Feature Extraction from Vibration Signatures Acquired from Railroad Bearing Onboard Condition Monitoring Sensor Modules	01

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From 2013 to 2022, 1671 derailments have been reported by the Federal Railroad Administration (FRA), 8.2% of which were due to journal bearing defects. The University Transportation Center for Railway Safety (UTCRS) designed an onboard monitoring system that tracks vibration waveforms over time to assess bearing health through three analysis levels. However, the speed of the bearing, a fundamental parameter for these analyses, is often acquired from Global Positioning System (GPS) data, which is typically not available at the sensor location. To this end, this research proposes to employ Machine Learning (ML) algorithms to extract the speed and other essential features from existing vibration data, eliminating the need for additional speed sensors. Specifically, the proposed method tries to extract the speed information from the signatures that are embedded in the Power Spectral Density (PSD) plot, which enables rapid real-time analysis of bearings while the train is in motion. The rapid extraction of data could be sent to a cloud accessible by train dispatchers and railcar owners for assessment of bearings and scheduling of replacements before defects reach a dangerous size. Eventually, the developed algorithm will reduce derailments and unplanned field replacements and afford rail stakeholders more cost-effective preventive maintenance.

Next Generation Onboard Sensor Technologies for Rolling Stock	02
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Train derailments like the one in East Palestine, Ohio, on February 3, 2023, result in costly economic damages and devastating societal effects. In the East Palestine incident, Hot Bearing Detectors (HBDs) captured the increase in bearing temperature at three separate locations ahead of the derailment site; however, the third reading which exceeded the threshold was not obtained until the bearing had started to catastrophically fail. HBDs are reactive in nature since they rely on temperature to access bearing health. Studies have shown that bearings exhibit high operating temperatures near catastrophic failure, allotting little time to implement preventative measures. Vibration-based sensors have been proven to detect early stages of bearing defect development. Hence, wireless onboard sensors pose a solution to prevent derailments by continuously monitoring rolling stock and allowing preventative measures to be scheduled. This project aims to develop the next-generation of sensors through optimal filters, higher resolution analog-to-digital conversion, and precision synchronization of all sensors on the same car compared to their previous counterpart. Precise synchronization enables separation of vibrations originating in one bearing from vibrations arising in adjacent bearings, wheels, brakes, track, and couplers. This enables more accurate monitoring of bearing condition and identification of other problems on the railcar or track.	

Powering Onboard Bearing Health Monitoring Sensors with Thermoelectric Generators Under Non-Uniform Temperatures	03
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Wireless onboard health monitoring devices are a promising preventive technology that can be included in the surveillance of train rolling stock. These devices can detect the early stages of bearing and wheel defects. However, the nature of continuous monitoring requires an energy source sufficient to record and transmit data. Thermoelectric energy harvesting is an effective solution to power onboard wireless condition monitoring sensors during railroad operations. Thermoelectric Generators (TEGs) are considered to be environmentally safe, are static and simple structures, and require little maintenance. TEGs can fill a crucial role in providing energy to run vibration and temperature sensors, as well as supporting LoRa communications. However, when mounted on a railcar, TEGs may be subjected to non-uniform temperature differentials caused by the forced convection generated by air motion relative to the vehicle. It can be shown that TEGs experiencing non-homogeneous temperatures can have reduced power output, and if the temperature difference is large, power is further reduced than with one TEG alone. This work presents analysis and experimental data comparing several possible design solutions: (1) a simple series connection, (2) a series connection with bypass diodes, and (3) isolated TEGs with separate boost converters for each module.	

Evaluating Feasibility of Geophone Technologies for Energy Harvesting on Rolling Stock	04

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Bearing failure continues to be one of the leading causes of train derailments that result in significant economic and environmental damages. To prevent these tragedies, researchers at the University Transportation Center for Railway Safety (UTCRS) are developing wireless onboard condition monitoring systems that can detect bearing defects preemptively by tracking the vibration signature emissions continuously. These systems utilize a rechargeable battery that can provide up to two years of operation on a single charge. However, a suitable energy harvesting system can significantly increase the batteries' longevity or allow for more frequent data collection and reporting. The main objective of the research presented here is to explore the feasibility of utilizing existing geophone technologies as an alternative energy harvesting approach for the onboard bearing condition monitoring system. The proposed method involves mounting a geophone device on a bearing adapter to harvest vibration-based energy produced by the rolling stock. By enhancing the reliability and safety of rail transportation networks, this research can help mitigate the risks associated with bearing failures and improve the overall safety of railway operations.

Linux-Based DAQ System for Testing Railroad Bearings in a Laboratory Setting	05

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An innovative data acquisition and monitoring system designed to enhance the efficiency, reliability, and safety of railroad bearing testing within a laboratory setting is presented. The system comprises five distinct testers, each interfaced with a dedicated Linux computer equipped with LabVIEW™ for conducting wired tests, and custom-developed software for wireless connectivity to a specially designed module by the electrical engineering team. The core of the system lies in its capability to autonomously collect 5200 samples from each module every 10 minutes, ensuring comprehensive data acquisition. To accommodate users of varying technical expertise, the software features both a graphical user interface (GUI) for ease of use and a headless mode for command line users. A unique aspect of the system is its integrated database infrastructure, which not only stores data locally on each tester but also synchronizes with a central 'whiteboard' database. The whiteboard, a Linux-based computer with expanded storage capabilities, serves as a nexus for aggregating data from all testers. Additionally, it supports security and monitoring efforts by displaying live camera feeds from the testing environments. This system represents a significant advancement in bearing testing technology, providing a robust, user-friendly, and scalable solution for real-time data collection and analysis.

Increasing Stability of Bearing Applied Load During Dynamic Testing	06

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A major activity at the University Transportation Center for Railroad Safety (UTCRS) is performance evaluation of freight railcar bearings using laboratory test rigs that closely simulate service operating conditions. A hydraulic system applies load to the bearings through the adapters, with controllable force ranging from that of an unloaded railcar to 125% of the maximum allowed load capacity. One issue in laboratory testing is variation in the applied load due to thermal expansion and contraction of the hydraulic fluid within the cylinder. To remedy this problem, a load controller that can adjust the force applied by the hydraulic cylinder to counteract thermal effects was designed and built. The fabricated load controller is a completely analog device with user adjustable controls for set point, sensitivity, and maximum load rate. It controls a motor driven lead screw and auxiliary cylinder that are used to adjust the main cylinder pressure. It has a manual mode, where the motor and lead screw are adjusted directly by the user. Most important, however, is the automatic mode, which controls the load set point with an adjustable dead band to reduce hunting that could shorten motor life. Future versions of this controller will allow the user to program specific load profiles, be under digital control, and have connectivity features.

Automated Curvature Calculation Algorithm in Rail Neutral Temperature Measurement System	07
John Stormes (presenter), Emerson Mitchell, Dimitros Rizos The University of South Carolina, Columbia, SC	
Researchers at the University of South Carolina have developed a non-contacting, reference-free technology for estimating the rail neutral temperature (RNT). The technology is based on deformation measurements of the top of rail (TOR) and the web. It is a non-contacting, reference free technique that has been validated in the laboratory and the field. RNT estimates are obtained by correlating changes in curvature of the TOR to temperature. The TOR deformations may be captured by stereo digital image correlation (stereoDIC) systems or high resolutions 3D laser profilers. Both techniques produce a point cloud in the 3D space that defines the TOR surface at different temperatures. The authors have developed an automated curvature calculation algorithm that automates the calculation of the required curvatures and optimizes the evaluation of the RNT. The method is based on a weighted sum approximation and least square regression and has shown excellent performance in reducing noise in the measurements.	

A Review of Requirements to Optimize the use of Digital Image Correlation (DIC) for Monitoring Rail Infrastructure	08

Stephen Wilcken (presenter), Dimitros Rizos
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A crucial aspect of safe and efficient operation of railway infrastructure is proper maintenance and inspection. Information on the condition of this infrastructure needs to be quickly and accurately determined through testing, ideally in a non-destructive and non-disruptive way. Digital Image Correlation (DIC) is a non-destructive, non-disruptive and uniquely non-contacting testing method that has been developed in the USC laboratories over the last thirty years. DIC captures full field shape, deformations and displacements through the acquisition and analysis of optical images. The Advanced Railway Technology Group at USC has introduced the DIC technology in the rail industry. DIC has been successfully implemented in rail neutral temperature (RNT) measurements, in the quality control of prestressed concrete crossties, including transfer length measurements, for material testing, and the structural assessment and monitoring of main girders of rai bridge. The effective use of DIC in such applications in the field that will maintain the high accuracy and reliability of the technology poses challenges with respect to: (i) the application of a speckle pattern on the area of interest (AOI), (ii) the varying lighting conditions of the AOI, and (iii) a stable and rigid camera hardware configuration that eliminates the adverse effects of vibrations. This presentation introduces the implementation requirements of the DIC technology in rail infrastructure monitoring and presents the solutions proposed by the research team to alleviate the challenges encountered in the field applications.

Development of Rail Anchor Testing Through Literature Review of CWR Buckling Resistance Evaluation	09
Teresa Salazar-Flores (presenter), Juan Rodriguez, Siang Zhou, Mustapha Rahmaninezhad, Constantine Tarawneh The University of Texas Rio Grande Valley, Edinburg, TX	
Continuously welded tracks (CWR) are among the most used railroad systems worldwide with great improvements compared to jointed tracks. Rail buckling is one of the key remaining issues for CWRs to further reduce safety hazards and infrastructure deterioration. CWR buckling results from a combination of longitudinal, lateral, and torsional forces acting on the track due to various factors such as rail components, moving train loads, track-substructure interaction, and thermal variations. An in-depth study of factors affecting rail stiffness (longitudinal, lateral, and torsional) is crucial to comprehend rail buckling and improve buckling resistance on CWR. This work summarizes and interprets existing research related to rail buckling resistance, considering parameters such as time-dependent neutral temperature of the tracks, the type of trains, various track resistors (rails, sleepers, and ballasts), and other accessories (anchors and fasteners). A discussion of previous experiments that studied resistors and rail buckling resistances is presented, which guides development of an experimental arrangement as part of an ongoing large-scale rail resistance testing project at UTCRS-UTRGV. The information summarized here identifies additional needs for experimental and numerical studies and provides structured background for prospective improvements on rail buckling and stiffnesses of CWR.	

Design and Testing of Full-Scale Track Panel Push Test	10

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For the past 40 to 50 years, the railway industry has increasingly focused on continuous welded rail (CWR) as a replacement for jointed tracks. The absence of rail joints in CWR systems increases the risk of thermal expansion-induced track buckling, which can result in catastrophic derailments and poses a significant safety concern. Longitudinal track resistance can play a critical role in ensuring track stability and minimizing temperature-induced rail stress damage. Rail anchors have long been used to enhance the longitudinal track resistance. Rail-tie anchors serve a multifaceted purpose in track stability - while they do distribute longitudinal or rotational loads to the ties, they also play a pivotal role in managing Rail Neutral Temperature (RNT). Although some investigations have been done on the longitudinal resistance of CWR tracks, there have been few comprehensive investigations that have isolated the influence of steel anchors on the longitudinal resistance of the rail-tie interface. The design and construction of a full-scale laboratory experimental track panel push test (TPPT) setup to assess the efficacy of rail anchors on longitudinal track resistance are presented along with some results acquired from the initial testing of TPPT evaluating several rail-anchor loading configurations.

Multivariate Calibration for an Onboard Load Sensor in a Shear Adapter Pad Assembly	11

Diego Aguila (presenter), Constantine Tarawneh
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To fully characterize the health condition of a railroad bearing, three parameters must be tracked and measured. These are: temperature, vibration, and applied load. Currently, there are onboard monitoring sensors that can track and record the temperature and vibration profiles, however, there are no onboard sensors that can accurately and reliably measure the load applied on each bearing within the railcar. Hum Industrial Technology, Inc., alongside researchers at the University Transportation Center for Railway Safety (UTCRS) are working on developing and deploying a prototype onboard load sensor for both static and dynamic operating conditions. This research aims to make this sensor ready for field applications by implementing a means to compensate for the effects of bearing operating temperature on the strain gauge. This temperature calibration is essential for effective functionality of the load sensor and to ensure the accuracy and efficacy of the sensor during dynamic rail service operation where the bearing operating temperature will fluctuate significantly depending on the railcar operating load and speed. This endeavor is well-aligned with the USDOT strategic goal of enhancing the safety and efficiency of railroad operations.

Experimental Investigation of Lateral Load Effects on Railway Tapered Roller Bearing Performance	12
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When a freight train railcar is at rest, the wheelsets and their bearings bear the weight and stress in a primarily static, radial loading. However, when set into motion, the scenario changes significantly due to the inherent imperfections in rail tracks and the presence of curves or turns in various locations. These imperfections can cause the loaded railcar to shift from side to side, subjecting the bearings to lateral forces. Surprisingly, limited research has been carried out or made publicly available on the effects of lateral loading on the performance of railroad tapered-roller bearings under various train speeds at empty and full railcar loads. Motivated by this, researchers at the University Transportation Center for Railway Safety (UTCRS) are conducting laboratory testing utilizing the available dynamic bearing test rig to explore the effects of lateral loading on bearing performance. The laboratory testing is designed to mimic lateral forces that bearings will experience during events like hunting, buckled track, uneven track, and instances where trains are navigating curved sections of track. The results of this study are expected to inform rail operators on the effects of lateral loads on bearing operating temperature and vibration levels with the goal of optimizing rolling stock condition monitoring technologies.	

Inactive Bearing Performance Characterization Study	13

Curtis Pena (presenter), Constantine Tarawneh, Robert Jones
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Railroad tapered roller bearings rely on grease to reduce friction and wear and to cool the components during dynamic operation. When the bearing is static for a prolonged period, the base oil and thickener may begin to separate, affecting cooling and anti-friction properties. The potential for such changes to impact bearing performance and reliability has led researchers at the University Transportation Center for Railway Safety (UTCRS) to investigate this aspect of bearing operational history to assess the performance of tapered roller bearings that have experienced long periods of inactivity while railcars are parked in railyards. A dynamic four bearing tester (4BT) designed by the UTCRS simulates operating conditions for bearing life assessment while differential scanning calorimetry (DSC) and standard grease characterization and viscosity measures are used to understand the effects of inactivity on the grease. The study includes bearings with varying storage durations and environments and assesses bearing performance, lubricant quality and performance, and bearing component degradation. Understanding the effects of prolonged storage on bearing performance can guide maintenance protocols, contributing to the reliability, longevity, and safety of rolling stock bearings.

Optimized Vibration-Based Health Metrics for Freight Rail Bearings	14
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In the railroad industry, monitoring the condition of freight railcar bearings in-service is carried out through two primary systems: wayside hot bearing detectors (HBDs) and trackside acoustic detection systems (TADS™). However, these systems face challenges in accurately assessing bearing fatigue and distress, especially during initial defect stages. To address this, the University Transportation Center for Railway Safety (UTCRS) developed a wireless onboard condition monitoring technology. Unlike existing methods, this system continuously monitors in-service bearings, offering precise health assessments. It utilizes calibrated vibration thresholds based on correlations between bearing operating speeds and vibration signatures for healthy and defective bearings. Additionally, the system identifies faulty components in tapered-roller bearings through frequency domain analysis. To maintain accuracy of the onboard sensors in detecting defective components, the thresholds are periodically reassessed by employing regression analysis to establish revised thresholds that incorporate the latest vibration data collected from laboratory testing of healthy and faulty bearings. These revised thresholds can enhance the health monitoring of in-service bearings, enabling rail operators to identify issues early, schedule maintenance, and prevent costly and unnecessary train stoppages. This research aims to improve bearing health monitoring in the railroad industry, ultimately reducing catastrophic derailments and associated human and capital losses.	

Railroad Track and Wheel Detection with Onboard Condition Monitoring System	15
Jeffery Pams[1] (presenter), Constantine Tarawneh[1], Brent Wilson[2], Lee Cantu[2] [1]The University of Texas Rio Grande Valley, Edinburg, TX [2]HUM Industrial Technology, Inc., St. Louis, MO	
The Federal Railroad Administration's (FRA) Office of Safety Analysis estimates that over 1,000 train derailments occur every year in the United States, with a significant number being caused by mechanical failures such as defects within the wheels and tracks. The use of wireless onboard health monitoring technologies has been receiving attention after recent catastrophic derailments. Through research, development, and implementation of onboard condition monitoring systems by the University Transportation Center for Railway Safety (UTCRS) and HUM Industrial Technology, Inc., a promising method to detect wheel and track defects has been field tested in freight revenue service. HUM's onboard condition monitoring system, which includes the Boomerang (the onboard module with a suite of sensors), and the Gateway (the wireless communication module), has improved the visibility of data pertaining to railcar operating conditions by measuring vibrations generated by the bearings, wheels, and wheel-track interactions. By correlating these data to measured vehicle speed and GPS locations, the data pertinent to wheel and track aberrations can be parsed and verified against known defect signatures of each component or track. This study highlights the capabilities of onboard condition monitoring systems for determining in-situ wheel defects and extrapolations to track defects and low-speed defect monitoring.	

Healthy And Defective Tapered Roller Bearing Temperature Metrics	16
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The safe and efficient transport of freight in the railway industry relies heavily on monitoring bearings and wheels. Bearing seizures remains a significant concern, capable of causing catastrophic train derailments. This underscores the critical need for effective monitoring practices. Wayside detection devices like Hot Bearing Detectors (HBDs) and Trackside Acoustic Detection Systems (TADS™) monitor, respectively, bearing temperatures and acoustic emissions as trains pass. However, these systems have shown inaccuracies in fault detection, resulting in unnecessary and costly train stoppages and delays. Additionally, bearing operating temperatures can exhibit random trends due to roller misalignments, even without defects. This study aims to provide comprehensive bearing operating temperatures for healthy and defective bearings under typical rail service conditions. It includes two decades of laboratory experiments on AAR Class F and K railroad bearings, covering bearings with defective cup (outer ring) and cone (inner ring) raceways of varying severity. Intriguingly, the data shows that bearings with relatively small defects operate at temperatures similar to healthy bearings. This raises concerns about HBDs' ability to detect faulty bearings in time for preventive maintenance. Nonetheless, the data offers valuable insights into healthy and defective bearing temperature metrics for the rail industry.	

Measuring Geometric Tolerance Changes in Reconditioned Railroad Bearing Raceways	17

Diego Leal (presenter), Constantine Tarawneh
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Railway maintenance has a major impact on the safety and efficiency of train operations. Among the critical components are bearing raceways within the cup (outer ring), where geometric tolerances are crucial for optimal performance. This project focuses on investigating the geometric tolerances of railroad bearing raceways after they have been reconditioned. Currently, a simple test setup is being utilized that allows the measurement of geometric concentricity of bearing outer ring (cup) raceways. Preliminary measurements of new, lightly used, and reconditioned bearing cups indicate that raceways of reconditioned bearings exhibit higher than normal geometric concentricity, especially near the spacer ring region. These tolerance deviations can compromise the integrity of bearing raceways, leading to increased friction and wear, which can ultimately result in bearing burn-off and train derailment. Understanding the reasons behind these geometric concentricity issues present in reconditioned bearings is key to implementing corrective measures to this process to ensure the safety and reliability of freight rail service. Future work will involve devising a sophisticated setup integrating precise LVDTs so that exact measurements of raceway geometric concentricity can be acquired and mapped.

Onboard Condition Monitoring Sensor Module Installation on Railroad Bearing Adapters	18
Daniel Reyna (presenter), Constantine Tarawneh The University of Texas Rio Grande Valley, Edinburg, TX	
With the adoption of onboard condition monitoring technologies on the rise, installation of these devices on freight railcars presents a challenge given the variations in bogie configurations in rail revenue service. Since sensors cannot be affixed to the bearing itself due to the possible indexing of the bearing outer ring (cup) during dynamic operation, the bearing adapter is commonly utilized for the installation of the sensor modules. The bearing adapter is the component on the railcar suspension system (bogie) that mates the bearing with the side frame. The work presented here aims to provide detailed steps on the installation of the HUM Boomerang – a wireless onboard condition monitoring sensor module developed by HUM Industrial Technology, Inc., in partnership with the University Transportation Center for Railway Safety (UTCRS) – on the bearing adapter. The installation involves machining the adapter to accept the sensor module while ensuring that: (1) the sensors are properly aligned, and (2) the sensor module is rigidly attached to the adapter to mitigate any relative motion that can affect the acquired vibration signatures. Methods used to optimize the installation process for time and effort are also presented.	

Kernel Ridge Regression in Predicting Railway Crossing Accidents	19

Ethan Villalobos[1] (presenter), Jia Chen[2], Evangelos E. Papalexakis[2], Ping Xu[1], Constantine Tarawneh[1]
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Expanding on insights gained from an initial investigation into railway accident patterns by the authors, the current research delves deeper into the predictive capabilities of machine learning to forecast potential accident trends in railway crossings. Focusing on critical factors such as "Highway User Position" and "Equipment Involved," Kernel Ridge Regression (KRR) models tailored to distinct clusters are integrated, as well as a global model for the entire dataset. These models, trained on historical data, discern patterns and correlations that might elude traditional statistical methods. The findings are compelling: certain clusters, despite limited data points, showcase remarkably Root Mean Squared Error (RMSE) values between predictions and real data, indicating superior model performance. However, certain clusters hint at potential overfitting, given the disparities between model predictions and actual data. Conversely, clusters with vast datasets underperform compared to the global model, suggesting intricate interactions within the data that might challenge the model's capabilities. The performance nuances across clusters emphasize the value of specialized, cluster-specific models in capturing the intricacies of each dataset segment. This study underscores the efficacy of KRR in predicting future railway crossing incidents, fostering the implementation of data-driven strategies in public safety.

Spectral Clustering in Railway Crossing Accidents Analysis	20
Miguel Gutierrez[2] (presenter), Ethan Villalobos[1], Biqian Cheng[2], Ping Xu[1], Jia Chen[2], Evangelos E. Papalexaki[2], Constantine Tarawneh[1] [1]The University of Texas Rio Grande Valley, Edinburg, TX [2]The University of California-Riverside, Riverside, CA	
This study employs graph mining and spectral clustering to analyze patterns in railway crossing accidents, utilizing a comprehensive dataset from the U.S. Department of Transportation. By constructing a graph of implicit relationships between railway companies based on shared accident localities, spectral clustering is applied to identify distinct clusters of companies with similar accident patterns. This offers nuanced insight into the underlying structure of these incidents. The results indicate that "Highway User Position" and "Equipment Involved" play pivotal roles in accident clustering, while temporal elements like "Date" and "Time" exert a diminished impact. This research not only sheds light on potential accident causation factors but also sets the stage for subsequent predictive safety analyses. It aims to serve as a cornerstone for future studies that aspire to leverage advanced data-driven techniques for improving railway crossing safety protocols.	

AI-Based Hazard Detection for Railway Crossings	21
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Grade crossings are vital components of railway infrastructure. However, potential risks of collisions between vehicle-train and human-train are of concern. In 2020 alone, the National Highway Traffic Safety Administration (NHTSA) recorded over 1,600 vehicle-train collisions and 500 human-train collisions. Efforts by researchers, scientists, transportation companies, and government agencies have explored methods such as sensors, barriers, motion detectors, and cameras. The research presented here aims to apply deep learning (DL) and artificial intelligence (AI) techniques to enhance rail grade crossing safety. The devised DL model aims to offer robust, cost-effective, and reliable ability to detect hazards at grade crossings, under any environmental, lighting, and weather conditions. Development of the model will be accomplished with a dataset of labelled images captured at grade crossings by the authors. The DL model aims to provide detection of hazardous conditions at grade crossings consisting of wildlife, vehicles, pedestrians for the sole purpose of preventing dangerous operating conditions.	