Outputs: The expected products include:

a. Finite element model(s) of a rail-track system in OpenSEESPy package which is an interpreter for Open System for Earthquake Engineering Simulation in Python including the dynamic effects of ties, rail pads, and the ballast. [File Format: PY]

b. Field measurement data on the vibration response of a rail-track system next to a rail grade crossing in a rural zone in Texas [File Format: TXT and CSV]. This task will be accomplished by partnering with the Rio Valley Switching Company that oversees the rail track system in the Lower Rio Grande Valley.
c. Final report on the results of finite element modeling and numerical simulation of the rail-track system under the moving load and time-history data collected during field measurement.
d. One or more conference or journal publications prepared by the PIs and students involved in this project.

Outcomes/Impacts: The research results of this project will be used to develop a cost-effective AI-enabled vibration sensing system to identify and track approaching trains in highway-rail-grade-crossings (HRGCs) in rural areas from a considerable distance (>1 mile) upstream. This will eventually help to improve the safety of railway travel and reduce the risk of accidents. Additionally, this project aims to foster diversity and inclusion in STEM education by supporting students from underrepresented racial and ethnic groups at UTRGV. This will be accomplished by creating hands-on educational activities and materials for K-12 students during summer camps in UTCRS and taking advantage of senior design courses in the Civil Engineering and Mechanical Engineering departments to involve undergraduate students in different research tasks of the project. The objective is to train a diverse and skilled STEM workforce to contribute to the safety and sustainability of the U.S. rail network. Furthermore, this project promotes partnerships between academia and industry, and engagement with stakeholders and policy makers by organizing workshops, webinars, and publicly available publications to share the potential applications of the developed technology once a proof of concept has been demonstrated.

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 Bearings

Exhibit D

Research Project Requirement Template

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), Heinrich Foltz (Co-PI, UTRGV)

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

Research Project Funding: $88,899 (Federal), $38,962 (Non-Federal Cost Share)

Project Start and End Date: 09/01/2023 to 08/31/2024

Project Description: The performance of railroad bearings that sit idle in railyards, large industrial plants, or shipping ports has not been previously explored. Some of the bearings, with documented periods of inactivity exceeding 18 months, have been associated with major derailments. The aforementioned has led to concerns in whether the inactive periods contributed to early failure, possibly through degradation of the grease properties brought on by moisture intake or grease separation leading to uneven protection of the metal components. The proposed work, to be conducted in collaboration with CSX Transportation and in consultation with the National Transportation Safety Board (NTSB), aims to answer the question of whether long-term inactivity has significant effect on bearing performance and service life, and whether these are tied to changes in the lubricant.

The proposed work would consist of (a) identification of installed bearings on railcars that have not moved for periods of six months or longer, (b) removal of the bearings with minimum disruption to the lubricant, (c) pre-test inspection of the still-assembled bearings, (d) installation and service life testing on a laboratory test rig, with continuous performance monitoring of temperature rise, vibration spectra, and power consumption, (e) post-test inspection including disassembly, teardown, and visual inspection of all bearing components, and (f) analysis of the grease composition with specific focus on loss of oxidation inhibitors and evidence of lubricant separation.

US DOT Priorities: The proposed work in this project is aligned with four of the six USDOT strategic goals, which are listed hereafter: **(a) Safety:** The project directly investigates a potential safety concern that has been identified by NTSB. **(b) Economic Strength:** Unscheduled stoppages and field repairs cause serious economic losses for rail companies and their customers, and other users of the track. **(c) Equity:** UTRGV is a minority serving institution with an established record of training students from underrepresented groups and placing them in professional positions in the transportation industry. This project will directly employ two students, and indirectly support the employment of several others. **(d) Sustainability:** Identifying causes of early bearing failure will reduce the number of environmentally significant derailments.

Outputs: The expected products and deliverables will include:

a. Completed laboratory testing of bearings.

b. Documentation of all pre- and post-test mechanical measurements, including photographs.
c. Logs of temperature, vibration, and power data acquired throughout each test.
d. Results of TGA and DSC analysis of lubricants.
e. Final report with findings.
f. One or more conference or journal publications. At a minimum, we will submit a paper to the ASME Joint Rail Conference (JRC) at the first conference after results are available.

Outcomes/Impacts: The primary impact of the research is answering the question of whether long periods of inactivity have a significant impact on bearing 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 remaining bearing mileage. **Educational Impact:** The UTCRS portions of the project will be conducted by students working under the supervision of the PIs. As a minority serving institution in a rapidly growing metropolitan area, we anticipate that most of the students will be from underrepresented groups and that some fraction of them may have the chance to work with CSX engineers. The students will gain invaluable experience in operating bearing test equipment and in conducting tests according to AAR standards. We anticipate that at least six 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.

Next Generation On-Board Sensor Technologies for Rolling Stock

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

Exhibit D

Research Project Requirement Template

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), Ping Xu (Co-PI, UTRGV), Constantine Tarawneh (Co-PI, UTRGV)

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

Research Project Funding: $117,971 (Federal), $72,073 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2023 to 08/31/2024

Project Description: In prior work, UTCRS has developed on-board, wireless sensor technology that makes early and accurate detections of defect initiation in railcar bearings and wheels. This technology has been transferred to industrial partners for field trials, and in the first deployment detected a condemnable wheelset. For the current project, we will develop next generation sensors to enable (a) detection of a wider range of safety hazards, including damaged couplers, track defects, and load shifts, (b) even earlier predictions of failures, and (c) further reduction of false positives. The key to these advances will be coordinated sensors with precision synchronization at the level of tens of microseconds and relative position self-awareness at the centimeter level across an entire train, combined with an order of magnitude improvement in sensitivity. This will provide richer datasets that allow comparison of signatures from different bearings on the same bogie, different bogies on the same railcar, and different railcars on the same train.

The challenge is implementing these improvements within limitations on power consumption and communication bandwidth. In this 15-month project we will design, fabricate, and demonstrate new modules that add temporal and spatial awareness to existing vibration, load, and temperature sensing. Due to power consumption and spatial accuracy requirements, this cannot be readily accomplished with GPS or other commercial off-the-shelf (COTS) systems at the wheel level; instead, a dedicated on-board system must be developed. The data acquisition will also be improved based on lessons from past projects, with the goal of obtaining a ten-fold improvement in resolution and sensitivity.

US DOT Priorities: The proposed work in this project is aligned with four USDOT strategic goals: **(a) Safety:** The project directly addresses safety through earlier and more accurate detection of impending failures in bearings, wheels, and other railcar components. The improved system also has potential to detect track damage and railcar coupling impacts that exceed recommendations. **(b) Economic Strength:** Unscheduled stoppages and field repairs cause serious economic losses for rail companies and their customers, and other users of the track. Early prediction allows repairs to be deferred to scheduled maintenance periods that will not disrupt the rail transportation system. **(c) Equity:** UTRGV is a minority serving institution with an established record of training students from underrepresented groups and placing them in professional positions in the transportation industry. This project will directly employ two students, and indirectly support the employment of several others.

(d) Sustainability: By enabling proactive preventive maintenance, this project will extend the useful lifetime of rolling stock, and thus amortize the carbon footprint of manufacturing a railcar over a longer period. It will reduce the number of environmentally significant derailments. **(e) Transformation:** The extensive high resolution data streams generated by the next generation sensors will be a rich resource that can be mined for new insights beyond the currently envisioned application, using recent and future advances in machine learning.

Outputs: The expected products and deliverables will include:

a. A set of working hardware prototypes for next generation wireless sensors.
b. Design files for the prototypes including schematics, layout, assembly instructions, and bill of materials, in format compatible with open-source EDA tools.
c. A working integrated prototype for a data collection hub suitable for both laboratory and test railcar use. The laboratory/testbed version will be based on commercial modules.
d. Embedded software for the sensor prototypes, documented and archived, using only bare metal code and open-source libraries, in format compatible with free IDE tools.
e. Software for the data collection hub, documented and archived.
f. Sample raw and processed datasets from test runs on laboratory bearing testers, annotated with information on test conditions and bearing conditions. These datasets will be archived and available for potential collaborators upon request.
g. Preliminary machine learning methods with experiment results that demonstrate the success of automated data analysis.
h. Final report including any DoT or UTCRS required information.
i. One or more conference or journal publications. At a minimum we will submit to the Spring 2024 Joint Rail Conference (JRC) with intermediate results.

Outcomes/Impacts: The research itself, as well as the training of engineering students, will have impacts beyond the immediate usage of the sensors to avert accidents and enable proactive maintenance. **Research Activities:** As stated earlier, the next generation of sensors, when deployed in the field, will produce data about railcars and track of type and quality that have not been previously available. Both industry and academic professionals will be able to conduct their own investigations and use the data in ways the current PIs have not yet contemplated. Our previous generations of wired and wireless sensors each generated multiple independent projects and publications using the data produced. **Educational Activities:** As a minority serving institution in rapidly growing metropolitan area, we anticipate that most of the students will be from underrepresented groups and that a good fraction of them will contribute to industrial development in the region. The project budget itself supports two students who will gain experience in developing rail-specific electronics and software, as well as bearing test equipment. The sensor platform will also enable several other students to be trained in the use of the system and its data for independent research projects on mechanical, thermal, and operational aspects of railcar and track performance. We anticipate that at least eight students will participate directly and indirectly 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.

Development of a National Track Safety Database

Exhibit D

Research Project Requirement Template

Recipient/Grant (Contract) Number: University of Texas Rio Grande Valley (UTRGV), Texas A&M University (TAMU)/Grant No. 69A3552348340

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

Research Priority: Promoting Safety

Principal Investigator(s): Dr. David Allen (PI, TAMU)

Project Partners: FRA, AAR, MxV Rail, and Class I Railroads

Research Project Funding: $135,142.50 (Federal), $68,336.75 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2023 to 08/31/2024

Project Description: This project supports our companion proposals to develop track safety models for both rail buckling and railhead cracking. While these two failure modes are not the most commonplace causes of train derailments according to the FRA, when derailments due to one of these causes occur, they tend to be both catastrophic and costly to the nation. It is, therefore, advisable to append to our models sufficient information for track engineers to be able to make timely and cost-effective decisions regarding track worthiness as it relates to these two failure modes.

Our track buckling and railhead cracking models are quite advanced mechanics-based models that account for track geometry, long-term cyclic loading, and local environmental conditions. Furthermore, our models indicate that these factors strongly affect track worthiness. As a typical example, a particular section of track is much more likely to buckle in summer than winter because the local track temperature in summer is usually significantly higher than RNT (Rail Neutral Temperature) in hot sunny climates. These local factors then strongly influence the probability of track failures due to rail buckling and railhead cracking.

It is, therefore, necessary for track engineers in the field to have easy and direct access to the necessary inputs to our models in order to assess local track worthiness when they encounter track sections wherein the likelihood of track failure is suspected. Because such information is not readily available to track engineers at this time, it is currently not possible for track engineers to make scientifically quantifiable decisions during track inspections regarding the necessity to perform track remediation and/or replacement. To that end, we propose to develop a National Track Safety Database (NTSD) for use by railway engineers as a means of deploying our track buckling and railhead cracking models on-the-fly, thereby, utilizing the latest technology to better assess track worthiness. Such technology would not only improve track safety, it would also provide a technologically-based tool capable of increasing cost effectiveness within the railway transportation industry.

US DOT Priorities: This project aligns with the following USDOT strategic goals, as established in the USDOT Strategic Plan for FY2022-FY2026: **(a) Safety:** The project directly addresses two major safety concerns, rail buckling and rail cracking. **(b) Economic Strength:** This tool will improve the cost effectiveness of rail inspections and reduce the economic impacts of unplanned stoppages and derailments. **(c) Transformation:** This project addresses the DOT goal of new projects applying novel data approaches to transportation problems, in particular the DOT's "transformative vision of a fully connected, integrated, accessible, and interoperative multimodal

system of systems".

Outputs: As a five-year objective for the NTSD, we hope to have a functional database in place that is accurate and effective for use by railway engineers. However, our goals for Year 1 of this project are more limited:

a. Based on our interactions with the agencies and companies listed as our project partners, an understanding of the exact nature and format of the NTSD.
b. The creation of a Beta-version of the NTSD.
c. Proof of concept of the NTSD via direct simulations of our track buckling and railhead cracking models with data supplied directly to them by the NTSD.

Outcomes/Impacts: The primary long-term impact of this project is improved rail safety and efficiency by providing railway engineers easy and direct access to data and models enabling quantifiable decision making.

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

Mining and Learning from Railway Safety Data with Graphs and Tensors

Exhibit D

Research Project Requirement Template

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

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

Research Priority: Promoting Safety

Principal Investigator(s): Dr. Jia Chen (PI, UCR), Dr. Evangelos Papalexakis (Co-PI, UCR)

Project Partners: University of Nebraska Lincoln (UNL), University of South Carolina (UofSC), University of Texas Rio Grande Valley (UTRGV).

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

Project Start and End Date: 06/01/2023 to 08/31/2024

Project Description: Railway systems are very complex pieces of cyberinfrastructure, interfacing with a number of transportation agents and other pieces of cyberinfrastructure. For instance, a railway crossing includes interactions between the railway system and a traffic intersection. Such a rich ecosystem of interactions among heterogeneous agents poses fascinating research challenges in modeling railway systems with data and conducting data-driven railway crossing safety assessment. In this project, we propose to leverage and extend powerful tensor and graph mining methods which can extract "needles in the haystack" within the abundance of collected data and produce actionable insights to stakeholders in order to better understand emerging accident patterns from historical data, identify underlying similarities in such patterns, towards ultimately reducing the number of accidents.

US DOT Priorities: This project aligns with the following USDOT strategic goals, as established in the USDOT Strategic Plan for FY2022-FY2026: **(a) Safety:** The project directly addresses a major safety concern, railroad grade crossings, which has been identified by the USDOT and the FRA as a major safety concern. **(b) Economic Strength:** Rail accidents cause major economic losses each year, which can eventually be reduced through adoption of the systems developed in this project. **(c) Transformation:** This project addresses the DOT goal of new projects applying novel data approaches based on artificial intelligence to transportation problems. It perfectly dovetails with USDOT's "transformative vision of a fully connected, integrated, accessible, and interoperative multimodal system of systems" as it seeks to represent data about railroad accidents, an inherently complex interconnected system of systems using graph mining and learning methods. This project aims to make public railroad accident data accessible to human analysts by extracting actionable insights and "needles in the haystack" from large amounts of interconnected multimodal railroad data. The project aligns perfectly with main USDOT objectives for "a fully connected, integrated, accessible, and interoperative multimodal system of systems" which "provides for a critical multimodal transportation knowledge base outside of the USDOT".

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

a. Research publications, targeted to top-tier data science, machine learning, and artificial intelligence venues.

b. 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 methods developed in this project have wide applicability beyond the immediate problem being analyzed and will contribute to the artificial intelligence and machine learning research community as well as the rail industry. It is expected that the results will inform decision making in rail operations and rail policy.

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

Pedestrian and Bicyclist Safety at Highway-Rail Grade Crossings (HRGCs)

Exhibit D

Research Project Requirement Template

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

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

Research Priority: Promoting Safety

Principal Investigator(s): Aemal Khattak (PI), M. Naveed Aman (Co-PI), and M. Umer Farooq (Co-PI)

Project Partners: University of California Riverside (UCR), University of South Carolina (UofSC), University of Texas Rio Grande Valley (UTRGV).

Research Project Funding: $150,000 (Federal), $75,000 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2023 to 08/31/2024

Project Description: Train crashes involving non-motorized pedestrians and bicyclists often receive little attention; nevertheless, they contribute significantly to the overall fatalities and injuries in incidents connected to railways. According to preliminary FRA statistics, 1,197 pedestrian-rail trespass casualties (fatalities and injuries) were recorded in 2022.

Currently, there is a lack of exposure data on pedestrians and bicyclists at Highway-Rail Grade Crossings (HRGCs), which prevents us from understanding the factors associated with high or low exposure of pedestrians and bicyclists at HRGCs. These exposure data are crucial because incorporating pedestrian and bicyclist related dynamic components into predictive modeling can enhance the precision of HRGCs crash frequency and severity prediction models. Ultimately, this improvement can lead to better decision-making on resource allocation and safety of HRGCs.

This study aims to develop a methodology for collecting pedestrian and bicyclist exposure data at urban and suburban HRGCs using video-based data collection devices to capture pedestrian and bicyclist volumes. Based on this data, we aim to create volume-prediction models that can predict pedestrian and bicyclist crash exposure at HRGCs.

US DOT Priorities: This project aligns with the following USDOT strategic goals, as established in the USDOT Strategic Plan for FY2022-FY2026: **(a) Safety:** 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. **(b) Economic Strength:** The project contributes to economic strength by reducing crashes at highway-rail crossings, which contribute to delays on both the rail and highway networks resulting in lost productivity. **(c) Sustainability:** This research will result in a more sustainable transportation network by making the rail and highway networks more resilient.

Outputs: The research team will produce new volume-prediction models for pedestrians and bicyclists at HRGCs. The research will provide guidance on improving the safety of pedestrians and bicyclists across the US. Specific products will include:

a. database on exposure of pedestrians and bicyclists,
b. statistical models on prediction of pedestrian and bicyclist volumes,
c. future research recommendations, and
d. the project final report.

Outcomes/Impacts: The proposed research is transformational in nature and its broader impacts include the potential for development of new models on prediction of pedestrian and bicyclist crash exposure at HRGCs. This will help enhance understanding of the safety hazards linked with HRGCs. Such an examination takes into account not just various traffic and train dynamic elements, but also the vulnerability of pedestrians and bicyclists. Ultimately, the research findings will empower transportation agencies to adopt proactive safety measures and reduce the occurrence of crashes, promoting the well-being of non-motorists at HRGCs.

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

Satellite Radar Data Analysis for Change Detection of Rural and Urban Railways

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

Exhibit D

Research Project Requirement Template

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

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

Research Priority: Promoting Safety

Principal Investigator(s): Dr. Dimitris Rizos (PI, UofSC), Dr. Michael Sutton (Co-PI, UofSC)

Project Partners: University of Nebraska-Lincoln (UNL), University of California Riverside (UCR), University of Texas Rio Grande Valley (UTRGV).

Research Project Funding: $54,542 (Federal), $27,729 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2023 to 08/31/2024

Project Description: Changes in vertical and horizontal alignment of railways impact service continuity, efficacy and safety of operations and may lead to cascading failures if they go undetected. Conventional methods (e.g. GPS, surveying, dedicated inspection and measurement vehicles) are expensive, disrupt operations, do not provide network-wide monitoring and, typically do not monitor the rate of change over time and, thus, are not predictive by themselves.

We propose to implement satellite radar image processing techniques for the intelligent monitoring of railway right of way and enable the change detection at critical areas, such as bridge approaches, grade crossings, or other areas with a history of geotechnical failures along the track. A web-based application will be developed for data management and visualization. The proposed approach employs Differential Interferometric Synthetic Aperture Radar (DInSAR), Persistent Scatterer Interferometric Synthetic Aperture Radar (PS-InSAR), and Coherence Change Detection (CCD) methodologies in radar signal processing. The proposed technology applies to (1) network-wide real-time monitoring and detection, (2) on-demand real-time monitoring of high-risk areas, and (3) accident investigation. The proposed work leverages on the findings and experience gained in current studies at UofSC that developed and demonstrated the process in detecting moisture changes in the railway track and slopes and measuring small- and large-scale deformations in millimeter resolution.

US DOT Priorities: This project aligns with four USDOT strategic goals: **(a) Safety:** Deployment of such system as part of railway monitoring improves rail safety since the detection of development of track settlement and movement in a timely manner facilitates the mitigation of the hazard risk. **(b) Economic Strength:** Service disruptions due to compromised track cause serious economic impact and loss of confidence in service reliability. Preventing track caused derailments minimizes the cost of derailments, especially when hazmat is involved. **(c) Sustainability:** The detection of factors that lead to track settlement and failures along the right of way enables predictive action for hazard mitigation, extending the life of track and structures. **(d) Transformation:** The ability to integrate data produced by our technology with information acquired by other track sensing technologies provides both comprehensive understanding and also detailed records of the state of the track over time based on more consistent, accurate, and useful information than that provided by any individual data source.

Outputs: The expected products will include:

a. The procedure for processing satellite radar images for active and/or historic monitoring of track movement over time.
b. The procedure for track change detection.
c. A prototype web-based application for data and results repository, as well as browsing and querying of data and results.
d. One or more conference or journal publications.

Outcomes/Impacts: The products of the proposed work apply to: (1) network-wide real-time monitoring and detection, (2) on-demand real-time monitoring of high-risk areas, and (3) accident investigation to identify possible contributing track condition changes. Deployment of such system as part of railway monitoring improves rail safety since the detection of development of track settlement and movement in a timely manner facilitates the mitigation of the hazard risk. In addition, the ability to integrate data produced by our technology with information acquired by other track sensing technologies provides both comprehensive understanding and detailed records of the state of the track over time based on more consistent, accurate, and useful information than that provided by any individual data source.

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

Track Intrusion Detection and Track Integrity Evaluation

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

Exhibit D

Research Project Requirement Template

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

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

Research Priority: Promoting Safety

Principal Investigator(s): Dr. Yu Qian (PI, UofSC), Dr. Dimitris Rizos (Co-PI, UofSC), Dr. Nikolaos Vitzilaios (Co-PI, UofSC)

Project Partners: N/A

Research Project Funding: $51,810 (Federal), $26,741 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2023 to 08/31/2024

Project Description: Other than train collisions, track intrusion (also referred to as track fouling) is a major factor causing railroad accidents, especially at the railroad-highway crossings. According to the Report to Congress "National Strategy to Prevent Trespassing on Railroad Property" issued by the Federal Railroad Administration, trespassing is currently the number one cause of all railroad-related deaths. The number of fatalities due to trespassing, including both illegally entering and remaining in the railroad right-of-way is even higher than the number of fatalities due to collision between vehicles and trains. The impact of loss of lives, but also the financial and societal impact associated with those accidents, is enormous. The FRA report indicated that the accidents during 2012 to 2016 have cost $43 billion to our nation. Unfortunately, at present, there is no dedicated system to tackle the issues associated with trespassing or other anomalous situations (e.g., suicide) and enhance railroad safety. Current track intrusion detection relies on high-rail inspection which is labor-intensive and requires significant track time. Clearly, there is an urgent need to develop practical solutions to identify track intrusion and mitigate risks of potential accidents. Railroad crossings are the locations where most of the trespassing has taken place, and almost three quarters of all trespassing events were located within 1000 feet of a crossing. This is largely due to the fact that pedestrians and vehicles alike cross the track through grade crossings. Therefore, it is a higher priority to address trespassing within the grade crossing area. However, it should be noted that the proposed effort is also generally applicable to broader areas along the track that are far away from the crossings. With the development of UAVs, including autonomous UAVs, it is possible to develop an autonomous track intrusion detection and track integrity evaluation system to identify any track fouling conditions ahead of collision and share critical information to both railroads and local first responders in time to minimize loss due to a potential impact. The system will integrate a surveillance unit, real-time communication unit, and computer vision and deep-learning artificial intelligence (AI) unit on an edge computing platform. Furthermore, the proposed system will be integrated to the proposed Intelligent Aerial Drones for Traversability Assessment of Railroad Tracks project. The success of this research will significantly enhance situational awareness at grade crossings or other installation locations, mitigate train collision risk, reduce local law enforcement workload, improve quality of life, and benefit all the stakeholders in industry, railroads, and local, state, and federal administration and legislation.

US DOT Priorities: This project implements robust measures to mitigate trespassing and track intrusion at railroad crossings that yield significant benefits across public safety, economic performance, and environmental sustainability. It aligns with two USDOT strategic goals: **(a) Safety:** By actively monitoring railroad crossings and

nearby track segments, we can potentially reduce related accidents and fatalities, bolstering public confidence in rail transportation. **(b) Economic Strength:** 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.

Outputs: The expected products include:

a. A tailored image training library for future track intrusion or track integrity detection model development.
b. 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.
c. A prototype integrated hardware system for edge computing.
d. A report including performance validation results compared with other state-of-the-art models on track intrusion detection.
e. One or more conference or journal publications.

Outcomes/Impacts: The broader impact of this project is implementing robust measures to mitigate trespassing and track intrusion at railroad crossings that 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.

Grade Crossing Monitoring Using Deep Learning

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

Exhibit D

Research Project Requirement Template

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. Gasser Ali (PI) and Dr. Constantine Tarawneh (Co-PI)

Project Partners: University of Nebraska Lincoln (UNL), University of California-Riverside (UCR), University of South Carolina (UofSC)

Research Project Funding: $43,685 (Federal), $21,763 (Non-Federal Cost Share)

Project Start and End Date: 09/01/2023 to 08/31/2024

Project Description: Railway crossings are critical elements of railway safety due to the heightened risk of train collisions. The USDOT's National Highway Traffic Safety Administration (NHTSA) reported more than 1,600 collisions between vehicles and trains in 2021, and 500 collisions at transit rail crossings in 2020. Transportation agencies and researchers are continuously working to enhance safety at railway crossings with better operating procedures and equipment to avoid accidents. Many innovative methods have been proposed to detect hazards at crossings and rail tracks using technologies such as sensors, computer vision, depth cameras, and many others. However, there is still a need to develop a holistic approach that is robust and generalizable to the many conditions and hazards related to grade crossing accidents. This project aims to investigate Artificial Intelligence (AI) and Deep Learning (DL) models to monitor grade crossings and detect various hazardous conditions such as vehicles, pedestrians, cyclists, animals, warning lights, arm positions, and others. There is a need for generalizable AI models that can be applied at different grade crossings and monitor the various conditions associated with accidents and near-miss events. To achieve that, the proposed methodology consists of (1) collecting visual data of railway crossings; (2) labeling the data for training; and (3) developing a computer vision model using deep learning that can detect hazardous conditions at railway crossings. Ultimately, the outcomes of this research support improving safety at crossings, modernizing unsafe crossings, optimizing traffic in crossings, and data sharing for research with UTCRS partners.

US DOT Priorities: The proposed work in this project is aligned with four of the six USDOT strategic goals: **(a) Safety:** The project directly investigates a potential safety concern that has been identified by the National Transportation Safety Board (NTSB). **(b) Equity:** This project is especially applicable to urban neighborhoods where there is high pedestrian activity close to tracks. It will be carried out at UTRGV, a minority serving institution with an established record of training students from underrepresented groups and placing them in professional positions in the transportation industry. This project will directly employ one student, and indirectly support the employment of others. **(c) Sustainability:** The deep learning approach used here relies on low-cost sensors (video cameras) that are already widely deployed. Extensive new infrastructure is not required. **(d) Transformation:** The project will enable and facilitate future research by producing a large collection of sorted and annotated videos of grade crossing scenarios.

Outputs: The expected results and products include:

a. Code for training and deploying deep neural networks to detect hazards at railroad crossings.
b. Dataset of labeled images of railroad crossing hazards for further research with UTCRS participants and grade crossing research subgroup.
c. Final report of all the above results and products.
d. One or more conference or journal publications co-authored with students.

Outcomes/Impacts: The proposed research project has potential for addressing societal challenges by advancing scientific knowledge and fostering tangible educational improvements in safety of the U.S. rail network. **Research Activities:** The results of this project will be used to develop deep learning models to predict potential hazards at grade crossings. This will eventually help to improve and reduce the risk of accidents. **Educational Activities:** This project will help to train a diverse and skilled workforce with direct experience in rail applications of the latest generation technology.

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