Advanced Model for Predicting Buckling in Rails

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))

Project Partners: MxV Rail and BNSF

Research Project Funding: $179,514 (Federal), $87,028 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2024 to 08/31/2025

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: 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 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 research aligns with the following U.S. DoT goals: safety, economic strength and global competitiveness, climate and sustainability, and transformation.

Outputs: The expected products include:

1. Further predictions of the effects of longitudinal and lateral 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.
3. The development of a Beta version of our buckling model applicable to track on curves.
4. Dissemination of our results via conference presentations, workshops, conference articles, and journal articles, as well as meetings with BNSF and MxV Rail.

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

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 Dr. Yong-Rak Kim (Co-PI, TAMU)

Project Partners: MxV Rail

Research Project Funding: $199,426 (Federal), $100,313 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2024 to 05/31/2025

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 part of the UTCRS 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. We have therefore begun the following rather challenging task of: 1) modifying 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.

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

Outputs: The expected products include:

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 proposal).
3. The validation of our rail fracture model versus our previously obtained rail fracture experimental data.
4. The dissemination of our computational model for predicting rail fracture to MxV Rail.

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.

Continuously Welded Rail Longitudinal Resistance Modeling

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): Siang Zhou (PI, UTRGV) and Constantine Tarawneh (co-PI, UTRGV)

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

Research Project Funding: $54,278 (Federal), $22,603 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2024 to 05/31/2025

Project Description: Continuously welded rail (CWR) is standard in North American freight railroads despite the common concerns for rail buckling and rail breaks. Rail longitudinal resistance is an important parameter for proper re-establishment of rail neutral temperature (RNT) after rail breaks and reducing longitudinal rail movement under external vertical and longitudinal loads. Existing rail longitudinal resistance values are based on limited rail cut field testing and are not applicable when it comes to special track conditions, such as near fixed assets, and have not been used to evaluate rail movement without a break. In collaboration with MxV Rail engineers who are consulting on this work, the proposed research aims to develop efficient 2D and 3D finite element (FE) rail longitudinal resistance models based on experimental studies and historical data, which can be implemented considering the effect of frozen ballast, frozen structures, vehicle forces, and maintenance disturbance. The FE models will be carried out in ABAQUS, and will consider various rail sizes, multiple material and geometric tie properties, and three critical forms of interactions: rail-to-tie friction, anchor slipping force, and tie-to-ballast restraint. These force-displacement interactions are nonlinear and are represented using springs, with stiffnesses determined based on experimental studies (for anchor slipping force) and historical data (for rail-sleeper friction and sleeper-ballast restraint). The development of FE rail longitudinal resistance models that consider efficient representation of rail-to-tie and tie-to-ballast interactions can have multiple practical applications, including: 1) provide improved RNT re-establishment guidance under special track conditions and 2) evaluate changes in RNT from vehicle and maintenance-induced longitudinal rail movement.

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 and lack of standard practice that has been identified by 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 one graduate student who will perform model development and data analysis as part of the student's thesis research. The proposed project also needs laboratory testing, which will be led by the graduate student and assisted by one undergraduate student. These students will also undergo professional training at MxV Rail facilities as part of them receiving relevant workforce development opportunities. **(d) Sustainability:** By proposing approaches to evaluate CWR longitudinal resistance, improved strategies to re-establish RNT after rail break (considering special rail conditions) and enhanced methods to evaluate change in RNT under external longitudinal and vertical loads will be available to practitioners, which will facilitate CWR maintenance and retrofit, extend the useful lifetime of CWR, and mitigate the number of environmentally-significant derailments caused by rail buckling and rail pull apart failures.

Outputs: The expected products include:

1. Rail longitudinal resistance evaluation charts considering various rail designs, special rail conditions, and external longitudinal and vertical loading conditions.
2. User-friendly 3D FE models that can be quickly deployed by railway engineers.
3. Dissemination of the proposed project will take form in the following ways: (a) final report documenting research procedures and results, (b) journal publications with peer-reviews to strengthen credibility of the work, (c) conference presentations (e.g. ASME Joint Rail Conference 2025 and Transportation Research Board Annual Meeting 2025) to help the research reach a larger audience, and (d) a Master's thesis documenting details of the proposed project.

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 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. 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 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.

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)), Dr. Yong-Rak Kim (Co-PI, TAMU), and Mr. Garrett Dorsett (Co-PI, TAMU)

Project Partners: MxV Rail

Research Project Funding: $50,026 (Federal), $25,206 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2024 to 05/31/2025

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. In this part of the UTCRS we will perform intricate experiments on rails with internal cracks as a means of both obtaining material properties and validating an advanced computational model under development in our companion proposal entitled Computational Model for Predicting Fracture in Rails Subjected to Long-Term Cyclic Fatigue Loading. Furthermore, with funding provided by MxV, we have recently completed cyclic crack growth experiments on seven bi-axially loaded rails with internal cracks that had previously been in service. We are therefore in this research 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. Should this model development prove to be useful, it is our ultimate intention to utilize this new advanced technology as a tool for determining how long rails in which 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, climate and sustainability, and transformation.

Outputs: The expected products include:

1. Development of a new advanced testing 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 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.
4. The dissemination of our computational model for predicting rail fracture to the U.S. railway community via our research relationship with MxV Rail.

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.

Experimental Determination of Track Friction Coefficients

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. Roger Cordes (PI, Texas A&M University (TAMU)) and Dr. David H. Allen (Co-PI, TAMU)

Project Partners: Siang Zhou (Collaborator, UTRGV), Mustapha Rahmaninezhad (Collaborator, UTRGV), Constantine Tarawneh (Collaborator, UTRGV); Industry Collaborators: BNSF (Class I Railroad), MxV Rail (Rail Testing Facility)

Research Project Funding: $55,946 (Federal), $28,656 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2024 to 08/31/2025

Project Description: It is well-known that aging track structure is one commonplace causal factor in train derailments. Furthermore, track buckling is observed to be more likely in older track. As described in our companion proposal, we are developing a computational track buckling model for deployment by U.S. Railroad Companies as a tool for predicting track buckling.

Over the course of the previous year, we have focused much of our attention on predicting the effects of both longitudinal and lateral crosstie-aggregate interfacial friction on rail buckling. We have shown that our model is capable of performing these friction-dependent predictions, but these predictions were made based on a very limited set of experimentally determined friction values. We therefore propose to set about the task of determining these complex material properties for a wide range of track structural materials. Obtaining these properties will then allow us to refine our predictive capabilities considerably.

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

Outputs: The expected products include:

1. The development of an experimental testbed for determining track structure coefficients of friction required in our buckling model.
2. The validation of accuracy of our friction testbed.
3. The ability to deploy these experimentally determined properties in our track buckling model (described in a companion UTCRS project titled *Advanced Model for Predicting Bucking in Rails*).
4. Dissemination of our results via conference presentations, workshops, conference articles, and journal articles, as well as meetings with BNSF and MxV Rail.

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.

Temperature 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, UTRGV), and Arturo Fuentes (co-PI, UTRGV)

Project Partners: Stephen Wilk (Collaborator, MxV Rail), Ryan Medlin and Charity Duran (Collaborators, BNSF)

Research Project Funding: $65,842 (Federal), $62,077 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2024 to 08/31/2025

Project Description: In contemporary railway infrastructure, continuous welded rail (CWR) has gained prominence due to its numerous benefits over jointed track, including enhanced ride quality, prolonged rail and rolling stock lifespan, and reduced maintenance costs. However, the absence of joints presents challenges such as thermal expansion-induced track buckling. The Rail Neutral Temperature (RNT), the temperature at which the rail experiences zero stress, is crucial for managing compressive rail stresses, especially during hot weather conditions. Rail anchors play a pivotal role in maintaining track stability and managing RNT by resisting excessive longitudinal rail movement. Despite their significance, there remains a need to comprehensively understand their behavior under varying temperature conditions.

This study aims to investigate the influence of temperature on the slip force of anchored rails with different steel anchor types. Through a series of full-scale laboratory tests, we will evaluate the slip force under varying temperature regimes, considering different anchor types, tightness levels, and environmental conditions. The test setup to be used for this research will allow for precise control and measurement of temperature variables.

This study represents a significant step towards enhancing our understanding of the interaction between temperature and rail anchor performance, ultimately contributing to the advancement of railway infrastructure resilience and reliability. Additionally, this research will provide insights into how temperature fluctuations affect the effectiveness of rail anchors in preventing longitudinal rail movement. By understanding the temperature-dependent behavior of rail anchors, railway engineers can develop strategies to optimize track stability and mitigate the risk of buckling-induced disruptions.

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 safety concern highlighted by Class I railroads and MxV Rail and BNSF engineers, focusing on the influence of temperature on the slip force of anchored rails with various steel anchor types. **(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 one graduate and two undergraduate students who will perform experimental testing and data analysis. These students will also undergo professional training at MxV Rail and/or BNSF facilities as part of them receiving relevant workforce development opportunities. **(d) Sustainability:** By understanding the temperature-dependent behavior of rail anchors and their slip forces, optimizing the design and field implementation of these anchors can extend the lifespan of rail track ties. This optimization reduces environmentally significant derailments caused by rail buckling and rail pull-apart failures.

Outputs: The expected products include:

1. Completed modification of the self-reacting loading system on a testing platform.
2. Rail anchors slip force measurements for several different rail anchor types at varying temperatures.
3. Final report documenting all the acquired results.
4. 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 and temperature conditions. 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 under different environmental temperatures that can help 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, who will also conduct a workshop for UTRGV College of Engineering and Computer Science students. 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 time during the summer at BNSF or 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 and guidelines. 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.

Rapid Detection of Track Changes from Onboard Data Acquisition Records: 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): Dimitris Rizos (PI, University of South Carolina (USC)) and Yu Qian (Co-PI, USC)

Project Partners: N/A

Research Project Funding: $64,628 (Federal), $31,282 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2024 to 08/31/2025

Project Description: Spurred by the findings of the current effort, the objective of this research project is to continue with the development of the simple yet efficient track stiffness assessment system, proposed in Year 1. The proposed system 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. Furthermore, it integrates the novel technique developed in Year 1 that is based on the frequency shift curve (FSC) framework to identify stiffness changes in the track, including loose or missing fasteners, damaged ballast, broken sleepers, etc. This method leverages the complementary strengths of wavelet packet analysis and the Hilbert-Huang transform for signal processing.

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 proposed technology applies 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. It is noted that the proposed system simply makes better use of existing data already being collected and does not require any additional instrumentation in the track.

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 addressing, thus, track infrastructure inspection for safer operations. It aligns directly with five 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:

1. IP (Intellectual Property) disclosure of the technology.
2. A minimum of one journal paper and one conference paper on the development and implementation of proposed technology.

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

1. Revolutionizing 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.
2. Quantifying 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 of additional sensors and instrumentation on track.
3. Automatically quantifying the track stiffness and detecting stiffness changes in real-time or near real-time for continuous track monitoring simultaneously with standard track geometry inspections.
4. Integrating the proposed system 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.

Development of a Multi-Resonant Impact-Driven Energy Harvester (MRI-DEH) for Electrification of Rural Rail Crossings

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): Mohsen Amjadian (PI, UTRGV) and Constantine Tarawneh (Co-PI, UTRGV)

Project Partners: Joseph Turner (Collaborator, University of Nebraska-Lincoln (UNL)) and Carl Nelson (Collaborator, UNL)

Research Project Funding: $48,634 (Federal), $32,534 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2024 to 05/31/2025

Project Description: This research proposal aims to address the critical need for enhancing safety at rural rail crossings where reliable power sources are often lacking. Building upon previous work of the PIs, where low-power vibration sensors were explored for detecting trains upstream in rural areas using deep learning-based time series prediction algorithms, this project focuses on designing, analyzing, and testing a Multi-Resonant Impact-Driven Energy Harvester (MRI-DEH) by incorporating an impact-driven mechanism for electrification of rural rail crossings. This innovative approach seeks to enhance electromechanical coupling by integrating multiple resonators, each tuned to a specific local excitation frequency of rail-track vibration, and to broaden the device's resonance frequency band by leveraging impact effects. The proposed tasks include analytical modeling with closed-form solutions for a parametric study, numerical simulations, and both laboratory and field testing. The optimization of the energy harvester's design will involve conducting a parametric study on key parameters to maximize the generated electrical power. These parameters include the geometrical dimensions and pole orientations of permanent magnets, dimensions of copper coils, their distances from the outer surfaces of the permanent magnets, and the size of gap between the copper coils and the stopper. The anticipated outcome of this research is a scalable, cost-effective energy harvester optimized for rural grade crossings to enhance their safety by providing electric power for train detection sensors.

US DOT Priorities: The proposed work in this project is aligned with three of the six USDOT strategic goals: **(a) Safety:** This goal is addressed by designing, fabricating, and testing a multi-resonant impact-driven energy harvester. This device is intended to power sensors and other low-power electrical safety equipment at rural rail crossings, enhancing safety measures. **(b) Equity:** The project promotes equity by offering training opportunities to citizen graduate and undergraduate students from underrepresented populations and diverse communities in the United States. It aims to equip them with the necessary skills and knowledge for successful careers in transportation and railway engineering, thus contributing to a more inclusive workforce. **(c) Transformation:** This goal is achieved by adopting innovative developments from several engineering fields (e.g., civil, mechanical, and electrical engineering) to harvest electrical power from vibrations in railroad track systems. The project involves research to understand the needs and implications of smart sensing technologies in railroad engineering and aims for the eventual transfer of technology to stakeholders and industrial partners, thereby transforming the field.

Outputs: The expected products include:

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. A comprehensive Finite Element (FE) model of the prototype and its critical components developed using COMSOL Multiphysics software. (File Format: MPH).
3. Extensive laboratory and field raw data capturing time history of acceleration, voltage, and electric power output of the energy harvester. (File Formats: TXT, CSV).
4. A fully operational proof-of-concept prototype based on an optimized design, which will undergo rigorous testing both in the laboratory and the field.
5. A detailed report (or publication) summarizing the findings from FE modeling, numerical simulations, and both lab and field tests, prepared to meet the specifications of the USDOT and UTCRS.
6. The dissemination of research findings through one or more conference presentations or journal publications. The PI will lead a session at the 2025 ASCE EMI Conference focusing on advancements in energy harvesting systems.

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 and Industry Impact:** The results of this project will be used to develop a cost-effective energy harvester to power train detection sensors and other basic safety electrical equipment at rural rail crossings. This will eventually help to improve the safety of railway operations and reduce the risk of accidents. **Educational Impact:** 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 CIVE and MECE to involve STEM 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 by understanding the concept of energy harvesting through vibration. Furthermore, this project promotes partnerships between academia and industry, and engagement with stakeholders and policy makers by organizing workshops, webinars, and publicly available publications (e.g., ASCE EMI Conference).

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 Performance

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): Robert Jones (PI, UTRGV), Constantine Tarawneh (Co-PI, UTRGV), Jose Taha Tijerina (Co-PI, UTRGV), and Heinrich Foltz (Co-PI, UTRGV)

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

Research Project Funding: $78,230 (Federal), $76,957 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2024 to 08/31/2025

Project Description: The performance of railroad bearings that sit idle in railyards, large industrial plants, or shipping ports has only recently been explored. Some of the bearings, with documented periods of inactivity exceeding 18 months, have been associated with major derailments. This provides a basis for concerns that 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 builds on prior efforts conducted in collaboration with CSX Transportation, MxV Rail, and the National Transportation Safety Board (NTSB), and seeks to improve our understanding of the effects of long-term inactivity on lubricant properties.

The proposed work will consist of (a) preparation of two test bearings which will be placed outdoors in a position to receive direct sunlight, (b) placement of grease samples in the same location in a simulated bearing housing to mimic the thermal cycle of a sun-exposed bearing, (c) regular sampling from the simulated bearing housing to monitor long-term changes in lubricant performance and condition, (d) at 23 weeks and 48 weeks, bearings will be retrieved and installed on a laboratory test rig and run for 15,000 simulated miles 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 at all stages with specific focus on loss of oxidation inhibitors and changes in tribological performance.

US DOT Priorities: The proposed work in this project is aligned with five of the six USDOT strategic goals: **(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:** 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 results of this study will provide invaluable information to the rail industry and federal agencies that can recommend policy changes leading to safety guidelines defining acceptable periods of bearing inactivity.

Outputs: The expected products include:

1. Completed laboratory testing of bearings.

2. Logs of temperature, vibration, and power data acquired throughout each test.
3. Results of Thermogravimetric Analysis (TGA) and Differential Scanning Calorimetry (DSC) analysis of lubricants before and at various aging times.
4. Results of Tribological evaluations: Coefficient of Friction (COF), Wear Scar Diameter (WSD), and friction torque.
5. Results of Rheological evaluations: viscosity, storage/loss modulus.
6. Final report with findings.
7. 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 what effects long periods of inactivity have on lubricant properties and 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 bearing mileage. **Educational Impact:** The UTCRS portions of the project will be carried out 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. 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.

FAST® Loop Comparison of Onboard Condition Monitoring Versus Wayside Detection Systems

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) and Constantine Tarawneh (co-PI, UTRGV)

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

Research Project Funding: $126,416 (Federal), $127,785 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2024 to 08/31/2025

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. Hum Industrial Technology, Inc., has further developed this technology to the point of field deployment in commercial applications with multiple railcar operators. Although these field deployments have already shown the ability to detect defective wheelsets, there is a lack of head-to-head comparison data in which the same bearings and wheels are monitored using both conventional wayside sensors (Hot Bearing Detectors (HBD) and Wheel Impact Load Detectors (WILD)) and onboard monitoring (commercial units from Hum and next generation prototypes from UTCRS), at the same time on the same track. This is a crucial step in validating the current onboard technology, as well as an initial field test of newer experimental techniques.

We propose a large scale (40+ sensor units) test to be conducted at the MxV Rail FAST® (Facility for Accelerated Service Testing) track loop. The test will acquire data from (a) commercial Hum Boomerang wireless sensors, (b) UTCRS prototype sensors developed during the 2023-2024 funding cycle, (c) an existing HBD installed at FAST®, and (d) an existing WILD installed at FAST®. The test will include several randomly selected cars, and one car intentionally installed with a combination of healthy wheels/bearings and wheels/bearings with known early-stage defects. At the end of the test run, selected bearings and wheels will be pulled and inspected for a "ground truth" evaluation of defect severity.

The outcomes of this project would include quantitative, calibrated comparisons of (a) temperature only (HBD) versus temperature and vibration (onboard) measures of bearing health and (b) wheel flat measurements from onboard accelerometers versus WILD. It will allow direct evaluation of the relative performance of onboard and wayside in early detection. The UTCRS prototype portion of the project would also demonstrate the viability of new techniques such as synchronized sampling and adaptive filter cutoffs and provide a large-scale public database for training AI/ML systems.

US DOT Priorities: The proposed work in this project is aligned with five 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) 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 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 reduce the number of environmentally significant derailments. **(e) Transformation:** The high-resolution data streams generated by the sensors will be a resource that can be mined for new insights beyond the currently envisioned application. In particular, it will provide extensive training and validation data sets for machine learning (ML) and artificial intelligence (AI).

Outputs: The expected products include:

1. A database that includes:
    a. Timestamps
    b. Train location at each timestamp
    c. BHI readings for all bearings
    d. Full vibration waveforms for eight bearings
    e. Direct (contact) temperature readings for eight bearings
    f. HBD readings
    g. WILD readings
    h. Annotations giving load condition for each car and identifying events of interest.
2. Post-inspection data including mechanical measurements, weight, photographs of disassembly, and measurement of spalls.
3. Complete test description for the UTCRS portion of the experiment including schematic diagrams, firmware, setup, and test procedure. The level of detail will be sufficient to allow independent replication of the experiment.
4. For the eight bearings with advanced instrumentation, analysis of cross-correlation between vibration waveforms acquired simultaneously will be carried out.
5. Recommended algorithms for identifying and suppressing external sources of vibration to improve the accuracy of bearing and wheel monitoring.
6. Publications and reports

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. As a minority serving institution in a rapidly growing metropolitan area, we anticipate that most of the students will be from underrepresented groups. The students will work directly on rail equipment and learn industry operating procedures as part of their MxV FAST® experience. We anticipate that at least eight students will participate, whether supported by the project directly or from other sources.

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

Lateral Load Effect on Railway Tapered Roller Bearing Performance

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): Arturo Fuentes (PI, UTRGV) and Constantine Tarawneh (Co-PI, UTRGV)

Project Partners: N/A

Research Project Funding: $70,226 (Federal), $35,342 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2024 to 05/31/2025

Project Description: Lateral forces are a critical factor in railroad tapered roller bearing performance. To improve the reliability and safety of railway systems, vibration and thermal signatures can be powerful diagnostic and prognostic tools for monitoring railway bearing health. While temperature variations can signal spall deterioration, they often become evident only after extensive damage. Therefore, understanding the effects of lateral loading on railroad tapered-roller bearings, including vibration and temperature behavior, under varying train speeds and loads is crucial. Unfortunately, there is limited publicly available research in this area.

Motivated by this area of opportunity, researchers at the University Transportation Center for Railway Safety (UTCRS) developed a dynamic bearing test rig to investigate the effects of lateral loading on bearing performance. The proposed study focuses on Association of American Railroads (AAR) class F and K bearings, widely used in freight rail service. A hydraulic cylinder setup will apply lateral loads up to 44.5 kN (10 kips), mimicking forces experienced during hunting, track irregularities, and curves. Healthy, reconditioned, and spalled bearings will be used for the experiments.

The proposed study will offer a unique contribution by exploring how lateral loads affect bearing vibration (in addition to temperature), providing insights into factors influencing bearing performance in the rail industry. The aim is to improve the long-term reliability and safety of rail systems by understanding how to mitigate performance-compromising issues. It is expected that, based on the findings of this study, the team will optimize onboard vibration, temperature, and load measurement sensors for more accurate and reliable monitoring of bearing condition.

US DOT Priorities: The proposed work in this project is aligned with five of the six USDOT strategic goals: **(a) Safety:** This project directly improves railroad safety by enabling the early detection of impending failures in railroad bearings. Furthermore, quantifying the effect of lateral loads on bearings can improve the ability of the onboard sensor technologies in identifying abnormal track and railcar operating conditions, thus providing a holistic approach to preventing accidents. **(b) Economic Strength:** This project aims to provide the railroad industry with reduced costs and improved efficiency. Unscheduled stoppages and field repairs significantly impact rail companies and the entire transportation system. By enabling early prediction of potential issues, this project empowers companies to schedule repairs during planned maintenance windows, minimizing disruptions and associated economic losses for rail companies, their customers, and other track users. **(c) Equity:** As a Hispanic Serving Institution (HSI), UTRGV is committed to fostering diversity within the transportation industry. This project directly contributes to this goal by employing one graduate and one undergraduate student and indirectly supporting the employment of others. By providing valuable research experience, this project equips these students with the skills and knowledge to become future leaders in the field. **(d) Sustainability:** This project contributes to environmental sustainability in two different ways. First, by enabling proactive maintenance, it extends the lifespan of rolling stock. This reduces the need for frequent replacements, resulting in a lower overall carbon footprint associated with bearing manufacturing. Second, by preventing bearing failures and potential derailments, the project directly minimizes the risk of environmentally damaging spills and accidents. **(e) Transformation:** The project will generate extensive experimental data that will serve as a rich resource for future advancements of onboard sensor technologies.

Outputs: The expected products include:

1. An improved experimental setup for testing railroad bearings with lateral loads.
2. Final report including any DoT or UTCRS required information on the experimental results of railroad bearings at different velocities and vertical/lateral loads.
3. One or more conference or journal publications by a graduate student working toward the completion of a master's thesis. At a minimum, we will submit to the Spring 2025 Joint Rail Conference (JRC).

Outcomes/Impacts: The research itself, as well as the training of engineering students, will have impacts beyond the immediate information of the lateral load effect on the railroad bearing performance to avert accidents and enable proactive maintenance. **Industry Impact:** As stated earlier, this study will offer a unique contribution by exploring how lateral loads affect bearing vibration (in addition to temperature), providing insights into factors influencing bearing performance in the rail industry. The aim is to improve the long-term reliability and safety of rail systems by understanding how to mitigate performance-compromising issues. It is expected that, based on the study's findings, the team will refine vibration and load onboard measurement sensors for even more precise onboard data collection considering the effects of lateral loads. **Educational Impact:** 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 one graduate and one undergraduate student who will gain experience in developing railroad specific experiments, as well as bearing test equipment. The enhanced experimental setup will also enable several other students to be trained in the use of the system and its data for independent research projects.

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

Project Partners: Mohsen Amjadian (Collaborator, UTRGV)

Research Project Funding: $73,750 (Federal), $50,576 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2024 to 08/31/2025

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. In order 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 feasibility of this approach has been shown in previous research and an initial prototype will be designed and tested as part of the research plan.

US DOT Priorities: This project aligns with three USDOT strategic goals: **(a) Safety:** The project plans to address the safety of rural grade crossings which represent a significant 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 to increase the graduate enrollments of these groups. In particular, the UNL MME 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.

Outputs: Expected results and products include:

1. Computational models will be developed to understand the impact of the various design choices on power generation.
2. Design implications for magnet arrays to modify the symmetry of the magnetic field will be quantified.
3. An initial laboratory prototype will be created for one or two of the designs.
4. Experimental data will be collected to quantify the potential for maximum power generation.
5. General concepts for implementation in the field will be initiated.
6. Conference presentations, reports, journal articles, and patent disclosures

Outcomes/Impacts: The proposed project will have broader impacts from both the research itself as well as the educational aspects. The anticipated **Research Activities** are focused on a new energy harvesting approach that could be implemented in many different locations, especially rural areas. The proposed design does not depend on motion of the rail so it could be integrated more easily at specific sites, which will reduce the installation costs tremendously. Overall railroad safety would be enhanced if additional signals could be installed, and the results thus far suggest that sufficient power could be generated with this concept. The expected **Educational Activities** include training of engineering students in multi-disciplinary subjects that involve both mechanical and electrical engineering. Future engineers will need to design with a team approach and this project will be an excellent training ground for students. In addition, the PI has a strong track record with respect to recruitment of students from underrepresented groups and that will continue so that a well-educated workforce is available.

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

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

Project Partners: N/A

Research Project Funding: $69,705 (Federal), $33,568 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2024 to 08/31/2025

Project Description: Other than train collisions, track intrusion (also referred to as track fouling) is the 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 collisions 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 the period 2012-2016 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. Instead, current track intrusion relies on high-rail inspection which is labor-intense 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, a real-time communication unit, and a 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 the 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 and railroads, as well as 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. The following USDoT priorities are addressed: **(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 and deliverables include:

1. A tailored image training library for future track intrusion or track integrity detection model development.
2. 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.
3. A prototype integrated hardware system for edge computing.
4. A report including performance validation results compared with other state-of-the-art models on track intrusion detection.
5. One or more conference or journal publications.

Outcomes/Impacts: 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.

Ultrasonic Inspection of Reconditioned Railroad Bearing Components - 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): Joseph Turner (PI, University of Nebraska-Lincoln (UNL))

Project Partners: Constantine Tarawneh (Collaborator, UTRGV), Anish Poudel and Matt Wenger (Collaborators, MxV Rail)

Research Project Funding: $73,749 (Federal), $25,088 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2024 to 08/31/2025

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. Previous research has shown clear differences between new and reconditioned bearing cups in terms of their ultrasonic signatures. That 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 project aligns with four USDOT strategic priorities: **(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 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 to increase the graduate enrollments of these groups. In particular, the UNL MME Department has a cooperative PhD program with UTRGV which has enhanced underrepresented groups 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: Expected results and products 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. Conference presentations, reports, journal articles, and patent disclosures.

Outcomes/Impacts: The proposed project will have broader impacts from both the research itself as well as the educational aspects. The anticipated **Research Activities** may lead to new ultrasonic inspection approaches that can identify positions within component raceways that may be candidates for early failure. Thus, overall railroad safety would be enhanced if suspect components are removed from further service. Although the measurements proposed here will take place within an ultrasonic immersion tank, other measurement modalities, such as a hand-held measurement tool, may result from this work. The expected **Educational Activities** include training of engineering students in NDE methods with applications to the rail industry. The PI has a strong track record with respect to recruitment of students from underrepresented groups and that will continue so that a well-educated workforce is available.

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

Enhanced Datasets and AI Models for Monitoring of Grade Crossings

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: Jia Chen (Collaborator, University of California Riverside (UCR)) and Vagelis Papalexakis (Collaborator, UCR)

Research Project Funding: $51,318 (Federal), $25,603 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2024 to 08/31/2025

Project Description: The safety of grade crossings is a major concern of transportation agencies and researchers due to the number of accidents every year. The Federal Transit Administration (FTA) reported 592 grade crossing collisions in 2022, resulting in 19 fatalities and 133 injuries. Many innovative technologies have been proposed to automate the monitoring of crossings. The goal of this project is to investigate the use of Artificial Intelligence (AI) and Deep Learning (DL) to monitor grade crossings and detect various hazardous conditions such as vehicles, pedestrians, cyclists, animals, warning lights, and others. In prior work, the research team developed a Convolutional Neural Network (CNN) model and trained it using a dataset of 1,364 images that was collected and manually labeled by the authors, reaching a validation accuracy of 98.90% to detect vehicles at grade crossings. However, there are limitations to the model stemming from the need to improve the size and balance of the data. The work in this proposal aims to address limitations in the current model and to make new advances by (1) increasing the number of photos in the dataset using real video streams; (2) using captures from a train simulator videogame environment; (3) addressing the issue of imbalanced dataset for training and validation; and (4) hyper-optimizing the model for accuracy and real-time performance. This project relates directly to the strategic research goal of UTCRS of reducing fatalities and injuries at highway-rail grade crossings (HRGCs); and relates to the railway operation systems research area of autonomous systems for grade crossing safety. The outcomes of this research will advance knowledge in automated monitoring of hazards at grade crossings, and result in a model that can be implemented in cameras for automated hazard monitoring at grade crossings.

US DOT Priorities: The proposed work in this project is aligned with five of the six USDOT strategic goals: **(a) Safety:** The project is directly related to improving safety at crossings using AI. **(b) Economic Strength:** Improving safety at crossings will lead to better operations of rail and road networks and fewer disruptions which would ultimately support economic strength. **(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 one graduate student and indirectly support several other undergraduate students. **(d) Sustainability:** Improving the safety of crossings will lead to improved operations of railways and roads which reduces overall energy needs. It will also reduce the risk of rail accidents that may involve environmentally harmful materials. **(e) Transformation:** The project will directly investigate the innovative use of AI for improving crossing safety. Models and data generated from this project will further support other AI-focused projects in the UTCRS.

Outputs: The expected products include:

1. Developed CNN model to detect hazards at railroad crossings.
2. A dataset of labeled images of railroad crossing hazards for further research with UTCRS partner institutions and grade crossing research subgroup.
3. One or more conference or journal publications.

Outcomes/Impacts: The primary impact of the research is providing a framework for using AI to monitor crossings and improve their safety. 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. UTRGV is a minority-serving institution. As such, the students will be from underrepresented groups and 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.

Federated Learning for Railway Safety Analysis and Prediction

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): Ping Xu (PI, UTRGV)

Project Partners: Jia Chen (Collaborator, University of California Riverside (UCR)) and Vagelis Papalexakis (Collaborator, UCR)

Research Project Funding: $44,113 (Federal), $28,056 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2024 to 08/31/2025

Project Description: Railway networks constitute intricate cyber-physical systems, engaging with various transportation entities and additional cyber-physical systems. For instance, a railway crossing necessitates interactions between the railway network and road traffic management systems. This complex web of interactions between diverse entities presents intriguing challenges for research in effectively modeling railway operations through data analytics and enhancing safety measures at railway crossings using data-driven approaches. In our previous work with our partner institution, the University of California Riverside (UCR), we adopted the spectral clustering technique to understand emerging accident patterns from historical data and identify underlying similarities in such patterns. We then adopted kernel ridge regression to predict the number of accidents based on the selected factors from identified patterns, making the first attempt to reduce the number of accidents. However, due to the large volume of data and high computation complexity, the amount of data involved in learning was only 10% of that available. Moreover, our work assumes that all data are centrally available. In practice, data from different transportation entities may not be shared or collected to a center for processing, due to privacy issues. To address these issues, this project proposes to develop a federated learning framework to enable (a) parallel computation when data volume is too large, and (b) local data processing when privacy is a concern.

US DOT Priorities: The proposed work in this project is aligned with five of the six USDOT strategic goals: **(a) Safety:** The project directly addresses safety through predicting accidents from historical data, which can help in future policy making to reduce the number of accidents. **(b) Economic Strength:** Early prediction mitigates accidents and their associated financial costs and train delays. **(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 one graduate student, and indirectly support the employment of several others. **(d) Sustainability:** By enabling proactive preventive prediction, this project aims to mitigate catastrophic accidents, which will preserve the rail infrastructure and the environment. **(e) Transformation:** The developed framework can provide new insights beyond the currently envisioned application, using recent and future advances in machine learning.

Outputs: The expected products include:

1. Research publications, targeted at 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 multifaceted, extending beyond immediate railway safety improvements. It promises to foster a data-centric culture within the transportation safety community, encouraging reliance on predictive analytics. The educational aspect is significant, as the research will provide hands-on experience in advanced data analysis and machine learning for graduate and undergraduate students. From an industry perspective, the implementation of predictive safety models has the potential to revolutionize railway operation, leading to long-term sustainability and safety in railway crossings.

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: 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): Nikolaos Vitzilaios (PI, University of South Carolina (USC)), Dimitris Rizos (Co-PI, USC), and Yu Qian (Co-PI, USC)

Project Partners: N/A

Research Project Funding: $43,759 (Federal), $21,209 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2024 to 05/31/2025

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. Current practice for the rail industry is to shut down traffic until the line has been inspected and any potential obstacles have been removed. This is, however, a process that may take a significant amount of time and imposes significant costs on top of the financial losses created by the track downtime.

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 identified blocking the 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 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 in providing 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. On this project (Phase/Year 2), the expected results and products include:

1. A set of AI\ML algorithms able to identify obstacles on railroad tracks.
2. Algorithms for autonomous navigation and collision avoidance for drone systems flying over railroad tracks.
3. A prototype drone system with online processing capabilities.
4. Demonstration of the drone system tracking\following a railroad line while identifying obstacles on the track.
5. 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.

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

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), and M. Umer Farooq (Co-PI, UNL)

Project Partners: N/A

Research Project Funding: $147,500 (Federal), $71,836 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2024 to 08/31/2025

Project Description: Non-motorist users at highway-rail grade crossings (HRGCs) include pedestrians, bicyclists, wheelchair users, skateboarders, and push scooter users, among others. 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 are particularly vulnerable at HRGCs 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.

In 2020, the Federal Railroad Administration (FRA) developed a crash frequency model for HRGCs; however, it does not consider non-motorist characteristics in its crash prediction. It is anticipated that adding components pertaining to pedestrians, bicyclists and other non-motorist users will improve the model's overall crash prediction. This improvement has the potential to guide more efficient resource allocation and HRGC's safety decision-making. Furthermore, the existing FRA model relies on conventional statistical analyses. In contrast, our proposed research aims to explore the efficacy of robust artificial intelligence (AI) based models for crash prediction at HRGCs. We seek to compare traditional statistical prediction models with AI-based models for crash predictions at HRGCs; the investigation aims to discern the superior performance of these models by evaluating their precision and fitness according to established criteria. These models will not only encompass physical characteristics of HRGCs grade crossings but would also integrate dynamic elements such as train and vehicular traffic, along with non-motorist exposure and its associated factors. The non-motorist exposure data will be acquired upon the successful completion of Phase I within our broader research framework.

Anticipated outcomes of this study include improved HRGCs' crash frequency prediction model. This research will contribute to a deeper understanding of safety hazards associated with HRGCs, considering various dynamic attributes related to traffic and trains, acknowledging the vulnerability of non-motorists at HRGCs. The proposed model would be developed through a comprehensive approach, incorporating policy perspectives on grade crossing safety, thorough data reviews, statistical analyses, AI-based techniques, and rigorous validation processes. Ultimately, the research findings are expected to empower transportation agencies to implement proactive safety measures, assisting in reducing the frequency of crashes and promoting the overall well-being of both motorized and non-motorized HRGCs users.

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. The primary focus on developing a new crash prediction model that encompasses all types of traffic at HRGCs is instrumental for optimizing resource allocation effectively. The inclusion of non-motorized crash exposure factors in the HRGCs crash prediction model can improve decisions related to non-motorists' infrastructure improvements, signal timings, automated technologies, warning systems, and enforcement strategies. The outcomes of this research are anticipated to play a pivotal role in shaping safer transportation ecosystems. The incorporation of pedestrian and bicyclist safety considerations within the rail industry signifies a proactive approach towards creating a more inclusive and secure transportation landscape.

Outputs: The research team will develop a new crash prediction model for HRGCs that will incorporate all types of motorized and non-motorized traffic. This model will offer valuable insights and guidance for enhancing the safety of various railroad grade crossing users, including drivers, train operators, pedestrians, and bicyclists, across the United States. The project will yield specific deliverables, including:

1. A database detailing the exposure of vehicles, pedestrians and bicyclists at HRGCs.
2. A final representative model based on the comparison of statistical and AI crash prediction models.
3. Recommendations for future studies and a comprehensive project final report, consolidating findings and insights to contribute to the improvement of safety measures at HRGCs nationwide.
4. Publications in industry publications and presentations at professional conferences.

Outcomes/Impacts: The proposed research is transformational in nature and its broader impacts include the potential for precise HRGCs crash prediction that will extend guidance on correct decision-making processes for HRGCs resource allocation and implementation of effective risk remedial measures.

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

Optimizing Emergency Response: Intelligent Routing Decision Support System for First Responders at Rail Crossings

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): Yuche Chen (PI, University of South Carolina (USC)) and Yu Qian (Co-PI, USC)

Project Partners: N/A

Research Project Funding: $52,606 (Federal), $25,132 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2024 to 05/31/2025

Project Description: This research project addresses critical challenges faced by emergency response teams operating at rail crossings, where suboptimal routing decisions can lead to increased risks and delays. Presently, a gap exists in dedicated Intelligent Routing Decision Support Systems designed for the unique challenges posed by incidents at rail crossings. The project recognizes the distinct characteristics of rail crossings, encompassing unpredictable train schedules, varied terrains, and potential traffic congestion, factors often overlooked by existing routing systems. In response, this research aims to develop and implement an Intelligent Routing Decision Support System, leveraging real-time data and advanced algorithms to provide first responders with optimized routes. The project focuses on mitigating inefficient routing, providing intelligent decision support tailored to rail crossing emergencies, and overcoming integration challenges associated with incorporating real-time data from rail systems, traffic conditions, and incident-specific information. By addressing these issues, the research project aspires to significantly enhance the overall effectiveness of emergency response teams, ensuring timely and safe interventions in incidents at rail crossings.

US DOT Priorities: This project aligns with the strategic goals outlined by the United States Department of Transportation, specifically addressing key facets: **(a) Safety:** The project focuses on enhancing the efficacy of routing decisions for first responding vehicles at rail crossings, with the potential to minimize time delays for responders and, consequently, contribute to life-saving outcomes. **(c) Equity:** The project directly involves the engagement of at least one minority student, fostering diversity within the research workforce and indirectly supporting the employment of several others. **(d) Sustainability:** The initiative aims to deliver an intelligent routing decision tool for first responders, incorporating an energy consumption calculation component for various routing paths. This information serves to enhance first responders' awareness of their vehicles' energy consumption. **(e) Transformation:** The project endeavors to develop an intelligent routing tool for first responders, specifically tailored for potential rail crossings. This tool seeks to revolutionize the current human decision-making paradigm, transitioning toward a data-driven approach to augment decision efficiency and reduce response times in the daily operations of first responders.

Outputs: The expected products and deliverables include:

1. A decision-making tool that is capable of estimating potential delay and travel time of first responding vehicles in different routes.
2. Final report including any DoT or UTCRS required information.
3. A prototype drone system with online processing capabilities.
4. One or more conference or journal publications. Submissions will be made to either the 2025 TRB

annual conference or Spring 2025 Joint Rail Conference (JRC) with intermediate results.

Outcomes/Impacts: This research itself, as well as the training of engineering students, will have impacts beyond the research outputs. **Research Impact:** Firstly, the development and implementation of an intelligent routing decision support system has the potential to substantially reduce response times for first responders at rail crossings. This, in turn, can enhance overall public safety by expediting the arrival of emergency services to critical incidents. Additionally, the project's focus on leveraging advanced technologies contributes to the evolution of intelligent transportation systems, setting a precedent for data-driven decision-making in emergency response scenarios. The dissemination of research findings through publications and conferences not only enriches the academic and professional discourse but also facilitates knowledge transfer to practitioners, influencing best practices in emergency response. Lastly, the potential incorporation of energy consumption considerations in routing decisions aligns with sustainability goals, offering insights into resource-efficient emergency response operations. **Educational Impact:** The project's commitment to diversity, as evidenced by the engagement of minority students, contributes to building a more inclusive research workforce. In summary, the project's broader impacts span improved public safety, advancements in intelligent transportation, knowledge dissemination, diversity enhancement, and alignment with sustainability objectives.

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

Towards Building a Foundation AI Model 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), and Yue Dong (Co-PI, UCR)

Project Partners: Ping Xu (Collaborator, UTRGV)

Research Project Funding: $95,000 (Federal), $47,500 (Non-Federal Cost Share)

Project Start and End Date: 06/01/2024 to 08/31/2025

Project Description: Foundation models, including large language models (LLMs), are revolutionizing multiple aspects of everyday life and work, with the use of LLMs such as ChatGPT being now commonplace and transforming life, work, and scientific discovery as we know it. Despite impressive performances in conversations, such systems still suffer from hallucinations and pose safety risks, which are critical for domain-specific applications, such as railway safety. In this project, we propose to harness the power of such foundation models in order to transform railway safety, by building a foundation model that can support various critical tasks of railway safety practice, such as understanding and summarizing possible causes for an accident, comparing different accidents and understanding commonalities and risk factors, and coming up with policy recommendations that can improve safety in a grade crossing or a locality at large. To do so, we outline a number of fascinating and hard research challenges that need to be addressed, and as part of this one-year project, we set out to build a prototype proof-of-concept that will demonstrate the viability of foundation models for railway safety.

US DOT Priorities: This project aligns with five USDOT strategic priorities: **(a) Safety:** One of the goals of our foundation model is to provide recommendations for improving the safety of crossings, thereby reducing the number of accidents. **(b) Economic Strength:** Our proposed foundation model can empower the automation of a lot of labor-intensive tasks. **(c) Equity**: UCR and UTRGV are minority serving institutions 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 several others. **(d) Sustainability:** By empowering the quick and accurate processing of vast amounts of information, our project can help railway safety professionals to be more efficient in their work. **(e) Transformation:** Our proposed work sits in the cutting-edge of AI research and by carrying out our research plan we will have to innovate in ways that not only advance railway safety research but also the state of the art in AI.

Outputs: Expected results and products include:

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.
3. Publicly available model weights for the foundation model we develop.
4. A select number of bearing components will be subjected to laboratory service life testing to quantify the inspection approach.

5. Publicly available model weights for the foundation model we develop.
6. Dissemination via seminars at universities and companies.

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; (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.