IDEA

Innovations Deserving
Exploratory Analysis Programs

RAIL SAFETY

New IDEAS for Rail Safety

Rail Safety IDEA Program Annual Report

December 2022

NATIONAL ACADEMIES Sciences Engineering Medicine

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NEW IDEAS FOR RAIL SAFETY

Annual Report of the Rail Safety IDEA Program

The Rail Safety IDEA Program is funded by
the Federal Railroad Administration (FRA)
and is managed by the Transportation Research Board.

December 2022

NATIONAL ACADEMIES Sciences Engineering Medicine

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INTRODUCTION

This annual report presents a summary of progress on investigations conducted as part of the Rail Safety Innovations Deserving Exploratory Analysis (Rail Safety IDEA) program sponsored by the Federal Railroad Administration. The program is managed by the Transportation Research Board, part of the National Academies of Sciences, Engineering, and Medicine, and technical oversight is provided by the Transportation Safety IDEA Program Committee.

Rail Safety IDEA is one of three IDEA programs managed by the Transportation Research Board (TRB) to improve railroad safety and performance. The Federal Railroad Administration is interested in proposals that will improve safety and performance in railroad systems, including in the following areas: security, environmental impact; human factors; rolling stock and components; track and structures; track/train interaction; grade crossings; hazardous materials transportation; train occupant protection; trespass prevention; signaling and train control systems; and employee safety.

The other IDEA programs managed by TRB:

- Highway IDEA, which focuses on technologies, methods, and processes for application to highway systems in broad technical areas such as highway design and construction, materials, operations, and maintenance (part of the National Cooperative Highway Research Program); and
- Transit IDEA, which focuses on products and results of interest to transit industry as part of the Transit Cooperative Research Program.

All of the IDEA programs are integrated to support advances in highway, transit, rail, and intermodal systems.

The IDEA programs can receive proposals from any individual, including entrepreneurs, small and large businesses, and institutions. The program provides funding to investigate new and unproven concepts or to evaluate novel applications of technologies that have been tried, tested, or used for highway, transit, high-speed rail, or intermodal systems practice.

The selection of each IDEA investigation is made by consensus recommendations from the Rail Safety IDEA Program Committee, which comprises national experts in railroad research and practice, and whose members are listed at the beginning of this report. A technical expert is selected from outside TRB to serve as a voluntary advisor for each IDEA project. The technical project advisor provides continuing advice and counsel on the IDEA investigation to the investigator and the IDEA program office. To begin the product transfer process from the initiation of each IDEA project, a regional panel of experts is nominated to work with the investigator on product development and transfer to railroad practice. The products emerging from the Rail Safety IDEA program support a range of innovative developments for promising but unproven innovations to advance railroad practice. Such proposals can apply to any type of railroad, including high-speed railroads, intercity passenger railroads, or freight railroads.

Section 1 of this report presents short descriptions of projects completed before or during the 2022 program year. The products and results from these projects have been applied or are available for further investigation for application to railroad practice. The product status is described under each project. Because of limitations on IDEA resources, not all IDEA concepts that prove feasible can be accommodated for follow-up funding by the Rail Safety IDEA program for product transfer. Section 2 presents reports of investigations on projects active or completed during the 2022 program year; several projects in this section are in the initial stages of investigation.

In selecting new concepts, the IDEA program balances the quest for new products with an understanding of the barriers each product may face for application to practice. Assessing the level of readiness for deployment of IDEA products and results is important in deciding on follow-up actions that are necessary to transfer the IDEA product to practice. The annual report is intended to provide railroad practitioners with the background on each IDEA investigation and product in development so that a dialogue on its potential transfer can take place between the investigator and railroad practitioners.

The IDEA program welcomes your comments, suggestions, or recommendations on Rail Safety IDEA projects, products, and results presented in this report. Please forward them to The Rail Safety IDEA Program (attention: Dr. Inam Jawed), Transportation Research Board, 500 Fifth St. NW, Washington, DC 20001, Email: ijawed@nas.edu.

General information on the IDEA programs, including how to apply for funding, may be found on the TRB website at https://www.trb.org/IDEAProgram/IDEAProgram.aspx.

SECTION 1
COMPLETED IDEA PROJECTS

Color-Corrected Motor Vehicle Headlight, Rearview Mirror, and Windshield Glare Control

Safety IDEA Project 01

Research Agency:	Dr. Gordon Harris
Principal Investigators:	Dr. Gordon Harris and Daniel Karpen
Completed:	February 2005
IDEA Contract Amount:	$90,000

The purpose of this project was to use clinical optometric research and field trials to investigate the reduction in glare and improvement in night visibility from the use of Neodymium Oxide doped headlights, rear view mirrors, and windshields.

Neodymium Oxide, as a component of glass, selectively filters out yellow light. Neodymium Oxide can be incorporated into the glass of the headlight lamp, rear view mirror, and windshield. When yellow light is filtered out of the spectrum, the color contrast of other colors is improved. Improvement in contrast can permit a motor vehicle driver to better discriminate viewed objects at night. Filtering yellow light from headlights reduces glare and should lessen eyestrain currently resulting from light emitted from conventional headlights of oncoming vehicles at night.

Neutral density filters and neodymium windshield glass were received and used in trial tests. Samples of windshield glass were received from windshield manufacturers.

Thirty subjects were tested in the offices of Dr. Gordon Harris, who is a doctor of optometry. Nine different tests were performed in the office. Field trials were conducted, in which 30 subjects carried out tests drives at night. The office test involved specific optometric tasks done in a clinical optometric setting, and the field trials involved road testing of standard headlights and Neodymium Oxide doped headlights.

The Draft Final Report was reviewed by members of the Expert Review Panel for this project and by the Safety IDEA committee. The revised Final Report for this project, addressing comments from these committee members' reviews, was submitted in February 2005. This project is completed.

The project investigators presented a Society of Automotive Engineers (SAE) paper on this project at the 2005 SAE World Congress in Detroit in April 2005.

The invention for headlights, which was tested in this Safety IDEA project, was subsequently commercialized and licensed to Federal Mogul Corporation following this project. That company sold over 1,000,000 Neodymium doped vehicle headlights under the trade name, True-View, in their Wagner Lighting Products division.

Auto Radio Override Alert System for Highway/Railroad Grade Crossings

Safety IDEA Project 02

Research Agency:	Midland Associates, Inc.
Principal Investigator:	Douglas Maxwell
Completed:	November 2005
IDEA Contract Amount:	$79,000

The purpose of this project was to test the proposed Auto Radio Override Alert System, which was designed to enable a train to override active AM and FM radios in motor vehicles in the immediate area of a highway/railroad grade crossing, to warn the motor vehicle drivers of the approach of the train. No modification or new device in the motor vehicle would be needed.

The concept of overriding the broadcast program was validated in earlier tests with the transmitter located on an emergency vehicle and transmitting only on certain FM frequencies. The objective of this investigation was to validate the design and application, with the transmitter located on a locomotive or at a highway/railroad grade crossing in a rural area, and transmitting the emergency message across the AM and FM broadcast bands.

The field tests, which would have been part of Stage 3 of this three-stage project, continued to be delayed as Midland Associates waited to get an experimental test license approved by the Federal Communications Commission (FCC). Since Midland Associates did not get a license from the FCC to allow them to do the field tests, following continued efforts by Midland Associates, this project was ended, as recommended by the Midland Associates' Principal Investigator.

The Principal Investigator prepared a project Final Report on the part of this project that was carried out, including what was learned in this effort. Lessons learned from this effort should be useful if there is any future consideration of a similar device. The Principal Investigator submitted the Final Report in November 2005. This project is completed.

Integration of LED Technology with Highway High Mast Illumination Equipment

Safety IDEA Project 03

Research Agency: Focus Illumination Limited

Principal Investigator: Phillip DeSantis

This proposal was withdrawn by the proposer. The proposer found technical difficulties involving the power supplies, which they felt would make the project unfeasible at this time. The Principal Investigator became ill also. This project would have been considered for joint funding by the NCHRP IDEA program and the Safety IDEA program if it had not been withdrawn.

Safety Effects of Operator Seat Design in Large Commercial Vehicles

Safety IDEA Project 04

Research Agency:	Virginia Tech
Principal Investigator:	Dr. Mehdi Ahmadian
Completed:	June 2005
IDEA Contract Amount:	$89,650

This project investigated the effect of seat cushion design in large commercial trucks on driver fatigue and vehicle safety. The project included field tests and evaluations, and development of guidelines for improving truck seat design to address driver fatigue.

This effort was motivated by the findings by the U.S. Department of Transportation and others that fatigue is a major factor in commercial vehicle accidents. The issues related to human fatigue (the long-term physical effect) are quite different and far more complex than those related to comfort (the short-term effect on human body) that have been studied extensively in the past.

The project validated the findings of Virginia Tech's laboratory studies, by investigators conducting a series of field tests and evaluations using class 8 trucks. This included the tests on a semi-truck (i.e., a Volvo VN Series class 8 truck) at the Advanced Vehicle Dynamics Laboratory of Virginia Tech. The tests, which included both subjective and objective evaluations, were aimed at better understanding the relationship between seat design and driver fatigue and vehicle safety, in terms of driver alertness and attentiveness, reduced rates of accidents, frequency of near misses, and ability to perform the tasks that are commonly required during driving.

The Draft Final Report was reviewed by the Expert Review Panel for this project and by the Safety IDEA committee. The revised Final Report for this project, addressing comments from committee members' reviews, was submitted in June 2005. This project is completed.

The results of the research have been implemented. The air-inflated seat cushions that were developed and tested in this Safety IDEA project are available to the trucking industry. The two companies that have sold them are ROHO (seat cushion manufacturing company) and Volvo Trucks, North America, who were both participating industrial partners and had been involved in testing in this Safety IDEA project. Follow-on activity by the project investigators, after this project, included working with these industrial partners to collect additional test data in the field to further validate the methods that had been developed under this project. There was a substantial amount of participation in follow-on activity on the part of the industrial partners, working with the investigators from Virginia Tech.

Assessment of Driver Safety in Trucks

Safety IDEA Project 05

Research Agency:	Waypoint Research Inc.
Principal Investigator:	Dr. Michael Cantor
Completed:	October 2006
IDEA Contract Amount:	$89,260

This project tested "WayPoint," a web-based, non-verbal cognitive assessment tool, which has been shown to identify people who are at risk to drive various kinds of commercial motor vehicles. Waypoint Research Inc. (WRI) developed norms for drivers of long haul and local trucks. Test data was compared with the following criterion measures: preventable crashes, crash severity, and performance on a driver training range. WRI also replicated previous research showing a relationship between sleepiness and "WayPoint" score.

The test assessed the match between a driver's channel capacity (speed of information processing) and his or her "situational awareness" (how aware the person is of the visual field). Potential applications for trucking companies that operate fleets of heavy trucks include driver selection, identification of drivers who would benefit most from training, a diagnostic for the kind of training that would be most effective and for feedback to the driver.

More than 1,200 truck drivers from seven different truck fleet operators took the "WayPoint" test on the web in this project. The research was done in cooperation with seven trucking companies.

The Draft Final Report was reviewed by the Safety IDEA committee and also by expert reviewers for this project. The revised Final Report for this project, addressing comments from committee members' reviews, was submitted in October 2006. This project is completed.

System to Detect Truck Hunting on Railroads

Safety IDEA Project 06

Research Agency:	Transportation Technology Center, Inc. (TTCI)
Principal Investigator:	Richard Morgan
Completed:	February 2006
IDEA Contract Amount:	$80,000

This project investigated the viability of using an array of non-contact, displacement measurement sensors (DMS) to detect railroad car truck hunting. The system is intended to provide information for monitoring the dynamic lateral stability performance of railroad car trucks passing a wayside installation. (See Figure 1.)

The system was developed using two stages: a laboratory stage (Stage 1) and on-track testing (Stage 2). During Stage 1, fiber optic DMS were selected and tested for the performance characteristics necessary for truck hunting detection; however, test results indicated that the selected sensors were unable to perform well in this application. The expert review panel recommended that an alternative DMS-based truck hunting detection prototype be evaluated in Stage 2 of the project. This prototype, developed by an Australian company known as Lynxrail, uses an array of paired inductive proximity DMS instead of fiber optic DMS.

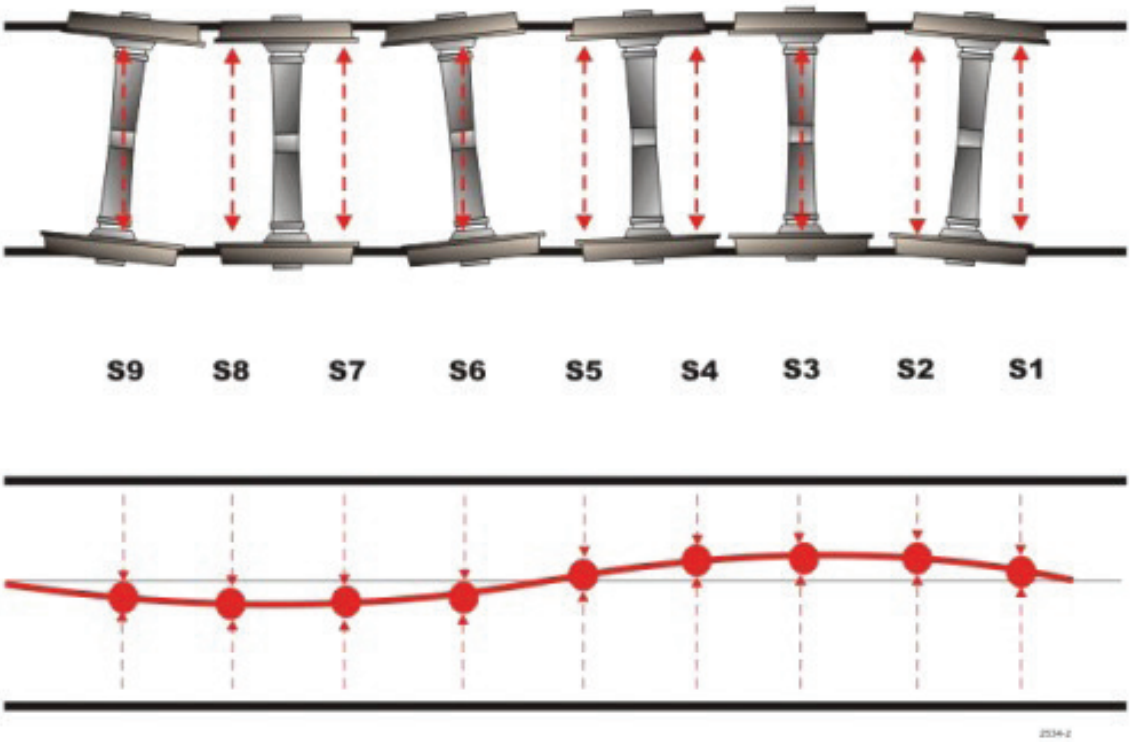


Figure 1: A wheelset's path captured by a multiple sensor array

At the time of the completion of Stage 1, there was an opportunity for an evaluation at a revenue service site for Stage 2. In July of 2004, the Norfolk Southern Corporation (NS), in conjunction with the Federal Railroad Administration (FRA), conducted a comparative test of truck hunting detection systems as part of their separate ongoing cooperative agreement for wayside component inspection demonstrations. TTCI was allowed to participate in the evaluation using the Lynxrail prototype in Flat Rock, Kentucky. (See Figure 2.)

The Stage 2 test results indicated that the Lynxrail prototype provided estimates of speed and Root-Mean-Square (RMS) of carbody end lateral accelerations that were highly positively correlated with those measured by onboard instrumentation. These results validated the concept of truck hunting detection via an array of paired DMS; however, variability was observed in the Lynxrail prototype estimates of RMS lateral accelerations, especially at higher vehicle operating speeds.

Changes in wheel/rail interaction and in truck performance make truck hunting a very dangerous event with the potential for derailment as a possible outcome. It is important to identify rail cars in service that exceed acceptable levels of truck hunting. Fulfilling this need through proper utilization of wayside, DMS-based truck hunting detection technology offers the obvious opportunity to curtail hunting related derailments, but it also provides possibilities to

Figure 2: Norfolk Southern test site for wayside detectors in Flat Rock, Kentucky

mitigate: (i) accelerated degradation of car suspension systems and wheel profiles, (ii) track damage, (iii) as well as damage to the payload of the car. Additional benefits may result from fact that the system is designed to be modular and transportable.

The prototype arrays of paired inductive proximity DMS performed adequately when compared with onboard data, and thus final development of the system should be encouraged. Several prototype enhancements needed to better support the operations of the North American railroad industry include: (i) incorporation of Automatic Equipment Identification (AEI) interface capabilities, (ii) ruggedization of track-mounted system components, (iii) protection of the system so it can successfully function in all North American climates, and (iv) possible improvements to the algorithms used to estimate RMS of carbody end lateral accelerations.

The Draft Final Report was reviewed by the Safety IDEA committee and also by the Expert Review Panel for this project. The revised Final Report for this project, addressing comments from committee members' reviews, was submitted in February 2006. This project is completed.

Driver Alertness Indication System (DAISY)

Safety IDEA Project 07

Research Agency:	Sphericon Ltd.
Principal Investigator:	Dr. Dan Omry
Completed:	December 2006
IDEA Contract Amount:	$78,000

This project tested the innovative concept for detecting driver inattentiveness that was developed by Sphericon. This concept is based on steering system dynamics: the separation of driver actions from the effects of the external world on the vehicle's lateral motion and using that relationship to evaluate driver alertness. When driver action is weighed against the effect of disturbances (bumps and road imperfections, wind gusts, etc.) on the lateral motion of the vehicle, a good measure as to the alertness or attentiveness of the driver can be obtained.

This project included the development and construction of a hybrid (hardware-in-the-loop) simulator which integrated a real steering system with a computerized simulator and with an elaborate set of sensors and data acquisition system. The use of such a simulator allowed experiments with inattentive drivers in the safe environment of the laboratory.

The last stage of the project included the enhancement of the DAISY algorithms. This involved conducting driving tests in the hybrid simulator with drivers at different stages of alertness and analysis.

Twenty-four tests were conducted of which eight were discarded due to various issues with the use of the new simulator system or with the test subjects. Analyses of the data were performed and the algorithms were enhanced to conform to the selected measurement approach. The results obtained from the tests were translated into an alertness indicator which was then compared with an index produced by subjective judgment: two investigators observed independently the recorded video of the test subjects and graded their level of alertness.

The comparative analyses conducted resulted in promising results. Although the analysis was qualitative in nature, the similarity of the pattern of the alertness index generated by DAISY to that produced by the subjective judgment method indicated the validity of the principles that govern the operation of DAISY.

The Draft Final Report was reviewed by the Safety IDEA committee and by the Expert Review Panel for this project. The revised Final Report for this project, addressing comments from these committee members' reviews, was submitted in December 2006. This project is completed.

Cracked Axle Detection on Moving Railcars

Safety IDEA Project 08

Research Agency:	Transportation Technology Center, Inc. (TTCI)
Principal Investigator:	Richard Morgan
Completed:	August 2006
IDEA Contract Amount:	$50,000

This project examined a method for remotely detecting cracks in moving railroad car axles. The objective of this project was to determine if Laser Air-coupled Hybrid Ultrasonic Technique (LAHUT) inspection methodologies developed for detecting flaws and defects in rail and railroad car wheels could be applied to wayside detection of cracks in freight car axles. Figure 1 shows a broken railroad axle that occurred in the FAST Track at TTCI.

The efforts focused on adapting LAHUT inspection methodologies for remotely detecting cracks in axles of test railcar wheelsets. This project includes developing procedures required to apply the LAHUT to detect axle cracks, followed by designing and conducting a proof-of-concept (POC) demonstration. Potential benefits include improved safety of railroad operations by removing cracked railcar axles from service prior to failure.

The developmental approach and testing of the cracked axle detection system included two stages. Stage 1 involved completing an extensive literature review of laser-based ultrasonic inspection methods. Stage 2 involved the planning and conducting of a POC demonstration in a dynamic environment.

Stage 1 activities included laboratory experiments using a high-energy pulsed laser to introduce ultrasonic wave modes into the axle body and an air-coupled transducer to monitor

Figure 1: Broken railroad axle

the ultrasonic waves. Figure 2 is a diagram of the lab set up used during Stage 1 testing. Data analysis techniques used during this stage of development monitored the ultrasonic signals for the arrival of both expected and unexpected waveforms.

Stage 2 activities focused on determining if the laboratory results could be used to construct a system for dynamic detection of surface breaking fatigue cracks in the axle body.

Figure 3 displays the components and Stage 2 test set-up used during the POC demonstration.

A single laser pulse was output by the high-energy laser. Some 206 axle passes were completed with six test axles containing defects. Forty-one passes were completed with axles containing no defects. At the conclusion of the POC demonstration, 88 percent of the defects were detected with only one false positive in 41 opportunities.

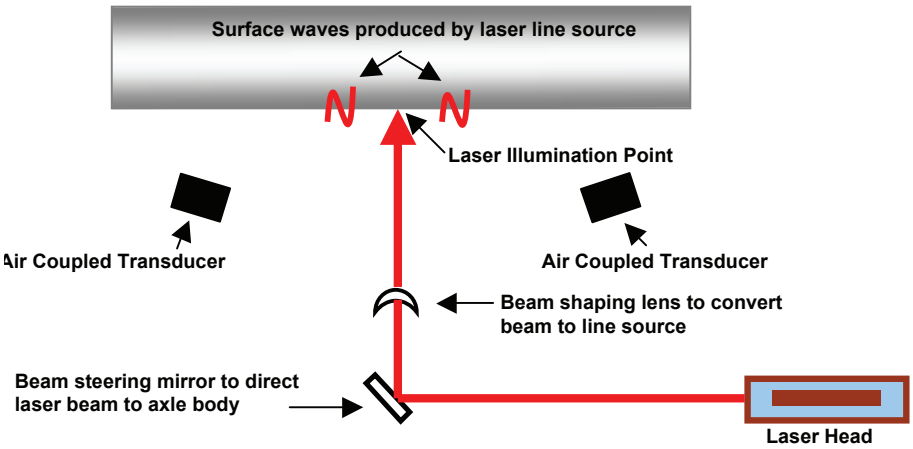


Figure 2: Axle inspection laboratory setup

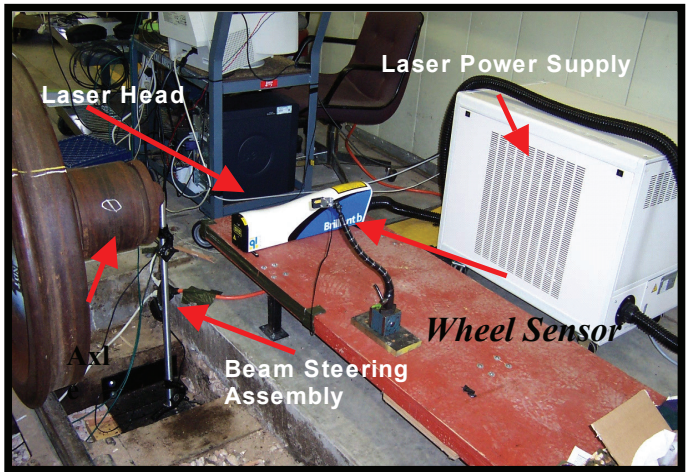


Figure 3: Proof of concept demonstration test setup

The results of the POC demonstration performed by TTCI clearly support the feasibility of using laser-based ultrasonic inspection to detect flaws in the axle body, both statically and dynamically. These results strongly suggest that this inspection technique could form the basis of a wayside system to detect cracks in the axle body. Further, it may be possible to extend the technique to find flaws in other axle segments (wheel seat and journal bearing area).

The Draft Final Report was reviewed by the Safety IDEA committee and also by the Expert Review Panel for this project. The revised Final Report for this project, addressing comments from committee members' reviews, was submitted in August 2006. This project is completed.

TTCI has continued development on an in-track system that will detect defects in both the axle body and wheel seat areas. Plans by TTCI after completion of this Safety IDEA project include system installation and testing at TTCI.

Driver Feedback Device for Passive Railroad Grade Crossings

Safety IDEA Project 09

Research Agency:	Westat
Principal Investigator:	Dr. Neil Lerner
Completed:	December 2006
IDEA Contract Amount:	$85,000

This project developed a low-cost, portable device to provide drivers with explicit feedback about the safety of their behavior at passive highway-railroad grade crossings. Passive grade crossings have no gates, barriers, or lights and are typically located in rural areas with relatively low traffic volumes and relatively low train volumes. At passive grade crossings, drivers are responsible for slowing sufficiently and searching for trains so that they can stop in time if a train is approaching.

Past research has indicated that many drivers do not behave properly at passive crossings. Any countermeasures to improve the situation at passive crossings should be low-cost. The concept in this project is to design an intelligent device that can determine whether drivers are exceeding safe approach speeds, given the sight distance, local train speeds, site geometry, and vehicle characteristics. Because the device would be portable, it could be used at multiple sites, in the same way speed trailers are used, thus making the cost per site low. It could be used for periodic or spot application at multiple passive grade crossings in a region or corridor.

Driver behavior research suggests that one reason for poor crossing behavior for some drivers is "benign feedback." Drivers may approach crossings too fast to allow effective visual search and safe stopping, however because the actual arrival of a train at about the same time is a relatively rare event, the experience is "benign" (no consequence) despite their errors. Thus they essentially think that what they did was OK. The driver feedback device under development here is designed to provide realistic, individualized feedback to inform drivers of unsafe behavior at grade crossings and teach them what is more appropriate. This driver feedback system is not intended to be a traffic control device that controls drivers' actions on their approach to a crossing. Rather it is an instructive system that informs the driver about what they did. It is meant to influence drivers in a given area even after the portable system has been removed for use elsewhere.

Figure 1 shows a conceptual example of the type of feedback provided to motorists after they encounter the crossing. This illustration is "conceptual" in that the message shown is idealized, but not really practical, given the on-road requirements for legibility distance, sign reading time, display size, and the capabilities of conventional portable changeable message signs. One of the tasks of the project was to devise an effective message and format that is both practical and well-understood.

Stage 1 of this two-stage project accomplished the following:

- Review of literature and technologies regarding state-of-the-art in traffic feedback systems
- Evaluation of road user requirements for message perception, comprehension, and acceptance (based on driver focus groups as well as literature and analyses)
- Determination of formal functional requirements and performance specifications.

The functional specifications developed in Stage 1 provide the basis for the engineering design in Stage 2 of this project. Functional specifications were derived for vehicle sensing, train sensing, environmental sensing, driver displays, user interface, rail crossing traffic data recording and storage, and other general device requirements.

In Stage 2, the project investigators designed and constructed a prototype system meeting the functional requirements. The system was then evaluated under systematic conditions in a test-bed setting.

There are close to 90,000 public passive highway-rail grade crossings in the U.S. The low vehicular and/or train traffic levels at passive grade crossings, or other factors, make it impractical to install and maintain upgraded levels of protection (e.g. gates or grade separation) at all of those crossings. The portable nature of the proposed device could provide a practical way to address safety at such locations. Feedback at any one location should also generalize in terms of improved driver behavior at other grade crossings. Thus there would be potential for widespread application and reduction of crashes.

The effectiveness of the device (measured in terms of improved driver behavior, during device operation and subsequent to device removal) would need to be verified and quantified through field evaluation at representative sites after this project.

The Draft Final Report was reviewed by the Safety IDEA committee and also by the Expert Review Panel for this project. The revised Final Report for this project, addressing comments from committee members' reviews, was submitted in December 2006. This project is completed.

Figure 1: Conceptual example of a driver feedback display for passive grade crossings

Monitoring Freight Train Position to Improve Emergency Response

Safety IDEA Project 10

Research Agency:	Union Switch & Signal Inc.
Principal Investigator:	Frank Boyle and Michael Pasternak
Completed:	May 2008
IDEA Contract Amount:	$71,000

The purpose of this project was to determine train location so that local authorities can respond more rapidly and effectively to emergencies. Web-based communication/information technologies were applied to the interaction and interfacing of local emergency response systems and freight trains. The application utilized GPS information to accurately display the positions of trains in real or near real time. A Geographical Information System (GIS) monitor for displaying train position is an improvement over existing displays, which present straight-line track diagrams.

This project included the technical development required to adapt the web-based information technology to handle railroad GIS data and concomitant displays. The project included testing the resulting "Civil Overviews" prototype display system. This project used CSX railroad track infrastructure data for analysis.

The Draft Final Report was reviewed by the Safety IDEA committee and also by expert reviewers for this project. The revised Final Report for this project, addressing comments from reviews, was submitted in May 2008. This project is completed.

Analyzing Near-Misses to Minimize Collisions at Railroad Crossings

Safety IDEA Project 11

Research Agency: University of California, Berkeley

Principal Investigator: Dr. Theodore E. Cohn

This proposal was withdrawn by the proposer. This was because they felt that it would be impossible to perform the work due to a number of technical issues, and because of the death of the Principal Investigator before the project could start.

Development of an Automatic Diagnostic System for Air Brakes in Trucks

Safety IDEA Project 12

Research Agency:	Texas Transportation Institute, Texas A&M University
Principal Investigator:	Dr. Darbha Swaroop
Completed:	December 2008
IDEA Contract Amount:	$80,000

This project developed a prototype system to automatically detect leaks in air brakes in trucks. This was an on-board diagnostic system. It estimated the push rod stroke, in real-time, from measurements of pressure in the brake chambers and supply reservoirs.

A leak in the air brake system is detected by making ``full" brake applications (i.e. a brake application where the steady state pressure in the brake chamber is nearly equal to the supply pressure) and comparing the steady state pressure measurements in the brake chambers with the supply pressure. The presence of a leak in the air brake system and the push rod stroke being greater than the re-adjustment limit, increases the lag in the response of the system to a pedal input by the driver, thus making the brake system response more ``sluggish". These factors will also lead to a decrease in the torque available for braking. A leak also increases the work load on the compressor and related components, thus leading to faster wear if undetected.

A diagnostic system was developed in this project that could be used by truck fleet owners to perform regular maintenance inspections and by road-side inspection teams as a fast and reliable tool in their enforcement inspections.

The Draft Final Report was reviewed by the Safety IDEA committee and also by expert reviewers for this project. The revised Final Report for this project, addressing comments from reviews, was submitted in December 2008. This project is completed.

Sensor Integration for Crash Avoidance for Trucks

Safety IDEA Project 13

Research Agency:	California Polytechnic State University (Cal Poly)
Principal Investigators:	Dr. Charles Birdsong and Dr. Peter Schuster
Completed:	February 2011
IDEA Contract Amount:	$75,000

This project developed and tested a low-cost crash avoidance sensing system for over-the-road class 8 trucks, by testing and integrating several different sensor technologies.

A good way to improve accident avoidance is through systems capable of detecting objects around the vehicle and detecting accident risk before it occurs (through improved situational awareness) and either warning the driver or preventing dangerous actions. This technology can enable commercial trucks to respond to potential risks and improve the driver's awareness of surrounding vehicles and situations.

This project investigated a system that combines several different low-cost sensors with an integration algorithm to achieve more information than the sum of the parts. This system was designed to balance weaknesses of one type of sensor with the strengths of others. The investigators worked with an over-the-road class 8 trucking company to test and evaluate the system.

The Draft Final Report was reviewed by the Expert Review Panel for this project and by members of the Safety IDEA Committee. The revised Final Report for this project, addressing comments from reviews, was submitted in February 2011. This project completed.

Onboard Railroad Wheel Monitoring System

Safety IDEA Project 14

Research Agency:	L-3 Communications Coleman Aerospace
Principal Investigators:	David Jacobs and Michael McCurdy
Completed:	February 2010
IDEA Contract Amount:	$70,000

The purpose of this project was to develop an economical onboard wheel monitoring system for railroad applications. Early detection of rail car wheel/bearing deterioration can help to minimize derailments and reduce damage to track. Advances in low power miniaturized sensors, processors and wireless communication systems could enable onboard wheel monitoring systems to be feasible.

The systems investigated in this project included a miniature device on the wheel axle assembly without any modification to existing equipment on the railcar; a wireless communication system forming a "discriminatory" mesh network, limited to the railcars on the train of interest, which communicates to a central monitoring station; and continuous monitoring of bearing temperature, vibration and acoustics, and wheel impact, allowing continuous data analysis.

The Draft Final Report was reviewed by the Expert Review Panel for this project and by members of the Safety IDEA Committee. The revised Final Report for this project, addressing comments from reviews, was submitted in February 2010. This project is completed.

Determination of the Longitudinal Stress in Rails

Safety IDEA Project 15

Research Agency:	Texas Transportation Institute, Texas A&M University
Principal Investigator:	Dr. Stefan Hurlebaus
Completed:	July 2011
IDEA Contract Amount:	$75,000

The objective of this project was to determine the longitudinal stress in rails, in order to reduce rail buckling due to temperature-induced stresses.

Continuous welded rails (CWR) are typically long members which are susceptible to failure caused by significant temperature changes. Such rail temperature changes can cause rail buckling, which can cause considerable disruption to railroad operations and, in the worst case, cause freight or passenger train derailment.

An important parameter in analysis of temperature induced stresses is the rail neutral temperature (RNT), defined as that rail temperature at which the net longitudinal force in the rail is zero. The objective of this project was to determine the longitudinal stress in rails using the polarization of Rayleigh surface waves, in order to reduce buckling and fracture.

Investigators at the Texas Transportation Institute, which is an Association of American Railroads (AAR) Affiliated Laboratory, worked together to develop a methodology to determine the RNT in a nondestructive and non-contact manner. This could give the railroads the opportunity to check their rail system and to adjust the installation of the rails by installing the track system at the RNT. The potential safety benefits of this method are that it could reduce rail buckling due to temperature-induced stresses, which could decrease the number of train derailments.

The Draft Final Report was reviewed by the Expert Review Panel for this project and by members of the Safety IDEA Committee. The revised Final Report for this project, addressing comments from reviews, was submitted in July 2011. This project is completed.

Rail Vehicle Bearing Defect Detection

Safety IDEA Project 16

Research Agency:	ENSCO, Inc.
Principal Investigator:	Dr. Yu-Jiang Zhang
Completed:	October 2011
IDEA Contract Amount:	$80,000

The investigators in this project conducted field testing to investigate the feasibility of detecting defective rail vehicle bearings using rail-mounted accelerometers.

The objective of this project was to test the technology under normal operating conditions to determine if the bearing signal detected by the accelerometers on the rail has sufficient signal to noise ratio to allow for reliable detection of bearing defects.

The project investigators worked with Norfolk Southern (NS) to conduct the field test on a continuously-welded-rail (CWR) railroad track that allows the test vehicle to travel at speeds up to 50 mph.

The project included test planning and design, equipment preparation, field testing, data collection, data analysis, and documentation.

The Draft Final Report was reviewed by the Expert Review Panel for this project and by members of the Safety IDEA Committee. The revised Final Report for this project, addressing comments from reviews, was submitted in October 2011. This project is completed.

Non-Contact Driver Drowsiness Detection System

Safety IDEA Project 17

Research Agency:	Case Western Reserve University
Principal Investigator:	Dr. Xiong (Bill) Yu
Completed:	2012
IDEA Contract Amount:	$100,000

This project developed and tested the effectiveness of an innovative real time drowsiness detection sensor to minimize vehicle crashes due to driver drowsiness. The sensor non-invasively monitors the physiological signs of drivers and determines the onset and extent of drowsiness. The project investigators developed the non-contact electrocardiography (ECG) and electroencephalography (EEG) sensing platform.

This project evaluated the system performance by installation on a laboratory high fidelity driving simulator and on a truck. It also evaluated the effectiveness of different countermeasures.

DRIVE-SMART Driver Monitoring and Crash Risk Mitigation System

Safety IDEA Project 18

Research Agency:	Virginia Tech Transportation Institute (VTTI)
Principal Investigator:	Dr. Thomas Dingus
Completed:	2012
IDEA Contract Amount:	$98,000

This project developed a driver monitoring and crash risk mitigation system, which is called DRIVE-SMART. This Safety IDEA project included development of the electronic hardware and software components, integration, and testing.

The system uses two small cameras, machine vision technology, on-board sensors, and data from the vehicle network to monitor driver distraction, drowsiness, speeding/aggressive behavior, alcohol impairment, and non-seat belt use. These are five major factors that can contribute to crash and injury risk. With the exception of seat belt use, redundant measures were used to reliably calculate individual and combined risk levels, for presentation of a real-time warning of elevated risk to the driver, and subsequent notification to authorities.

The relatively inexpensive system is wholly enclosed within a small and unobtrusive housing, which can be mounted to the windshield or dash to provide camera views of the driver's face and the forward roadway. Integrated, high-speed electronic components, including digital signal processors (DSPs), were used to ensure that warnings occur with sufficient speed to mitigate crash occurrence and/or severity, while avoiding false alarms. A single connection provides power and data access via the vehicle network's diagnostic connector.

Increasing Driver's Traffic Awareness around the Truck: Use of 3D Sounds

Safety IDEA Project 19

Research Agency:	Volvo Technology of America
Principal Investigator:	Dr. Dominic Paul Piamonte
Completed:	2012
IDEA Contract Amount:	$100,000

This project developed and tested a system using 3D sounds as a technique for augmenting the truck driver's traffic awareness around the truck. This is intended to contribute to increased safety of road users near and around the truck.

Work showed the potential of spatial or 3D auditory icons for accurately informing and warning the truck driver of vulnerable road users (pedestrians, cyclists, small vehicle motorists, etc.) near and around the truck, with high acceptance and satisfaction of use among truck drivers.

Most modern large truck cabs have a lot of sound insulation, since too much noise inside a truck is known to affect the driver's concentration and stress level. However, sound insulation of the truck cab, along with the inherent limited view around parts of the truck from inside the truck cab, contribute to the reduction in the driver's traffic awareness around the truck. The system developed in this project is designed to improve the truck driver's traffic awareness around the truck.

Material with Improved Absorption of Collision Forces for Railroad Cars

Safety IDEA Project 20

Research Agency: North Carolina State University

Principal Investigator: Afsaneh Rabiei

Completed: November 2014

IDEA Contract Amount: $100,000

This investigation examined the feasibility of using novel composite metal foams (CMF) with extraordinary properties of impact energy absorption capability, high temperature resistance, and fire retardant, with high sound and vibration dampening to improve the crashworthiness and safety of rail passenger cars and tank cars. CMF integrated into the structure of passenger cars or tank cars has the potential to significantly increase the crash energy absorption and safety of such structures. This would provide additional protection in case of collisions or derailments.

Numerous efforts have gone into understanding the mechanical properties of metallic foams in general and CMFs in particular. While most of those studies have covered the properties of the material under a variety of low-speed loading conditions, this study aims to extend the current knowledge by investigating the behavior of CMFs under high-speed loading rates to mimic the speed at which high-speed trains travel. For this purpose, the optimization of processing techniques for manufacturing CMFs took place first in order to enable the processing of large-scale and low-cost CMFs. Next a Split Hopkinson pressure bar was used to investigate the mechanical performance of CMFs under high-speed impact speeds of 13, 22, and 30 m/s (equal to about 30, 50, and 68 mph). The results showed that elastic modulus, strength, and total energy absorption of CMFs under such loading rates is significantly higher than those under quasi-static (slow) loading. This makes CMFs even more attractive for application in collision protection of railroad cars or other vehicles.

In the second set of high-speed loading experiments, mechanical properties of CMFs under higher strain rates of between 60 and 120 mph were studied using Hopkinson bar experiments. While most high-speed loading tests in the literature are up to low strain levels, this study is performed up to 50% stains. The results indicated high strain rate sensitivity for both steel-steel CMF (processed through powder metallurgy) and aluminum-steel CMF (processed through casting) samples, especially at lower strain levels up to 30% strain. This leads to a significant improvement of the energy absorption capacity of CMFs at higher strain rates. While the strain rate sensitivity of the parent material, micro-inertia effect, and shock wave propagation may contribute to the strain rate sensitivity of CMFs, the strengthening at high strain rates is mostly attributed to the kinetics of entrapped air inside spheres.

Moreover, our studies showed a great improvement in volume and weight saving while maintaining the same safety level, or dramatically improved safety levels, if the current weight of the Crash Energy Management System (CEMS) of railroad cars is maintained by using steel-steel or aluminum-steel composite foams.

Energy absorption per unit volume of steel CMFs at different loading rates (Figure 1).

Energy absorption @ 50% strain of 2 mm steel sphere in steel matrix CMF	Energy absorption @ 50% strain of 4 mm steel sphere in steel matrix CMF
76 (MJ/m^3)	67 (MJ/m^3)

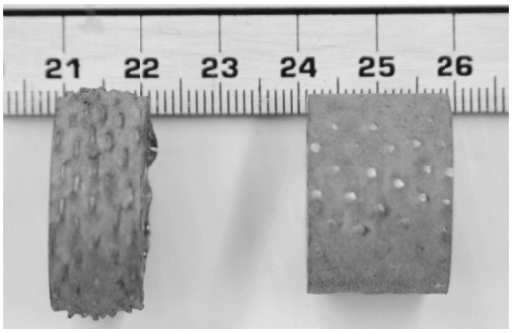


Figure 1: CMF samples with 4 mm steel spheres before and after high-speed impact.

The results of these studies provide us with a wealth of knowledge about the properties of CMF in different loading conditions with a variety of sizes and configurations, which is necessary for the design and manufacturing of full-scale CEMS prototypes in the future. This information is very useful for the utilization of CMFs in collision protection of railroad cars or other vehicles, as well as crushable workstation tables, tank cars, and more. It is notable that workstation tables on board rail cars need to deform in a graceful manner protecting the passengers sitting at the table, according to APTA standards. The current crushable tables are heavy in comparison with regular tables and require substantial structure to support them. CMFs can provide lightweight and exceptional energy absorption that can resolve the current issues with such tables.

The results of this study indicated a high strain rate sensitivity for both steel-steel CMF (processed through powder metallurgy) and aluminum-steel CMF (processed through casting). This can be translated to a significant improvement of their energy absorption capacity at higher strain rates, similar to those in collisions of railroad cars, which mostly resulted from the kinetic of entrapped air inside the spheres. The air will be heated due to fast plastic deformation of the foam under high-speed loading, resulting in higher air pressure inside the porosities and higher resistance against deformation under impact. This makes CMFs an excellent candidate for improving the safety of our trains. It is worth mentioning that the CMFs can provide additional capabilities such as being stable at high temperatures, fire resistant and not producing toxic fumes in the case of fire, and having high resistance against corrosion and chemicals compared with other current candidates of lightweight energy absorbers made of fiber composite plastics or polymers.

According to the results of this study, using steel-steel or aluminum-steel composite foams in the structure of CEMS of railroad cars will result in a great improvement in their performance while weight or volume is maintained. In the mean time, maintaining the same performance will result in a great volume and weight saving. The maximum force absorption by either type of CMF (aluminum-steel or steel-steel with various sphere sizes) is well exceeding the current FRA regulations of 800 kips buff strength for under-frame of conventional equipment and 1200 kips for alternatively designed equipment. This can be translated to a more efficient CEMS when CMFs are implemented.

Now that the properties of the material at various high- and medium-speed impacts are established in this current project, the application of the material in an optimized design structure of CEMS is necessary in order to take full advantage of the capabilities of the material in a final railroad car structure.

It will make sense to continue this research with a final step of design optimization, manufacturing a full-scale CEMS prototype, followed by a full-scale crash testing prior to the utilization of this novel material in railroad cars.

The technology for manufacturing CMFs is very easy to scale up and can be retrofitted into any production line. The PI is actively working to bring this technology into the market so that end users can benefit from its potentials in improving the safety of any structure such as trains, buses, or even cars.

Laser Cladding of Welds to Improve Railroad Track Safety

Safety IDEA Project 22

Research Agency:	University of Houston
Principal Investigator:	Francisco C. Robles Hernandez
Completed:	2015
IDEA Contract Amount:	$100,000

The purpose of this project was to explore the use of a laser-based technology, laser cladding, to reduce surface and near surface defects resulting from thermite field welds of rail. If a successful laser cladding process can be developed, it would prevent plastic deformation, particularly along the heat affected zone (HAZ) at the weld site. The process has the potential to enhance rail safety and integrity and increase rail life expectancy.

Laser cladding is a process to apply metal coatings using a laser as a heat source. The laser melts the base metal and an additive powder to create a protective coating (Figure 1). Previous attempts to use this procedure resulted in cracking of the cladding. This project examined the cracking problem, investigated potential solutions, and explored the feasibility of using this technique in the field.

The main reason for the problem of cracking previously encountered in laser cladding is the formation of martensite during the cladding process. Martensite is brittle under dynamic impacts, so it negatively affects the fracture toughness of the cladding. The focal point of this work was the reduction (retention) of martensite during laser cladding in order to solve the cracking problem and thereby improve the service life of the welds.

Project tasks included the selection and testing of various powder compositions, thermal analysis during cladding, mechanical testing of the cladding, development of an improved laser cladding procedure, and in-service testing of laser cladding samples.

Initial project tasks included the evaluation of powders and the selection of a powder composition for use in the cladding process, and an investigation of alternative heat treatment protocols to solve the cracking problem. Sample sections of laser cladded rail welds were then prepared using the revised process. These test sections were then installed and tested in the tracks at the Transportation Technology Center Inc. (TTCI) high-tonnage FAST loop at Pueblo, Colorado. The objective of these tests was to subject the test welds to 50 MGT (million gross tons) of heavy axle load train traffic and to monitor the welds during the tests.

Six test welds using the new laser cladding process were prepared. Two of the six were never installed in FAST due to the presence of pores in the cladding. The remaining four test welds were installed as two sets of two welds. The two welds in each set were installed in the same location. One weld was removed after approximately 20 MGT due to delamination of the clad-

ding. TTCI also removed the adjacent weld in that pair for safety reasons. Another test weld was removed after approximately 42 MGT, also due to delamination. TTCI again also removed the adjacent weld in that pair for safety reasons.

The project also examined the entire process necessary to apply laser cladding in the field. This included in situ heat treatment using induction or torch heating, and a preliminary assessment of other elements of the process including the use of CNC or robot arms and shot blasting or grinding of the welds.

The following is a summary of the results, conclusions, and recommendations of this project:

- Based on a limited sample of six welds made using the procedure developed in this project, the new heat treatment protocol appears to have solved the cracking problem previously encountered with laser cladding.
- The appearance of pores on two of the six test welds indicates the need for further investigation to determine the cause and cure for this problem.
- The delamination of the cladding on two of the four welds installed in the test track also indicates the need for additional investigation if laser cladding is to be further considered.
- Further consideration of laser cladding would also require a more comprehensive investigation of the entire process of laser cladding of thermite welds in the field from the standpoints of practicality and costs. Elements of this process of particular concern are the need for a heat treatment process suitable for use in the field, the need for high-precision CNC or robot arms, and the requirements for grinding or shot blasting of the rail as part of the cladding process.

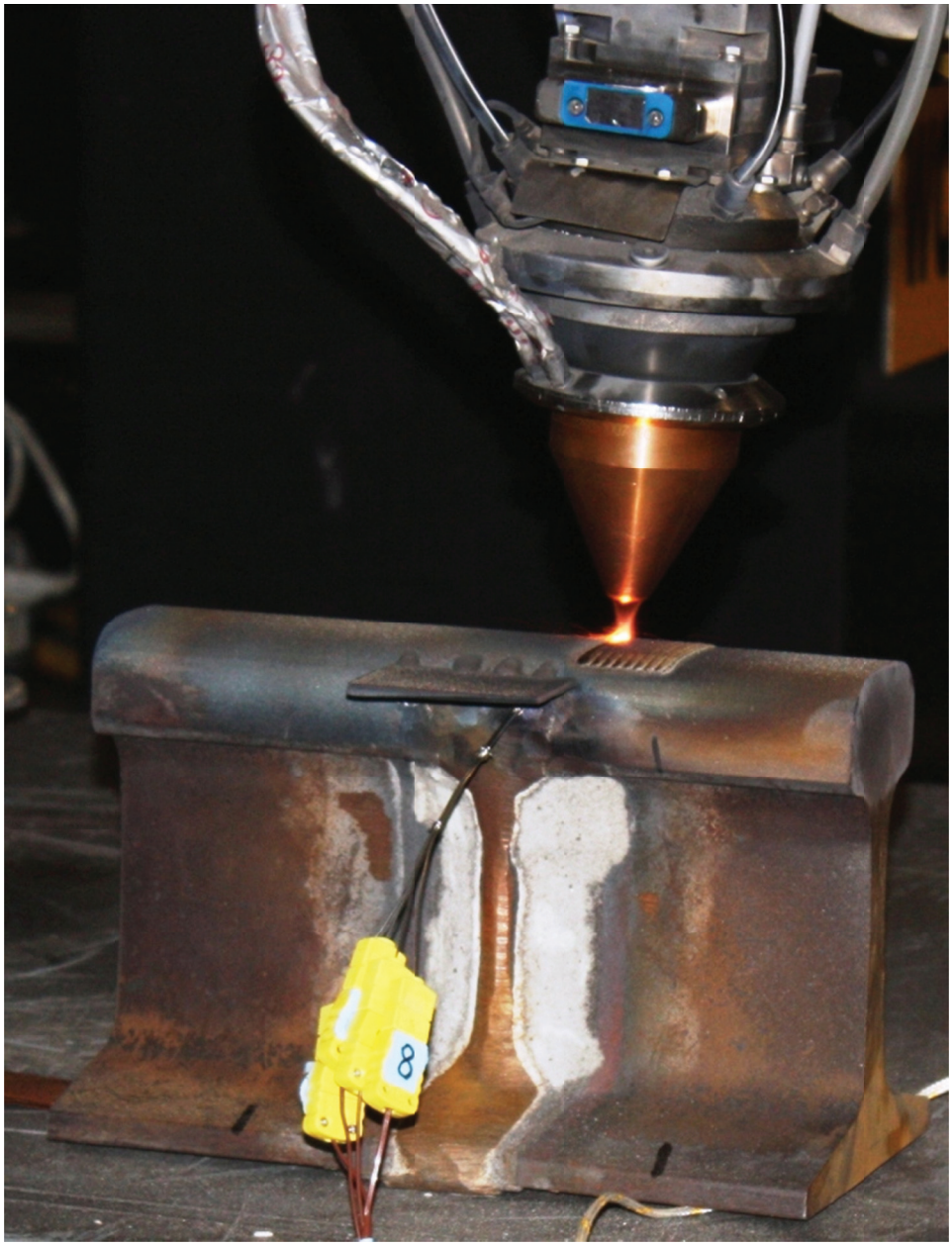


Figure 1: Laser cladding application showing thermocouples to record temperature.

Reducing Wheel Climb at Switch Points to Reduce Derailments

Safety IDEA Project 23

Research Agency: University of Delaware

Principal Investigator: Allan M. Zarembski

Completed: 2014

IDEA Contract Amount: $75,000

Wheel climb derailments in switches remain a major derailment category for both freight and passenger rail operations in the U.S. Wheel climb derailments occur at both high and low speeds, in both facing and trailing moves through the switches. While some causes are relatively straightforward, such as over speed entering or leaving the switch, or a broken point, most wheel climb derailments are a combination of a worn switch point (to include profile and angle of the switch point) and a worn wheel. A number of European railroads have adopted switch maintenance practices that focus on wheel climb in the switch point area, several of which have the potential to improve current U.S. rail maintenance practices.

This project included the results of a survey and detailed engineering analysis of international maintenance practices aimed at reducing the risk of wheel climb at switch points and describes the potential application of these practices for U.S. freight and passenger railways. As part of this activity, the study team examined international standards and practices from several major international rail systems and compared them with American Railway Engineering and Maintenance-of-Way Association (AREMA), FRA, and individual U.S. railroad switch point inspection practices. They then analyzed several of these practices from the perspective of the dynamic load environment of U.S. railroads to include expected lateral (L), vertical (V), and L/V force levels and the associated potential for wheel climb in the switch point areas.

The specific problems addressed by these practices and corresponding measurement gauges include:

- Improper flange contact between the wheel flange and the switch point (switch rail) that could lead to wheel climb.
- Excessive or unusual wear of the switch point (switch rail) and of the stock rail. This includes the condition where the stock rail head wear is greater than the wear on the switch point.
- Excessive switch point damage to include chipping and wear.
- Improper switch point (switch rail) profile to include switch rails with sharp gauge corner profiles.
- Excessively worn gauge face of the switch point or stock rail with corresponding sharp gauge face wear angle that could lead to wheel climb.

The researchers, working with an Expert Review Panel and Norfolk Southern research staff, developed a series of hand held measurement gauges to address these problem areas, based on European practice, and then modified to reflect U.S. conditions and practices. These gauges

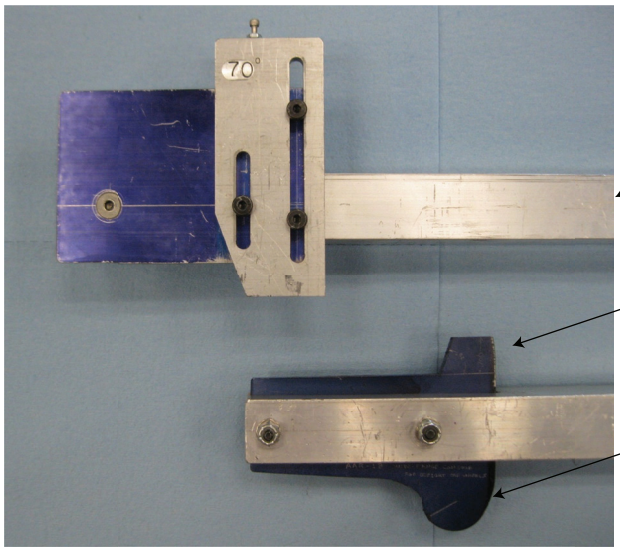
were then taken out into the field, for evaluation on a series of switches in various conditions, by a team of rail experts. Those gauges that were considered to be ineffective were dropped from consideration. A series of three such field evaluations were performed in a yard provided by Norfolk Southern.

The specific focus of the evaluations and gauges was on switch point conditions not currently fully addressed by FRA, AREMA, or known railroad practices, but which have been shown to contribute to wheel climb derailments in switches.

The Study Team determined that several gauges were of real value in defining poor switch conditions that could potentially result in a wheel climb derailment. These include gauges that looked at several problems commonly seen in U.S. switch points, such as improper flange contact between the wheel flange and the switch point, excessive switch point damage, and excessively worn gauge face of the switch point or stock rail with corresponding sharp profile angle.

Specifically, the following gauges were recommended by the Study Team for further development and field evaluation, and potential adoption by U.S. railways and transit systems to control wheel climb derailments:

- Chipped Point (CP2) Gauge: This gauge addressed chipped or damaged switch points.
- TGAAR1B Gauge: This is the U.S. version of the Network Rail TGP8 gauge, using an AAR 1B new wheel profile. Switch point contact below the 60° mark appears to be an undesirable condition, and this gauge was judged to be a helpful aid to inspection.
- Severe Profile Gauge (SP Gauge). This is the new (third) generation severely worn profile gauge that appears to work well in the field and gives an indication of potential for wheel climb derailment for a severely worn wheel. Additional development work is required for their use as a go/no go inspection tool.
- Gauge face angle gauge (GFAG) with a 32 degree gauge face angle is recommended as a check on gauge face angle and potential for wheel climb, particularly for high L/V conditions.



Unsafe wheel-rail contact as determined by TGAAR1B Gauge with contact below the 60° mark.

Based on the above tests and evaluations, it is recommended that railroads look into implementing the above recommended gauges for use in manual track inspections. A field demonstration of the gauges is recommended as the next Phase of the IDEA implementation activity.

High Speed Railroad Bridge Dynamics and Ratings

Safety IDEA Project 24

Research Agency:	Hatch Mott MacDonald, LLC
Principal Investigator:	Kevin Bollinger
Completed:	2014
IDEA Contract Amount:	$99,000

Bridge rating calculations are performed to determine the safe capacity of existing bridge structures. The American Railway Engineering and Maintenance-of-Way Association (AREMA) *Manual for Railway Engineering* (MRE) contains the current recommended practice used by the great majority of railroads in North America. The Foreword to MRE Chapter 15, Steel Structures, limits the application of the chapter to freight train speeds of up to 70 mph and passenger train speeds of up to 90 mph. Therefore, the chapter provisions do not provide a method to calculate a bridge rating for train speeds beyond 90 mph.

As speeds increase, impact values either increase or decrease depending on the dynamic characteristics of the bridge structure and equipment using the track. Currently, Amtrak is operating high-speed passenger trains at speeds of up to 150 mph on the Northeast corridor. This project investigated impact factors for speeds above 90 mph, to be used in capacity ratings of existing bridges. To accomplish this, basic structural dynamic methodologies and current structural engineering codes and procedures were utilized to propose an impact evaluation methodology consistent with current North American railroad bridge practice.

The current MRE impact equation includes rocking and vertical effect components. The rocking effect reflects the side-to-side movement of a train as it travels down the track, while the vertical effect component reflects the dynamic load amplification effect caused by the following key factors:

- Bridge stiffness and mass
- Structure natural frequency
- Damping
- Span length
- Axle weight and spacing
- Train speed

These factors were applied to various structural dynamic equations and known procedures common in the high-speed rail community. This allowed development of a moving load model used to determine the impact factor for train speeds greater than 90 mph. Results of the moving load model were then compared with field observations taken in November 2013 at Amtrak Bridge 155.85 (Figure 1) and prior impact tests reported by William Byers in 1970. Review of the field data showed that the mathematical model solutions compared well with actual bridge responses.

Once the model was verified with field data, calculations were performed establishing dynamic vertical effects at various train speeds (Figure 2), including those that induce resonance. The dynamic vertical effect value at resonance was then inputted into the AREMA MRE impact equation for a normal bridge rating. A flow chart was developed that illustrates the steps required for an accurate rating calculation.

In addition, calculations of vertical effects for five additional span lengths were completed. Examination of the phenomenon of resonance associated with different bridge span lengths confirms that resonance has a great influence on the dynamic vertical effect associated with the bridge and, as a consequence, the vertical acceleration of the bridge deck.

The authors recommended that steps now be taken to revise the AREMA MRE to incorporate these findings in order to accommodate higher train speeds.

Figure 1: Amtrak Bridge 155.85 over Usquepaug River, Rhode Island.

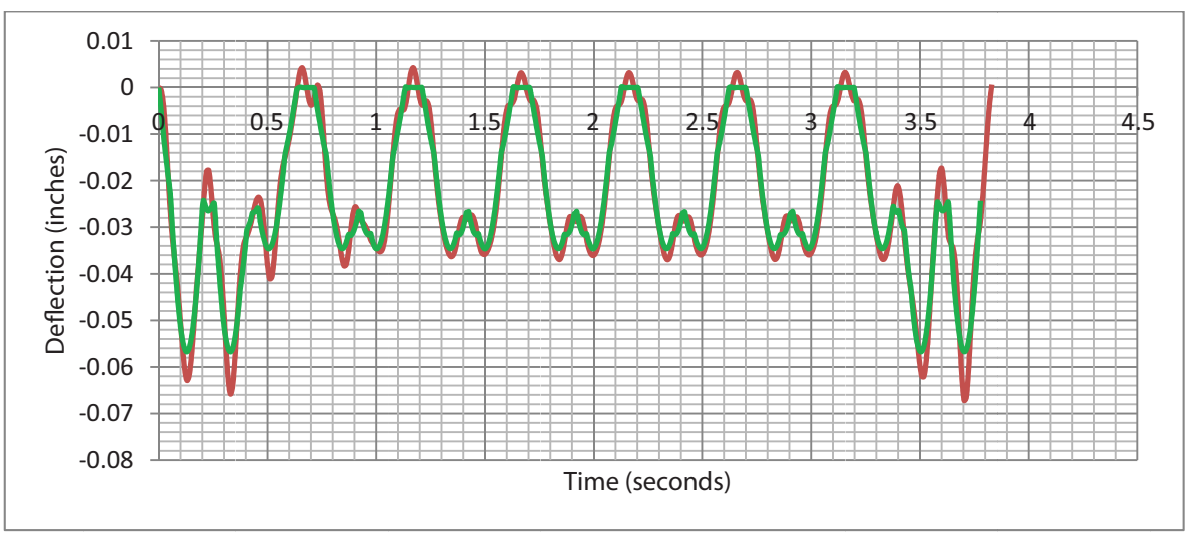


Figure 2: 120 mph train speed-induced girder deflections at midspan superimposed on the quasi-static 6 mph train.

Dynamic Impact Factors on Existing Long-Span Railroad Bridges

Safety IDEA Project 25

Research Agency:	University of Connecticut, Storrs
Principal Investigator:	Ramesh B. Malla
Completed:	February 2017
IDEA Contract Amount:	$100,000

Idea Concept and Product

There are many railroad truss bridges in the United States approaching or exceeding 100 years of age, which still carry a significant number of freight and passenger trains. Many of them are on passenger routes that are planned by Amtrak and FRA to be upgraded to carry passenger trains at much higher speeds than now authorized. Since these bridges are frequently part of a multi-span river crossing, the cost of replacement is very high. Thus, it is likely that these old steel structures will be called on to carry the higher speed trains. Hence, to ensure the safety of the bridges, it is essential to have a thorough understanding of the effects on them from higher speed trains.

This investigation aimed at understanding the live/dynamic load impact factor on existing older, long-span, steel truss railroad bridges caused by modern high-speed trains. The methodology is based on analytic/finite element modelling and field testing on an existing bridge. The first objective of this study was to develop an accurate finite element model (FEM) of the subject bridge. Second, field testing on the subject bridge was conducted under different types of common rail vehicles, with varying axle loads, axle spacings, and speeds. Using sensors on the bridge, static and dynamic responses, including strains, stresses, displacements, mode shapes, and frequencies, were recorded. The test results were compared with those obtained from the FEM. Once desirable correlation was achieved, thus confirming the validity of the analytical/computational model, the computer model was used to determine the effects of higher train speeds on the response of the bridge.

Project Results (or Planned Investigation)

A FEM of the eastern most, 217 ft., 2- track, Span 7 (next to the east abutment) of the nearly 110-year old seven-span Devon through open deck truss bridge over the Housatonic River between Milford and Stratford, Connecticut (Figure 1) was developed. Several field tests were performed at the bridge in 2014 and 2015. The 2014 tests were conducted under regular Amtrak Acela and Regional and Metro-North passenger trains at speeds close to or at 40 mph, the authorized speed limit on the bridge. The 2015 field tests were conducted using "test" trains provided by Metro-North Railroad and Amtrak (Acela train) at varying speeds of 5, 10, 20, 30, and 40 mph. Bridge response data (strains, stress, displacements, and accelerations) in floor systems members (stringers and floor beams), bottom chord eye bars, diagonals and end posts of the truss have been collected using appropriate sensors, strain gages, linear variable

displacement/differential transducers (LVDT), or accelerometers, The results of these tests have shown a close correlation with those predicted by the FEM analysis. Figure 2 shows sample strain gage readings from bottom chord eyebars, pictured in Figure 3. Figure 4 shows a comparison of LVDT measured displacement readings at node L8, north truss, at five speeds ranging from 5 to 40 mph. Figure 5 shows one of the bridge trusses with locations of various nodes indicated.

Figure 1: Span 7 of the Devon railroad bridge showing the open deck floor system and the truss structure.

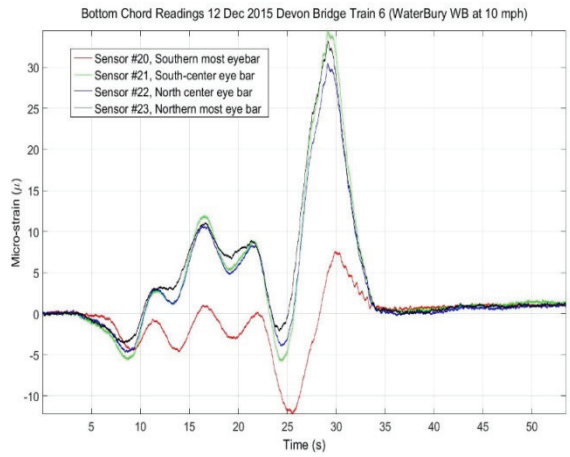


Figure 2: Strain readings on four eyebars, bottom chord L6-L8 South truss under Waterbury train westbound, on track 3 traveling at 10 mph.

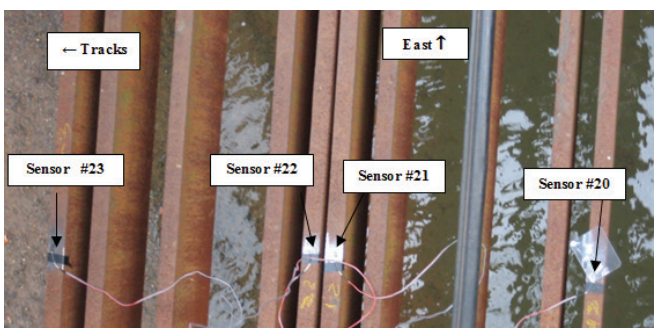


Figure 3: Plan view of bottom chord eyebars between nodes L6 and L8 (Figure 5) showing strain gages attached.

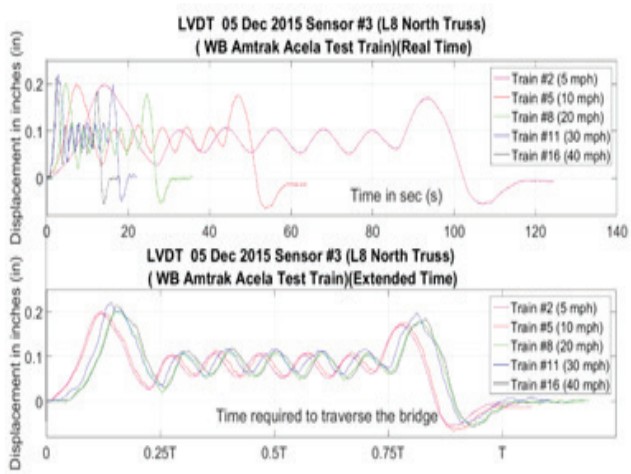


Figure 4: Vertical displacements at node 8 of Devon bridge north truss under Amtrak Acela train at various speeds.

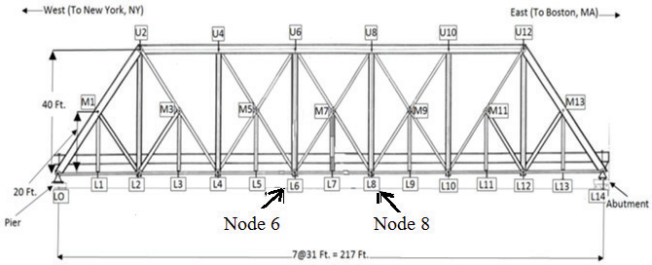


Figure 5: Elevation of the Devon bridge truss showing locations of various nodes.

A couple of representative conclusions based on the study include: (a) the strain readings from a group of eyebars making up the truss' bottom chord show evidence of the unequal stresses from one eyebar to another between the same two panel nodes; and (b) within the speed range considered, although the field test results indicated no noticeable difference in the amplitudes of vertical displacements of selected nodes with different train speeds, the results from the FE analysis of the bridge showed that at resonant train speeds there was a sudden increase in the displacement of a node, and different trains would induce this peak displacement at different speeds.

Product Payoff Potential

The ultimate objective of this research was to understand, through analytical/ computational study and field testing, the effects of train speeds on the dynamic impact factor on long span open deck steel truss railroad bridges. Of particular interest is to predict the effects on the bridge response due to trains operating at speeds higher than now authorized on these structures. Therefore, the research outcome has the potential to provide railroad bridge engineers with the a more rational basis in which to establish the safe loading carrying ability of old bridges, as well as its remaining life. Thus, it will have the potential to give the railroad industry better tools for rating existing bridges, designing new ones, and increasing bridge safety by better quantifying stresses due to live load impact.

Product Transfer

The results from the project should contribute to improving railroad safety and reducing the costs of upgrading existing railroad bridges to accommodate high-speed rail service, predict remaining life, improve rating of the structures, and increase structure safety and reliability. Therefore, the research results should find immediate use by state departments of transportation, USDOT FRA, Amtrak, and private railroad companies. The results from the research have been and will be continued to be shared through various modes of technical publications and presentations.

Acknowledgments: The principal investigator acknowledges, with much gratitude and appreciation, the financial and/or in-kind supports received for this research project from the following organizations: U.S. DOT Federal Railroad Administration; Transportation Research Board of the National Academies of Sciences, Engineering, and Medicine; Bentley Systems, Inc.; Connecticut Department of Transportation; MTA Metro-North Railroad; AMTRAK; STRAAM Group; Trans-Tek, Inc.; and the University of Connecticut.

Remote Sensing with Mobile LiDAR and Imaging Sensors for Railroad Bridge Inspections

Safety IDEA Project 26

Research Agency:	Florida Institute of Technology
Principal Investigator:	Luis Daniel Otero
Completed:	August 2016
IDEA Contract Amount:	$100,000

IDEA Concept and Product

The overall goal of this research project was to investigate the applicability of mobile Light Detection and Ranging (LiDAR) and imaging sensors to help detect concrete cracks and displacement of railroad bridge components. This overall objective was divided into three research objectives. The first research objective included developing and evaluating prototype image processing algorithms for concrete crack detection and classification. The second included developing and evaluating three-dimensional (3D) models from LiDAR data to identify signs of bridge component displacements. The third evaluated the effects to the image processing algorithms and 3D models with data collected using an unmanned aerial system (UAS) with integrated LiDAR and imaging sensors.

Research Objective #1 - Algorithms to Detect/Classify Concrete Cracks:

The research team developed prototype unsupervised image processing algorithms to detect and classify longitudinal, transversal, or block cracks on concrete bridge surfaces (e.g., pile caps). The algorithms were evaluated using non-processed images collected with a UAS. The algorithms were 83% effective in correctly detecting and classifying concrete cracks.

Research Objective #2 - 3D Models to Evaluate Bridge Component Displacements:

For this research objective, a mockup bridge structure was constructed using polyvinyl chloride (PVC) material to conduct experiments prior to conducting more expensive field tests (see Figure 1a). A LiDAR sensor was placed on a tripod mount at a distance of x feet from the PVC structure, and a portion of the PVC structure was inclined y inches using wooden stakes. The alignment (i.e., registration) of LiDAR data to develop 3D models was accomplished using an algorithmic approach that does not require any GPS/IMU metadata. The resulting 3D models showed that a 0.5 inch inclination was easily identified with the sensor located 10 feet from the structure, and using only 20 LiDAR scans (see Figure 1b). Afterwards, 3D models were developed from LiDAR data collected with a UAS. Comparisons among the resulting 3D models from the UAS data acquisition approach versus those from the controlled sensor location approach indicated that there was no noticeable difference between them.

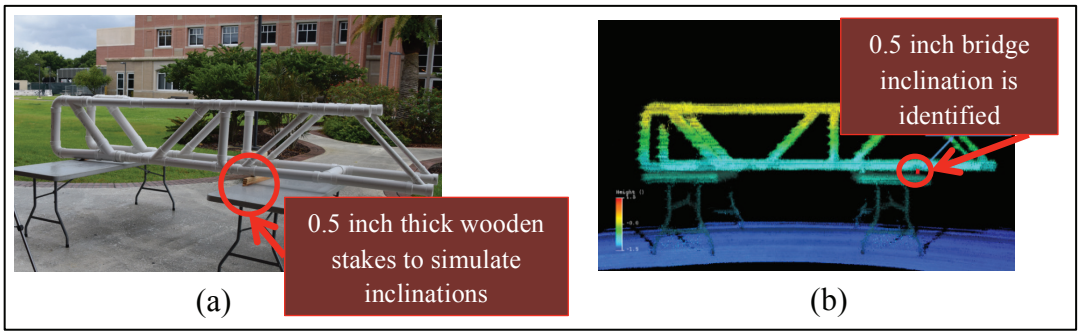


Figure 1: (a) PVC bridge for controlled experiments; (b) 3D model showing 0.5 inch structural deviation.

Research Objective #3 - UAS Prototype with Imaging and LiDAR Sensors:

A customized UAS was fully built by the research team to accommodate key subsystems such as the mobile LiDAR sensor and an onboard LiDAR data storage unit. The UAS, denoted multi-purpose autonomous vehicle–flat eight (MAV-F8) was designed as a sensor testing platform capable of lifting relatively heavy and large sensor payloads. Figure 2a shows a snapshot of the fully integrated prototype MAV-F8 UAS. Figure 2b shows the UAS collecting LiDAR data during an indoor controlled test.

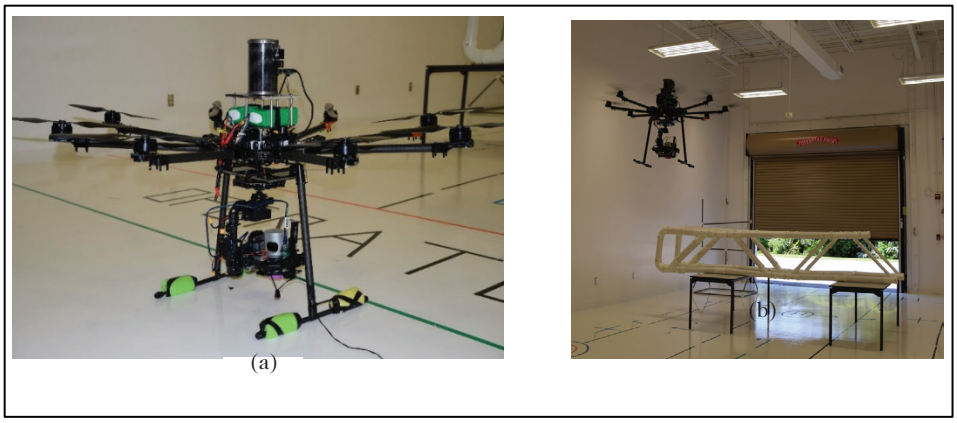
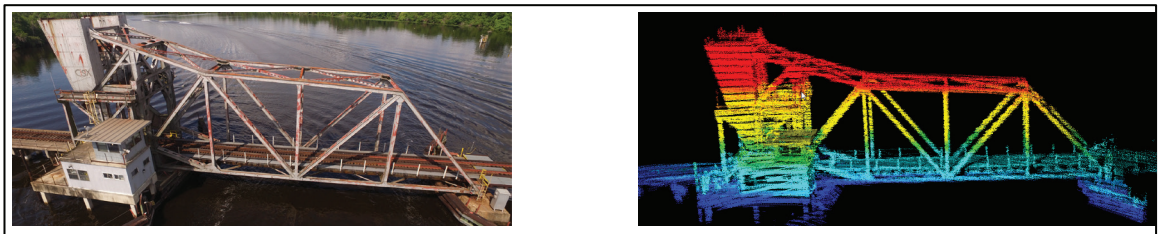


Figure 2: (a) Fully integrated UAS; (b) Indoor UAS flight around PVC bridge.

Figure 3a shows a CSX-owned railroad bridge in Palatka, Florida. Figure 3b shows a resulting 3D model from LiDAR data collected using the MAV-F8 UAS during field tests.



(a) (b)

Figure 3: (a) CSXs railroad drawbridge; (b) 3D model of drawbridge from LiDAR data.

This research highlighted the potential practical value from using UAS and sensor technology for bridge inspection purposes. Potential payoffs for practice include improved safety and accuracy of inspections, and reduced inspection costs.

This research project significantly benefited from the support of the Florida Department of Transportation and CSX Transportation, Inc., which is one of the nation's leading transportation rail-based suppliers. The overall consensus from industry partners was that this technology has the potential to mature into a bridge inspection system that could positively and significantly impact performance, effectiveness, and safety associated with bridge inspections. Some of the future research directions that were identified by industry partners to realize such a system include more field tests on structures with known defects to determine the system's capabilities for defect detection; the development of user-friendly software interfaces for efficient user-system interactions on the field; the development of supervised learning algorithms for concrete crack detection and classification; and implementing a geo-referenced approach for LiDAR data registration.

Field Evaluation of Ballast Fouling Conditions Using Machine Vision

Safety IDEA Project 27

Research Agency:	University of Illinois at Urbana–Champaign
Principal Investigator:	Erol Tutumluer
Completed:	September 2017
IDEA Contract Amount:	$100,000

IDEA Concept and Product

The IDEA product is a proven machine vision concept for performing ballast condition assessment along the track. A new degradation index, Percent Degraded Segments (PDS), was introduced based on the machine vision algorithms developed to analyze in-service ballast cut section images and effectively quantify the level of ballast degradation in the field. This technology can potentially replace the current state-of-the-practice of visual inspection, sampling, and mechanical sieve analysis. As a component of a comprehensive Ballast Management System (BMS), the developed technology would help to evaluate designs and deterioration mechanisms of ballasted track and provide predictive service life and life-cycle analysis for improving the safety and network reliability of the U.S. railroad transportation system.

Project Results (or Planned Investigation)

Field images of vertical (longitudinal and/or transverse to the track) and horizontal cut sections of in-service ballast were collected from different track locations. An image processing algorithm was developed with three main modules including pre-processing, segmentation, and post-processing. The ballast cross section images collected in the field were analyzed to quantify different levels of ballast degradation from the images by the use of a newly introduced imaging based index called PDS. The PDS values from the field-collected images of ballast cut sections correlated well with the commonly used Selig's Fouling Index (FI) values obtained from sieve analysis results of the field collected ground truth samples. A color coding approach highlighting different sized particle images was found to be effective for the use of the image-processing algorithm. A Graphical User Interface (GUI) supported the efficient determination of image segmentation parameters.

Regression analysis established a significant correlation between FI and average PDS values. Using 28 field cut section ballast images and their sieve analysis results in the laboratory, a simple linear relationship was found to exist between the FI and PDS values with a coefficient of determination (R^2) equal to 0.84. Accordingly, this imaging based ballast degradation model was quite effective in estimating in-service ballast FI values, which typically ranged from 4 to 46 for a wide variation, from the image processing algorithm PDS results.

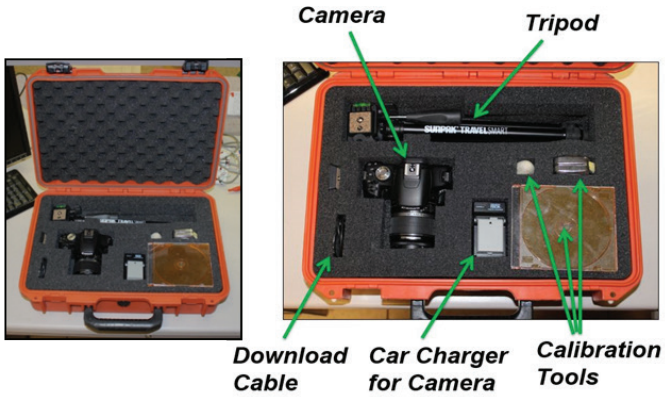


Figure 1: Ballast imaging kit.

Figure 2: Ballast evaluation kit.

Capturing horizontal cross section images of ballast from the shoulder is a feasible approach for determining the condition of ballast at different depths and along extended stretches of track. These horizontal sections indicated similar degradation trends to those produced by Shoulder Ballast Cleaner (SBC) equipment during routine maintenance operations. As such, horizontal imaging of shoulder ballast cross sections showed promise to enable SBC equipment to obtain degradation quantification at desired cutting depths and therefore, identify an optimum depth of shoulder cleaning or undercutting to achieve targeted ballast maintenance goals for improved drainage and stability.

Product Payoff Potential

The developed technology can quantify in-service ballast condition and its properties at any location, possibly identified by ground penetrating radar or other network condition monitoring devices, without the need for ballast sampling from trench cut sections. It can also be used with shoulder cleaning and undercutting equipment to automate the condition assessment using images of ballast cut sections below the ties. As such, this automated evaluation could greatly improve the quality and efficiency of ballast maintenance activities. In addition, the results of this process can be used for inspection purposes and to map out recommendations of follow-up rehabilitation strategies. Further, the proposed method has the potential to be applied for in situ evaluation of permeability and strength properties of railroad ballast at different degradation levels.

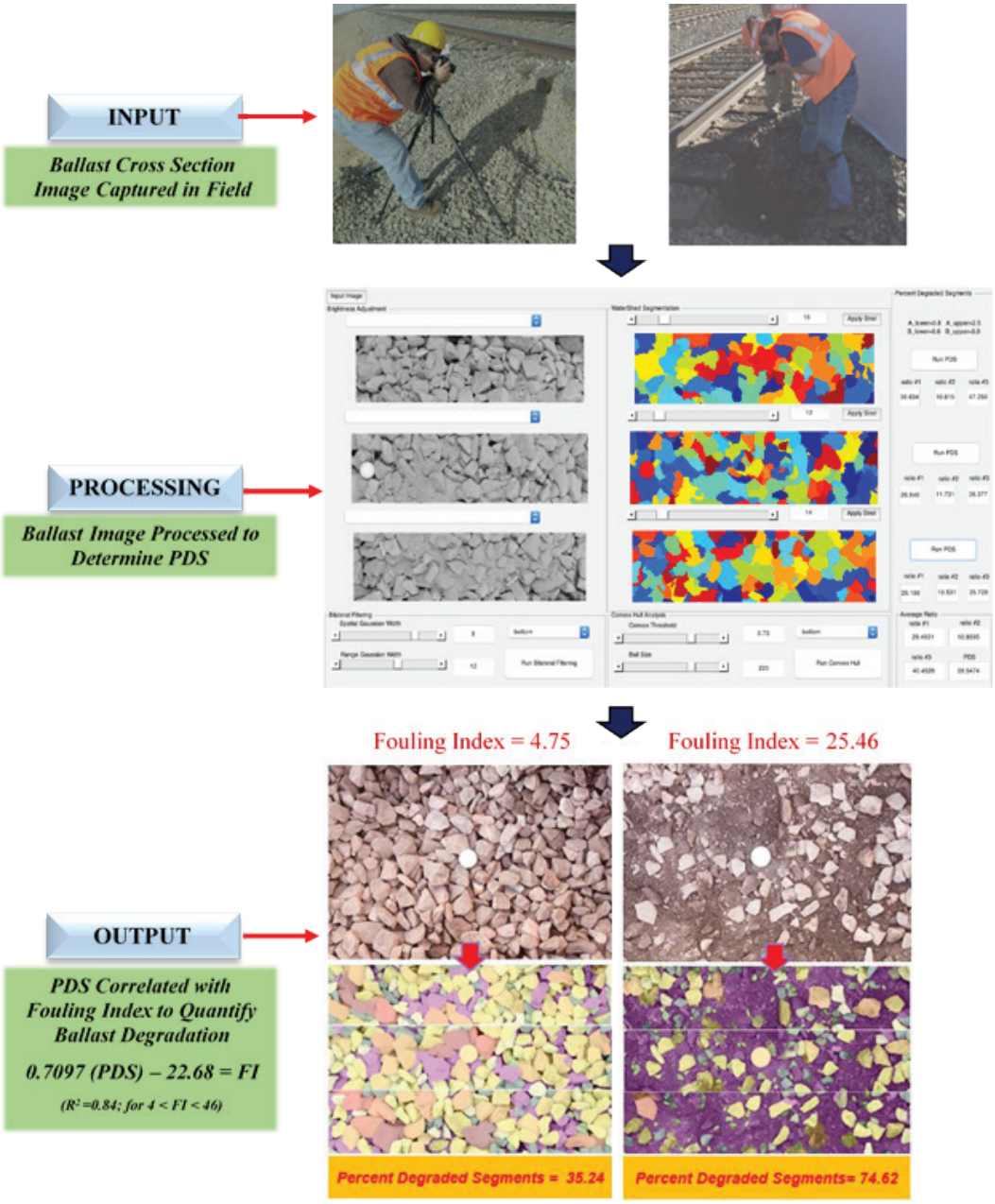


Figure 3: Imaging kit process.

Product Transfer

The IDEA product developed in this study provides an immediate application for a simple portable method, or inspector's kit, that can be used in the field, called the Ballast Imaging Kit (BIK), (Figure 1). A single inspector can perform spot-checking of ballast degradation levels in suspected problem areas by quickly gathering quantifiable evidence through imaging, and then, process these images using the innovative PDS method to determine suitable mainte-

nance and renewal decisions. A next step product will be the further development of the PDS technique into a user-independent image analysis software package. The conceptual Ballast Evaluation Kit (BEK), also shown in Figure 2, has been envisioned to run the proposed user-independent image analysis software on a laptop computer. This will enable the user to quantify ballast degradation levels using the BIK camera images taken on-site simultaneously. The integration of these two kits will be part of a future Machine Vision System for Shoulder Ballast Cleaners, which can be implemented over long sections of track to provide objective and continuous quantification of railroad ballast degradation levels. This future product will offer the capability to quantify railroad ballast field conditions objectively, continuously and reliably without the need for periodic ballast bucket sampling and laboratory sieving.

Field Validation of Inspection Gauges for Wheel Climb Safety at Switch Points

Safety IDEA Project 28

Research Agency: University of Delaware

Principal Investigator: Allan M. Zarembski

Completed: January 2017

IDEA Contract Amount: $82,179

IDEA Concept and Product

Wheel climb derailments in switches are a major derailment category for both freight and passenger rail operations in the United States. A recent IDEA project (S-23) looked at improved inspection tools that can be used to reduce wheel climb derailments at switch points. A set of four gauges were developed, each addressing a potential wheel climb mechanism:

- Chipped switch point gauge that examines potential for wheel climb at a chipped or damaged switch point.
- Wheel profile gauge that examines wheel/rail contact point and the potential for wheel climb due to improper contact associated with a worn switch point.
- Severely worn wheel gauge that examines potential for wheel climb at the switch point for severely worn (but non-condemnable) AAR1B wheel profiles.
- Gauge face angle gauge that examines excess gauge face wear of the switch point that can lead to a wheel climb derailment.

This activity is a field assessment and validation of four hand held inspection gauges on several major railroad systems to include Norfolk Southern (NS), BNSF, LIRR, and CN. It is intended to develop practical gauges that can be used by railroad and transit field inspectors to evaluate the condition of a switch point to prevent derailments at a worn or degraded point.

Project Results (or Planned Investigation)

The project has been completed. There were two rounds of field inspection, with the first using the prototype gauges developed under S-23 and the second using a modified set of gauges, based on the results and feedback of the first field test (Task 1). Under Task 1 a complete set of four inspection gauges were provided to six railroads and/or railroad consultants and measurements were taken by four railways plus an independent consultant who looked at a total of 272 switch points of different design configurations and conditions using the four study gauges. The tests were taken in more than 20 yards. Analysis of the results show reasonably good agreement with the railroad inspectors, as can be seen in Table 1 and feedback from the railroad using these gauges was extremely favorable. Agreement with inspectors ranged from 84% agreement between the inspectors and the gauges for LIRR to 44% for BNSF.

Case/Railroad	Number of inspections	% Agreement	% Disagreement
1. All inspections	272	58%	42%
2. CN only	135	49%	51%
3. All others	137	66%	34%
4A: BNSF	41	44%	56%
4B: LIRR	45	84%	16%
4C: NS	16	50%	50%
4D: Gary Wolf	35	77%	23%

Table 1: Turnout inspection results for Task 1.

Following the initial correlation analysis, a statistical decision tree analysis was performed on the data. Decision tree analysis is a "data mining" technique learning from a set of independent data events, which are in this case switch points inspections. The specific analysis approach used here made use of WEKA Data Mining Software and specifically the J48 algorithm, which chooses one attribute of the data that most effectively splits its set of samples into subsets enriched in one class or the other. For this data set, the J48 algorithm chooses a "sufficient" gauge in the top of the tree followed by gauges that are less "sufficient" further down the decision tree. In the analysis of the four gauges used, all were found to be "sufficient" for at least some part of the data and as such all four were determined to be needed.

Gauges	Case 1A: Full Data Set.	Case 1B: Full Data Set-Alternate CN Logic.	Case 2: CN Data Only.	Case 3: Non-CN Data.
Chipped point gauge	*Not relevant*	*Not relevant*	*Most sufficient*	*Not relevant*
AAR 1B wheel contact gauge	*Least sufficient*	*Not relevant*	*Not relevant*	*Most sufficient*
Severely worn wheel profile gauge	*Most sufficient*	*Less sufficient*	*Not relevant*	*Less sufficient*
Gage-face wear angle gauge	*Less sufficient*	*Most sufficient*	*Not relevant*	*Not relevant*

Figure 1: Decision tree matrix.

Based on the results of the field inspections and analyses, two of the gauges were modified and a complete new set of gauges sent to five railroads for evaluation (to include two new railroads). This new set of gauges was used in the follow-up field evaluation of the modified gauges which was conducted during the period from September 2016 to October 2016. Measurements were taken by four railways, TTCI and an independent consultant who looked at a total of 74 switch points of different design configurations and conditions using the four study gauges. As can be seen in Table 2, there was generally good agreement with the gauges, ranging from 74% to 100%[1] and an overall agreement of 82%.

[1] Not including CP which appears as an outlier.

Case/Railroad	Number of inspections	% Agreement	% Disagreement
All inspections	74	82%	18%
BNSF	19	74%	26%
LIRR	19	95%	5%
NS	10	100%	0%
CP	7	43%	57%
Gary Wolf	15	93%	7%
TTCI	4	75%	25%

Table 2: Summary of comparison between inspectors and gauges for Task 3.

Concurrent with this analysis, a probabilistic simulation analysis was performed, where the agreement percentages for the individual gauges and for all gauges combined were used with an analysis logic based on Monte Carlo Simulation. The probabilistic analysis showed agreement of no less than 82%, but with some gauges (e.g. gauge 2) having agreement as high as 92%. Furthermore, the overall agreement was 82%, which is consistent with the correlation results presented in Table 2 and supported the validity of the gauges in evaluating switch point condition.

Product Payoff Potential

Approximately 1,000 derailments per year are associated with worn or broken switch points, and these derailments are rarely if ever a simple single cause derailment. If properly designed and implemented, gauges developed under this task have the potential for significantly reducing the number of switch point related derailments together with an even higher number of "near misses."

Product Transfer

Based on the results of this program, the committee has recommended that these gauges be made available to the railroad industry as well as to such railroad standards organizations as AREMA for industry implementation. The review panel has been in contact with AREMA committee 5 to review the gauges and has forwarded specific information to the relevant AREMA committees for review and potential incorporation into AREMA's Manual of Recommended Practices.

In addition, the team has already stated to disseminate information about these gauges through railway media, conferences, and organizations. This includes an article published in the April 2017 issue of *Railway Track & Structures*, a presentation scheduled for the September 2017 AREMA annual conferences, a presentation at the January 2016 TRB annual meeting, a presentation at the University of Illinois RIVIT conference in June 2017 as well as direct discussion with several railroads and railway suppliers.

Self-De-Icing LED Signals for Railroads and Highway Intersections

Safety Idea Project 29

Research Agency:	University of Kansas
Principal Investigator:	Hongyi Cai
Completed:	August 2019
IDEA Contract Amount:	$50,000

IDEA Concept and Product

This project has developed a new type of self-de-icing LED signals for highway-signalized intersections and railroad-signaling applications to solve a well-known problem of the existing LED signal light whose lens is too cool to melt snow and de-ice in wintery conditions. The snow-clogged signal lights can decrease the performance of signalized intersections and railroads and may result in collisions in inclement weather conditions. The self-de-icing LED signal light adopts an innovation of "Integrated Light and Heat Arrangement of LEDs in Low Profile" (Patent Nos. US 10,215,441 B2, US 10,253,965 B2, and US 9,851,086 B2) (Figure 1) to harvest both the light and the heat generated by the same LEDs for illumination and heating of the signal lens.

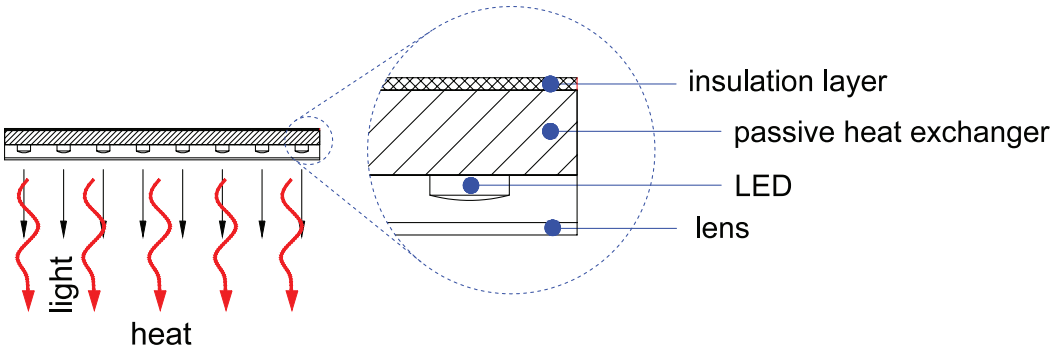


Figure 1: Concept and prototypes of the self-de-icing LED signal light, which adopts new architecture of "Integrated Light and Heat Arrangement of LEDs in Low Profile" to harvest both the light and the heat generated by the same LEDs for lighting and heating uses. The heat generated by the LEDs is harvested by the passive heat exchanger and stored to heat the lens for melting snow and de-icing in wintery conditions.

Project Results

The investigative approach was divided into three stages. Stage 1 focused on laboratory research, development, and tests of the prototype self-de-icing LED signals. The research team developed and tested prototypes of the self-de-icing LED signals (12 in.) in red, green, and yellow light colors. The research team tested their thermal and lighting performance to meet all requirements. Stage 2 focused on testing three fully working prototypes mounted in closed-course settings on the roof of an engineering building and powered by the signal controller cabinet, to avoid interruption on people and ground traffic. The research team evaluated their thermal and lighting performance of the prototypes to ensure their readiness for follow-up field tests in winter. Stage 3 focused on the field tests of the working prototypes on identified highway-signalized intersections and rail track sections. The prototypes are installed on pole-mounted signals as backup to the existing primary signals. At each test site, the real-time performance of the prototype signals is monitored and recorded by a field monitoring system using three cable cameras and four temperature sensors. Year-around test data (pictures and temperature data set) are recorded every 20 seconds in winter seasons [when the ambient temperature is lower than 4°C (39.2°F)] and every hour in summer seasons, stored on USB flash drivers, and also sent back to the team via remote cellular data transmission on daily basis. The collected data are used for real-time performance evaluation of the new signals for future implementation in practice by the project partners.

Product Payoff Potential

Once validated, the self-de-icing LED signal light is expected to be a viable replacement of the existing "cool" LED signal lights, the obsolete incandescent signal lights, and other emergent LED signal lights using additional heat generators and control sensors. If the self-de-icing LED signals were to be implemented in practice, significant benefits, including safety and efficiency, cost savings, and environmental sustainability, are expected for transportation agencies, districts and cities, the railroad companies, and the driving public in the snow-belt states. This system will not alter the function and sizes of the existing signal lights. There will be no need to add additional wiring inside and outside of the existing signal controller cabinets, and no need to change anything outside of the signal housing. The self-de-icing LED signal lights could save on annual maintenance costs.

Product Transfer

Two patents were granted for the innovation of "Heated Lens Lighting Arrangement" (Patent Nos. US 9,851,086 B2 and US 10,253,965 B2). Another patent was issued for the innovation of "Integrated Light and Heat Arrangement of Low Profile Light-Emitting Diode Fixture" (Patent No. US 10,215,441 B2). The research team and the University of Kansas Center for Technology Commercialization have been reaching out to the signal industry for patent licensing. Pilot replacement programs are planned to displace the existing signals with the self-de-icing LED signals in some collaborative state departments of transportation (e.g., Kansas, California, Maryland, Michigan, New Jersey, Pennsylvania, and Wisconsin), the Union Pacific Railroad, and the Burlington Northern Santa Fe Railroad. Once validated, it is expected the self-de-icing LED signals will be installed at highway intersections, Class I railroads, commuter railroads, and short-line railroads in cold weather zones.

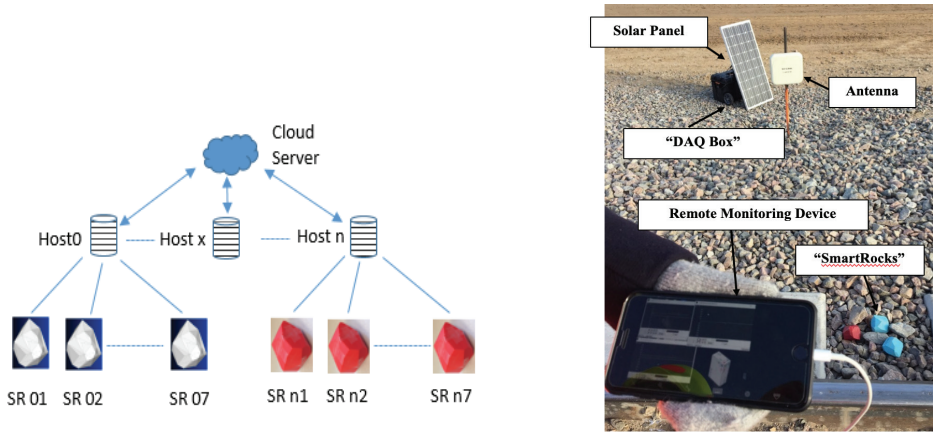
Ballast Real-Time Information System

Safety IDEA Project 30

Research Agency:	Pennsylvania State University, Altoona
Principal Investigator:	Hai Huang
Completed:	January 2020
IDEA Contract Amount:	$100,000

IDEA Concept and Product

This IDEA project aimed to develop and validate an integrated system of SmartRocks–Ballast Real-Time Information System (BRIS) for accurately monitoring individual ballast particle movements and software (Smart computing) components that can predict track substructure safety concerns. BRIS is a communication network system that consists of multiple SmartRocks, a solar panel, antenna, remote monitoring device, Wi-Fi hotspot, and data acquisition (DAQ) box containing a storage battery, power inverter, and data acquisition system. The DAQ box works as a trackside host to communicate with SmartRocks and enables SmartRocks to start data collection and transmission. The host can then pass the SmartRock data to the cloud-computing center using Wi-Fi. A user interface (software) that will allow engineers to customize SmartRock network parameters after installation, such as sampling frequency, sampling strategy, warning threshold, and so forth, has been developed (a graphical user interface is available upon request). To ensure SmartRocks reflect the actual granite ballast particle movements and to test the communication quality and reliability, service life, and durability of the "SmartRock," a laboratory test and field installation were conducted. Finally, connections between SmartRock networks were set up, and a computing scheme based on real-time data fusion between a sensing mechanism and real-time (SMART) computing was developed, implemented, and validated. Laboratory large-scale triaxial tests on ballast specimens were conducted, and the results compared with traditional discrete element method (DEM)-only and SMART computing simulations. Results indicated that SMART computing, if implemented with appropriate physical models, can be used to simulate the large-scale shearing tests with high fidelity and accuracy.



(a) *(b)*

Figure 1: Ballast Real-Time Information System: (a) data sensing network and (b) field instrumentation.

Project Results

SmartRocks, wireless embedded sensors, were manufactured to form BRIS. This system consisted of SmartRocks (numbers depend on the real projects), a solar panel, antenna, remote monitoring device, Wi-Fi hotspot, and DAQ box containing a storage battery, power inverter, and data acquisition system. A user interface (software) that will allow engineers to customize SmartRock network parameters after installation, such as sampling frequency, sleep/wake-up time, warning threshold, and so forth has been developed (a graphical user interface is available upon request). BRIS can be installed in the laboratory and in the field for measuring ballast particle movements under different ballast conditions.

Five SmartRocks were installed at the Norfolk Southern mainline (Class 4) near Bellwood, Pennsylvania, with two sites, one control site with clean ballast and one mud pumping site, chosen. During the laboratory test, a series of ballast box (with dimensions of 3.96 m long × 3.36 m wide × 1.22 m high) tests were conducted to investigate the ballast particle movement pattern inside railway ballast under different ballast, loading, moisture, and shoulder confinement conditions. Eight wireless embedded devices, SmartRocks, were used in the laboratory tests in three different locations to study different ballast particle movement patterns under different conditions. Results proved that SmartRocks are capable of recording particle movements under different ballast, loading, and moisture conditions; of recognizing the ballast fouling; and of possibly serving as a potential monitoring tool to monitor the ballast behavior and performance in the real ballast maintenance.

The SMART computing algorithm can enhance DEM simulations using a wireless device, that is, the SmartRock. The SmartRock is capable of recording real-time particle translation and rotation if embedded in a granular assembly. SMART computing is a Kalman-filter-based data fusion technique that can incorporate real-time SmartRock recordings into DEM simulations to improve the accuracy of the simulation. SMART computing, if implemented with appropriate physical models, can be used to simulate the large-scale shearing tests with high fidelity and accuracy.

Product Payoff Potential

SmartRocks are confirmed to be capable of recording particle movements under different ballast, loading, and moisture conditions and may serve as a potential monitoring tool to monitor the ballast behavior and performance in the field. With the help of statistical analysis methods, BRIS can be employed in the field and used to identify ballast conditions, such as fouling and shoulder instability. The system can be used in 24/7 for real-time ballast condition monitoring. Engineers can also access the data remotely and perform maintenance in real time. In addition, SMART computing is considered an effective algorithm to precondition the particle movement at an individual particle level and hence to improve the accuracy at a macro level.

Product Transfer

After completion of this project, the research team will work with the Transportation Technology Center Inc. (TTCI) and the Federal Railroad Association (FRA) to test the functionality and the reliability of BRIS in the field environment. After that, the team will contact one of the Class I companies (such as Union Pacific Railroad) to discuss the possibility of employing BRIS. Railroad Technology and Supplies (RTS), a small business, will partner with the team in terms of the hardware and software development and support during the implementation process.

Modeling and Validation of Standards for a Sleeper Compartment on Accessible Passenger Rail Vehicles

Safety IDEA Project 31

Research Agency:	Oregon State University
Principal Investigator:	Katharine Hunter-Zaworski
Completed:	September 2018
IDEA Contract Amount:	$99,435

IDEA Concept and Product

This IDEA project extends the 3-D modeling of the accessible passenger train restroom and built a full-scale soft mock-up of the sleeper compartment that contained a restroom with a shower for evaluation by people with disabilities. The project developed new designs and these were first verified and evaluated using 2-D and 3-D digital modeling of the sleeper compartment. An online survey is also being implemented to gather feedback from people who are unable to visit the soft mock up. Representatives of the passenger rail industry are involved throughout the project and the project results will be disseminated for use by the passenger rail industry.

Project Results (or Planned Investigation)

The user and technical requirements for the sleeper were established with the input from the Project Technical Advisory Committee that is familiar with the operating environment of high-speed and long-distance trains. This includes the U.S. DOT, U.S. Access Board, VIA, Amtrak, and several car builders regarding dimensions, materials, standards, safety/crash regulations for high-speed/long-distance trains. Guideline criteria were based on technical, operational, and user requirements. Based on consultation with the Project Technical Advisory Committee, the design is proposed for the next generation inter-city passenger rail cars, specifically for long-distance passenger cars with two levels. The accessible sleeper compartment would be located on the lower level adjacent to the vestibule by the accessible door and also where an elevator will be co–located. It is recommended that the accessible sleeper compartment be located in a car that enhances the travel experience of people with disabilities, and it is strongly suggested that the accessible sleeping compartment be located in the lower level of the lounge or observation car that is usually located adjacent to the dining car and where the elevator will not impact revenue seating.

The use of 3-D digital modeling permitted evaluation of different configurations and layouts prior to construction of the soft scale mock-up. The sleeper design was based on several existing sleeping and restroom designs. The key design difference is the incorporation of two berths at low level and two upper berths. The accessible sleeping compartment can accommodate four passengers and two may have reduced mobility. Feedback about spatial consumption, reach, inclusion of amenities, and accessibility was received. At the project kick-off meeting,

the Advisory Committee strongly recommended that the shower and toilet area be incorporated into the sleeping compartment. Additional design objectives include maximizing accessibility and satisfying user needs and at the same time considering seat revenue and real estate of the car. Figure 1 is a 2-D layout and Figure 2 is a picture of the soft mock up. This version is designed to accommodate up to four passengers with two sleeping berths at floor level and two upper bunk beds.

A version of the accessible sleeping compartment for a single level train has been developed, but due to the need to provide a passageway throughout the train, the restroom does not include a shower and the turning circle in the seating area could not be accommodated. The soft mockup permitted flexibility to adjust some of the spatial arrangement of features, making it possible to demonstrate the spatial limitations of the single level design.

Figure 3 is a schematic of the sitting room in the daytime configuration. Also shown are the two bunk beds that would be fully stored away during the daytime but are rendered to illustrate their location. This figure shows a large wheeled mobility device and a personal care assistant who can provide assisted transfers to the seat. This figure also shows the biomechanics analysis toolbox that will be used for analysis.

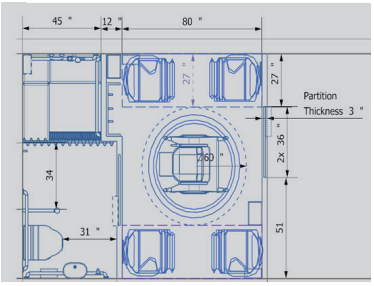


Figure 1: Bi Level Design – Accommodates 4 passengers.

Figure 2: Constructed soft Mock-up showing combination of seating and upper berth.

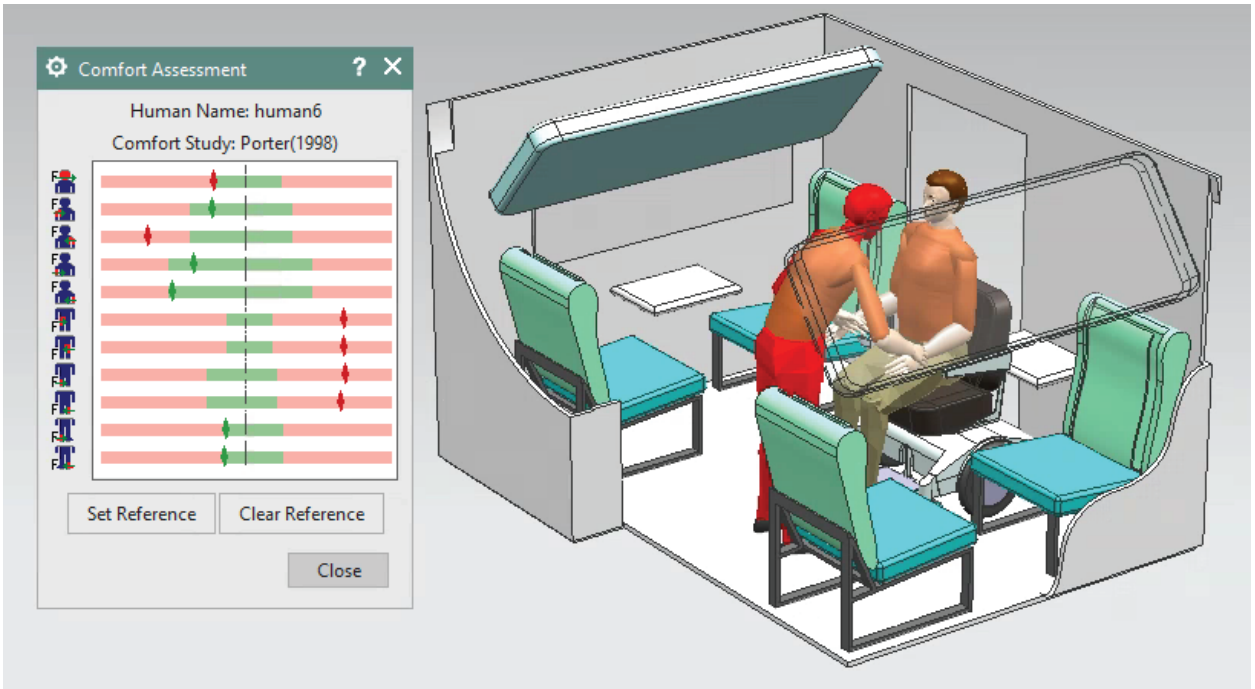


Figure 3: 3-D Schematic of sitting room in daytime configuration with bunk beds shown in semi-down position for illustration. Transfer model and evaluation form are shown.

Product Payoff Potential

The need to develop fully accessible rail cars has already been expressed by the industry through the FRA, RVAAC, and the PRIIA accessibility working group. Involvement of the industry stakeholders in the development of the specifications through modeling and full scale soft mock up evaluation is very important for developing guidelines that are cost effective. A key part of the design optimization is to balance the use of space and impact on revenue seats. The design has four revenue seats and berths in the accessible sleeping compartment and is designed to accommodate families and one or two people with disabilities. The new designs and guidelines allow cost effective implementations to standardize applications and provide consistency for the industry and the user. Implementing new designs from the beginning are more cost effective than retrofitting existing rolling stock; however the new design does have the potential to be retrofitted onto existing rolling stock. The use of a 3-D modeling for evaluation of the designs saves the industry both time and money.

Product Transfer

The rail industry is a key stakeholder that is involved in most of the project activities. It is anticipated that the design guidelines for the sleeper compartment will assist the rail industry to introduce universal sleeper compartment modules for the next generation of long-distance and high-speed trains for persons with mobility and sensory impairments, and seniors.

Railroad Bridge Inspections for Maintenance and Replacement Prioritization Using Unmanned Aerial Vehicles (UAVs) with Laser Capabilities

Safety IDEA Project 32

Research Agency:	University of New Mexico
Principal Investigator:	Fernando Moreu
Completed:	July 2018
IDEA Contract Amount:	$99,400

IDEA Concept and Product

This research focused on the development and implementation of contact-free, reference-free transverse bridge displacement measurements. Recent research had shown that transverse displacements of timber trestle bridges can capture critical changes in bridge serviceability (the ability to safely carry out railroad operations) as a function of railroad loading, speed, and direction. Measuring bridge movement under trains in the field is difficult and expensive because a fixed reference point is not normally available, thus creating the need to erect independent scaffolding to create good reference points near the bridge from where to measure. The research included a concept test for integrating UAVs and laser technologies to assess the structural condition of simply supported spans of conforming steel railroad bridges, which can be instrumental in informing the subsequent prioritization of more detailed inspections. The primary tasks for developing this system was a robust integration of a Laser Doppler Vibrometer (LDV) sensor with a copter-type UAV, optimization of sensor data accuracy, optimization of UAV positioning and movement characteristics, and effective data analysis methods to measure displacements. The main emphasis of this research was freight traffic and transportation, but the application is expected to assist any other type of railroad operation.

Project Results (or Planned Investigation)

Initial testing focused on characterizing constituent components of the system: the behavior of the copter UAV, the data from the LDV, and the expected data from current measurements of this type using conventional methods. Researchers compared the data of the LDV sensor to a common tool for linear displacement, the linear variable differential transformer (LVDT), to analyze the relative data outputs before mounting to the UAV. Subsequently, the researchers completed the characterization of the constituent components, and integrated the components into a preliminary testing platform. Finally, researchers collected data to determine their effects on data output of the LDV. The research team collected data outdoors for preliminary validation of the new technology. Results indicated that the prototype was able to monitor movements simulating the vibrations of a train crossing (Figures 1 and 2).

(a) (b)

Figure 1: First outdoor laser UAV testing for measuring contact-free, reference-free displacements compared with reference displacements: (a) experiment general view; (b) reference displacement detailed view.

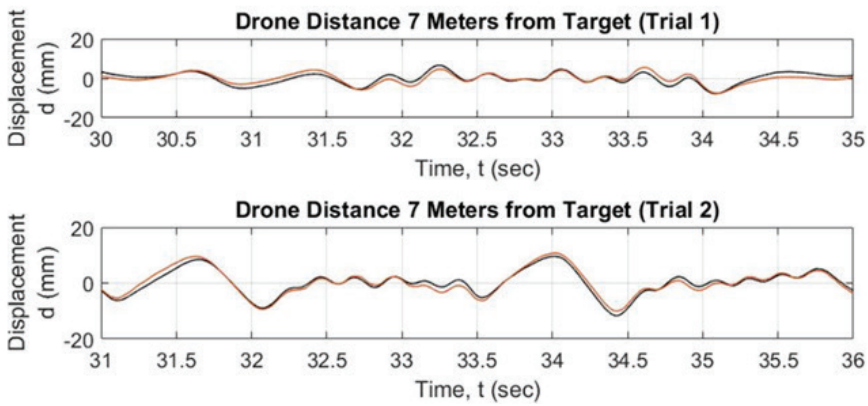


Figure 2: Contact-free, reference-free displacement and reference displacement comparison from field testing.

The research team discussed with the Transportation Technology Center, Inc. (TTCI) in Pueblo, CO, the CN railway, and Polytec, Inc. challenges and opportunities to demonstrate that the results can be useful for potential field implementation. Their critical feedback was discussed and included in this report.

Product Payoff Potential

The implementation of this technology allows for more efficient and effective measurements of displacement on railroad bridges during train crossing events, measuring bridges displacements without the need of installing sensors. This data is valuable for assessing safety of bridges at the network level and to inform bridge management prioritization.

Product Transfer

The current implementation was limited by the cable connection from the data collection module to the LDV mounted on the UAV. Current discussions with the sensor manufacturer, Polytec, Inc., evaluated the potential use of a smaller form factor sensor to avoid this cable connection for field implementation. This would allow for measurements to be taken on structures of any height, rather than just those within the height of the cable.

There is one patent filed by the principal investigators of this research: STC Technology Ref. No. 2016-070: "Assessing the condition of railroad bridges enabled by reference-free, non-contact displacement under revenue service train loads using Unmanned Aerial Vehicles (UAVs) and laser cameras" developed by Fernando Moreu, and Mahmoud Reda Taha. U.S. Utility Application No. 15/477,775 filed on April 3, 2017 (http://www.flintbox.com/public/project/29930/.)

Adaptive Prestressing System for Concrete Crossties

Safety IDEA Project 33

Research Agency:	University of Illinois at Urbana–Champaign
Principal Investigator:	Bassem Andrawes
Completed:	November 2019
IDEA Contract Amount:	$100,000

IDEA Concept and Product

This project introduced an innovative technology that aims to resolve one of the most critical issues related to the safety, durability, and serviceability of railroad track systems, namely, cracking of prestressed concrete crossties. Conventional prestressing methods apply constant prestressing to the entire length of the crosstie to achieve the desired strength, resulting in an inefficient system. This proposal suggests an innovative and cost-effective concept for introducing, monitoring, and adjusting prestress forces within the tie, in the field, using adaptive prestressing system (APS). With the use of innovative prestressing materials, it is believed that a method can be developed to introduce prestress in specific areas of concrete as needed by embedding shape memory alloy (SMA) fuses in the required region (see Figure 1). This novel concept will enable users to control the level of prestress at certain regions of the crosstie, to accommodate the variations in support conditions, loads, and even climate conditions throughout the service life of the crosstie. The proposed technology will improve the safety and longevity of the ties.

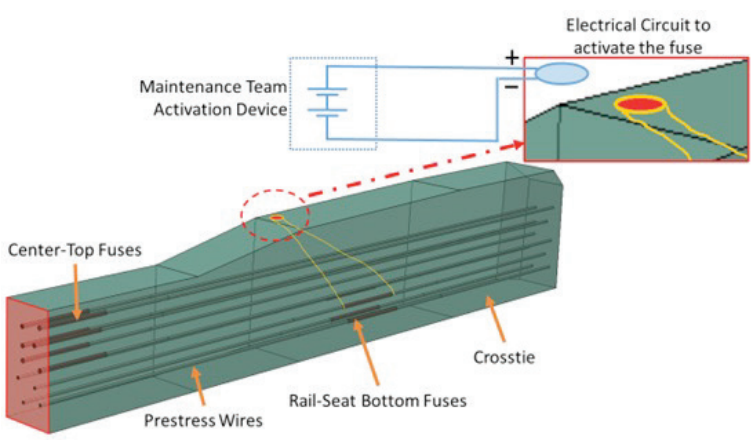


Figure 1: Schematic illustrating the use of SMA fuses to develop APS in concrete crossties.

Project Results

The research for this project was conducted in two main stages. Stage I focused on examining the proposed concept of using APS in crossties using 3-D finite element (FE) analysis and material testing. Stage II focused on examining the APS concept experimentally using large-scale components and crossties. The research work included the following tasks:

1. Utilizing the FE numerical method to analyze concrete members reinforced with the new APS system.
2. Studying the new APS prestressing system numerically on concrete crossties.
3. Designing the connection between SMA fuses and prestress wires.
4. Performing proof-of-concept testing on small-scale crosstie specimens with embedded SMA fuse and prestress wires.
5. Performing prestressing and flexural testing on ½-scale crosstie using digital image correlation (see Figures 2 and 3).

FE analysis results showed that the SMA wires embedded in concrete are applying the prestressing as designed.

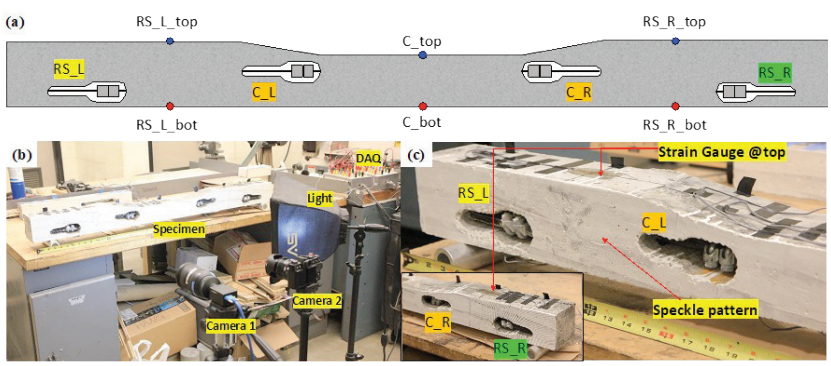


Figure 2: Test setup for 1/2-scale ties with APS (DAQ = data acquisition).

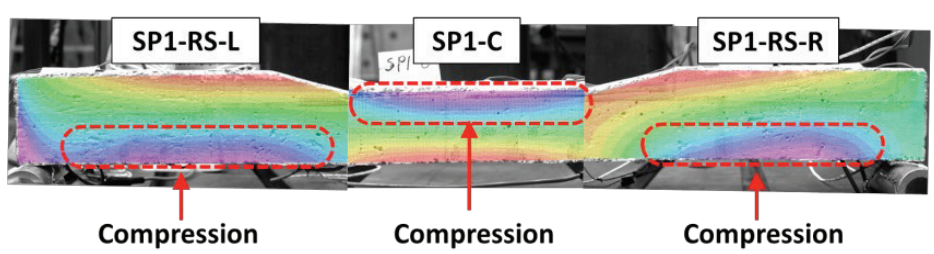


Figure 3: Digital image correlation results proving the validity of the new APS concept.

Product Payoff Potential

The proposed APS will provide designers with the ability to easily adjust the design of the crossties (i.e., location and amount of prestress force), based on track and load conditions. The current pretensioning technique provides designers with no control over the area of the cross-section where prestressing is being applied. The proposed APS will provide maintenance teams with a tool to inspect/monitor the level of prestressing in the crosstie while in service and, if needed, to adjust the level of prestressing force at certain areas where under-stressing or over-stressing has been observed. The delayed application of prestress in the proposed APS will help reduce significantly the level of prestress losses due to concrete creep/shrinkage and steel relaxation compared with that in the conventional pretensioning method, where prestressing is applied early (typically a few days after concrete casting).

Product Transfer

The next step toward advancing this technology is to develop and test a full-scale prototype of crosstie prestressed with APS. This is important to demonstrate the practicality and cost–benefit of this new technology, as well as its appropriateness for future mass production. Toward the end of the project, the PI filed for a provisional patent for the APS technology. Since then, the PI has been approached by Innovyz, a leading company in commercializing innovative ideas. The PI is working with them on studying the market readiness for this new technology.

Prototype System for Managing and Analyzing Enterprise Rail Transport Risks for Hazmat

Safety IDEA Project 34

Research Agency:	FACTOR, INC.
Principal Investigator:	Ravi Palakodeti
Completed:	February 2019
IDEA Contract Amount:	$99,942

IDEA Concept and Product

This completed IDEA project resulted in a novel, web-based prototype system for freight rail carriers to evaluate network-level safety risks for comprehensive hazardous material (hazmat) traffic flows. The unique concept is the application of a quantitative framework for risk accumulation (Figure 1) occurring from multiple hazmat movements across rail carrier networks, rather than evaluating risks only on a route-by-route basis. The product application aims to provide a systemic understanding of risks that railroads need for making risk-based investments and resource allocation decisions to improve overall railroad safety.

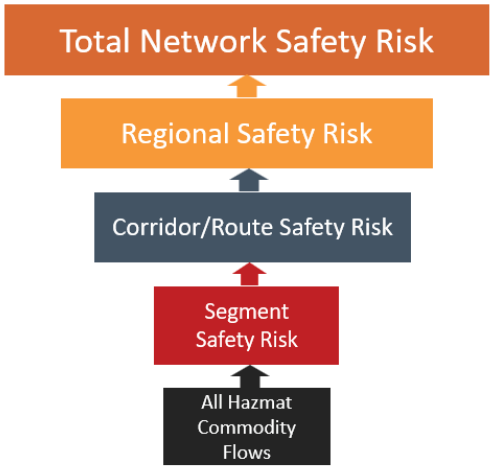


Figure 1: The concept of safety risk accumulation from comprehensive hazmat movements to support a network-level measure of risk.

Project Results

The tasks in this project were divided into two stages: Stage I and Stage II. The objective of Stage I was to lay the methodological framework for assessing hazmat safety risks to support network-wide decisions. This analytical task required assessing and comparing the railcar-based modeling approaches, commonly accepted as standard practice in rail hazmat risk assessment studies, and contrasting them with the more recently developed train/multicar release-based risk assessment models. We found that although the train-based methodology offers more nuanced features to evaluate hazmat safety risks, in general, the car-based and train-based methodologies were both consistent in identifying higher risk locations within the rail network resulting from multiple commodity flows. The more detailed train-based methodology allows better characterization of release likelihoods and accounts for potential multiple car releases but comes with additional data and analytical requirements. To meet the main objectives of the project, the car-based methodology was found to be sufficient and was selected to support Stage II activities.

Stage II activities included developing and testing the prototype system (Figure 2). We developed web-based user interfaces and data visualization capabilities with HTML5, React/Redux stack, and other modern web technologies to process and interact with network-level safety risk data and supporting datasets. Additionally, the prototype was enhanced to support basic quantitative evaluation of potential risk modification strategies. Through collaboration, testing, and review from our railroad partner Norfolk Southern, we gathered feedback and insights to further improve the utility of the prototype system.

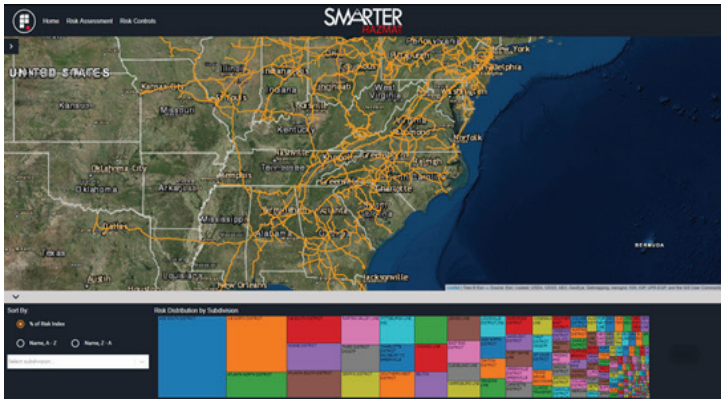


Figure 2: Snapshot of the prototype showing subdivisions and areas in an example network that may pose an elevated risk (hypothetical data shown). The prototype also allows exploration of some risk reduction strategies and their effect on overall safety risk and location-based safety risk. Additionally, potential risk accumulation from future or planned hazmat movements can be analyzed through the prototype system.

Product Payoff Potential

The prototype system provides a significant enhancement to the state of the practice for the freight rail industry and specifically supports critical decision-making for improving network safety, including (1) determination and prioritization of high-risk network locations by considering comprehensive hazmat movements across operational networks, (2) evaluation of the impacts of additional shipments from adding new hazmat customers, (3) monitoring network safety risk for significant changes in trends, and (4) comparison of the effectiveness of proposed risk mitigation strategies and identification of the network locations where those strategies potentially achieve the greatest risk reduction for limited safety investments.

Product Transfer

Through collaboration and testing with our railroad partner Norfolk Southern, we obtained valuable insights into how this prototype system can be scaled-up and enhanced to mesh with existing commodity flow systems and prepare the prototype for wider adoption. Based on the feedback received, the project team plans to continue development on the prototype by creating security protocols for making the prototype support multiple users, adding data export functionality, developing functionality to conduct "what-if" analysis by modifying the mix of rail cars, and improving visualization capabilities by adding 3-D map views.

Non-Contact Deflection Monitoring System for Timber Railroad Bridges

Safety IDEA Project 35

Research Agency:	Florida Atlantic University
Principal Investigator:	Sudhagar Nagarajan
Completed:	March 2019
IDEA Contract Amount:	$100,000

IDEA Concept and Product

This project developed an innovative non-contact linear feature based deflection measurement system using Terrestrial Laser Scanning (TLS) and cameras for timber railroad bridges. The requirement of control points to register images was overcome by using the 3-D model of the bridge collected in dead load condition by TLS. This research project developed a rigorous linear feature-based registration mathematical model to determine the orientation of images so they can be used to derive 2-D/3-D deflections under different static and live load conditions. Though this research mainly focused on timber railroad bridges, the research can be applied on other railroad bridges such as steel and masonry. The project developed (1) a deflection monitoring system (DMS) with camera (see Figure 1), (2) linear feature-based registration methodology for the data collected by DMS, and (3) non-contact methodology to compute instantaneous 2-D/3-D deflections under live-load conditions.

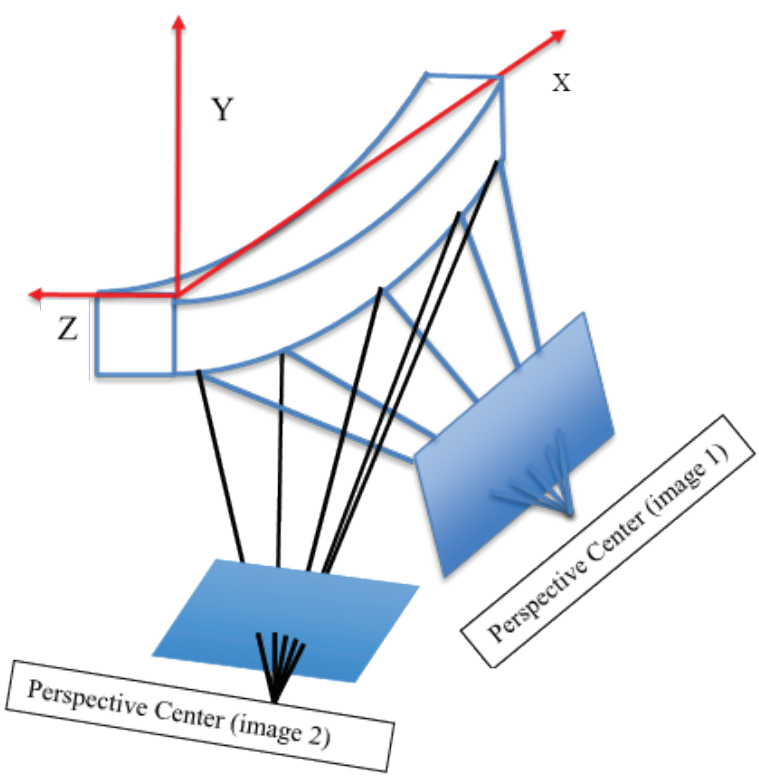


Figure 1: 3-D deflection measurement from cameras.

Project Results

This research project was performed in two stages. Stage 1 of the project has developed non-contact DMS and necessary rigorous mathematical models. Stage 2 of the project implemented the algorithms in the field and validated the overall methodology in collaboration with the railroad industry.

The tasks of Stage 1 of the project successfully developed the DMS and necessary linear feature- based mathematical models to use it for 2-D/3-D deflection monitoring. The system and methodology were tested in a lab environment using sample and simulated data.

Stage 2 of the project selected suitable sites for the field implementation of Stage 1 results in collaboration with railroad industry. Based on the field results, the research methodology was validated, and a final report was made available to the railroad bridge owners for consideration to use in their regular maintenance.

Product Payoff Potential

New federal regulations from the Federal Railroad Administration (FRA), U.S. Department of Transportation, now mandate North American railroad bridge owners to closely assess the structural capacity of their bridges. Consequently, railroad companies are currently looking into developing and exploring monitoring systems for specific bridges, to aid them improve and develop bridge safety in order to comply with this new rule (FRA, 2008). U.S. timber railroad bridges comprise 24% of the total inventory length of 418 miles (FRA 2008). The timber components in bridges have already exceeded their traditionally accepted life span of 50 years in many locations. In the absence of a feasible and convenient means to measure displacements, railroads can hardly justify including displacements and limits as part of the standard bridge management program. The collection of actual displacement data in railroad bridges is rather rare, because of the high mobilization cost associated with installing a reference point by the bridge. This project results are expected to assist the railroad bridge owners to come up with an economical and safe method that will be useful for timber railroad bridge deflection monitoring.

Product Transfer

The research team will continue to work with the CSX and other railroad bridge owners in implementing the developed bridge monitoring system in their regular maintenance practices in the near future.

Onboard High-Bandwidth Fiber-Optic Sensing System for Broken Rail Detection

Safety IDEA Project 36

Research Agency:	Intelligent Fiber Optic Systems Corporation (IFOS)
Principal Investigator:	Richard J. Black
Completed:	November 2020
IDEA Contract Amount:	$100,000

IDEA Concept and Product

This project will result in an innovative, fiber-optic (FO)-based onboard broken rail and defect detection system that will utilize the research agency's high-speed, broadband fiber Bragg grating (FBG) sensing technology. The broadband and high-speed nature will enable measurement of strain, shock, and vibration signals as indicators of rail condition autonomously while the train is in motion. The system provides unprecedented rail breakage detection capabilities with high resolution (order of 1 mm at 65 mph train speed) and high sensing accuracy at high monitoring speeds (order of 1 Mega samples per second or 1 MS/s per sensor). The proposed onboard FO sensing system provides the ability to detect rail breakage where inspection tools such as non-destructive testing (NDT), hand-held inspection, visual inspection, and signaling are either unavailable or impractical.

Project Results and Planned Investigation

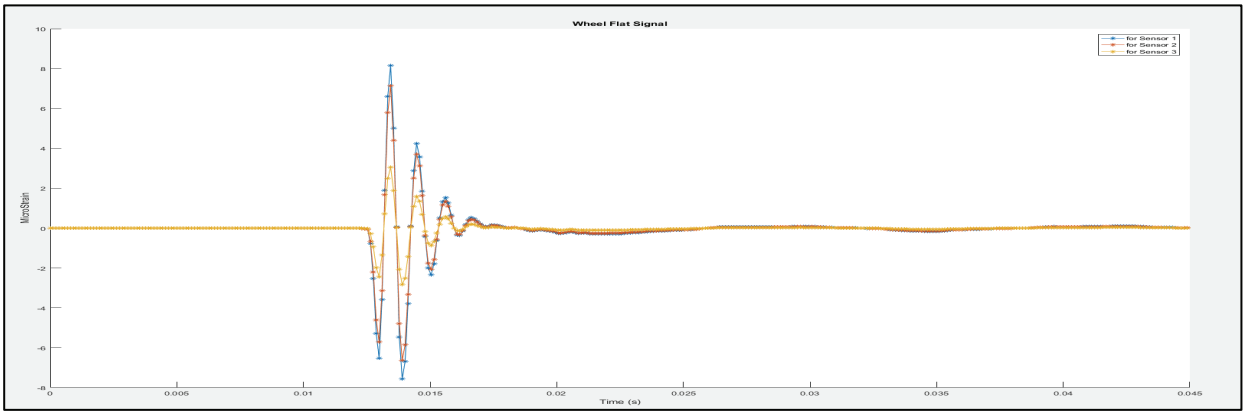
During this project, the research agency's R&D and engineering team used computer simulations of the train–wheel–track system and designed a test in the laboratory for simulating the event of the train wheel hitting a breakage point in the rail. The team developed signal-processing algorithms for detection of the rail break signals in presence of noise. Environmental noise as well as wheel-flat transients were added to the laboratory test data, and the R&D and engineering team demonstrated that the signal processing algorithms perform well in presence of noise and spurious signals.

To achieve these results, the team explored the broadband and high-speed capabilities of its advanced FBG sensing and optoelectronic interrogation technology to enable real-time high-speed measurements of dynamic strain, shock, and vibration signals, as well as their wideband spectral signatures as indicators of rail integrity (health) condition, both reliably and autonomously, while the train is in motion. The work was organized into four technical tasks:

1. Design FO sensor array in conjunction with data collection hardware and software.
2. Test onboard high-bandwidth FO sensor system in simulated broken rail condition scenarios.
3. Develop customized application-specific algorithms for broken rail detection.
4. Perform computer simulations of the train–rail system.

Some example laboratory test results are shown in Figure 1, *a* and *b*, with breaks simulated by a hammer hit and realistically modeled flat wheel signatures added to the data.

(a)



(b)

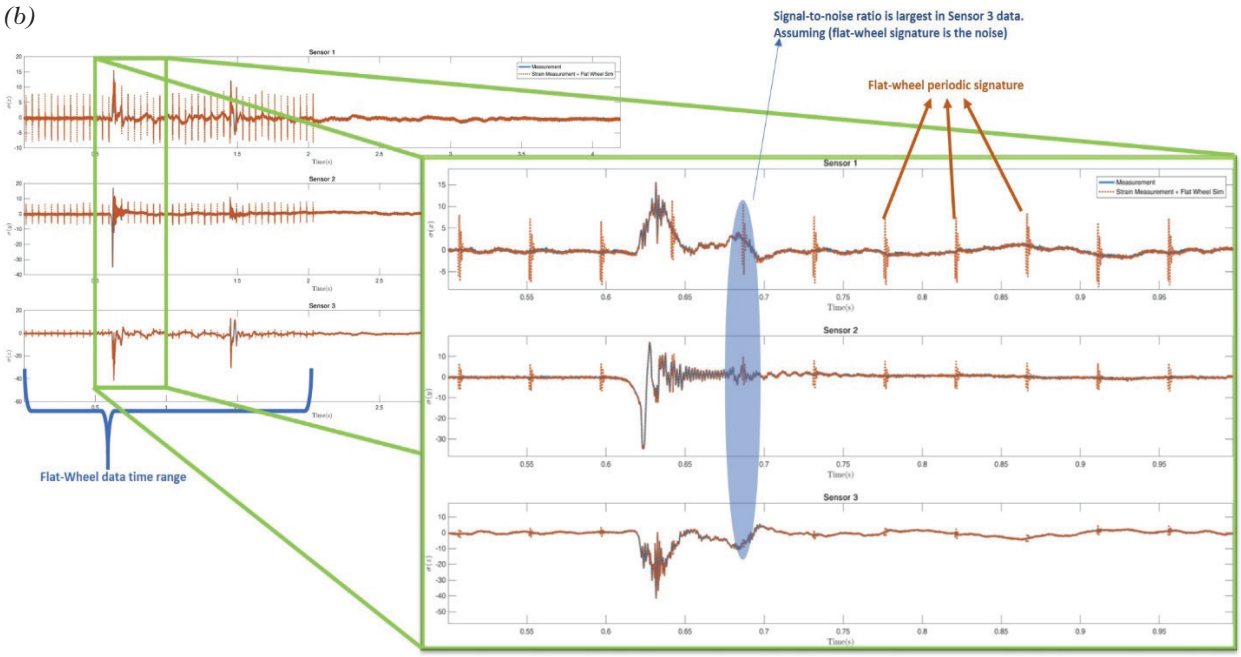


Figure 1: (a) Simulated wheel flat signal at FBG sensor Locations 1, 2, and 3 and (b) hammer test measurements with added flat wheel simulated signals.

Product Payoff Potential

This project has provided unprecedented pre–catastrophic–failure rail breakage detection capability with high spatial and temporal resolutions (on the order of 1 mm at 65 mph train speed), and excellent sensing accuracy at high monitoring speeds (order of 1 Mega samples per second or 1 MS/s per sensor). The proposed onboard FO sensing system provides the enabling capability to detect rail breakage where other inspection tools such as NDT, hand-held inspection, visual inspection, and signaling are unavailable, impractical, or of limited value.

Product Transfer

The research team plans to conduct post-project testing in a relevant environment in collaboration with the leading transportation testing facility within the United States to pave the way for commercialization.

Measuring Behavior of Railroad Bridges Under Revenue Traffic Using Lasers and Unmanned Aerial Vehicles (UAVs) for Safer Operations: Implementation

Rail Safety IDEA Project 37

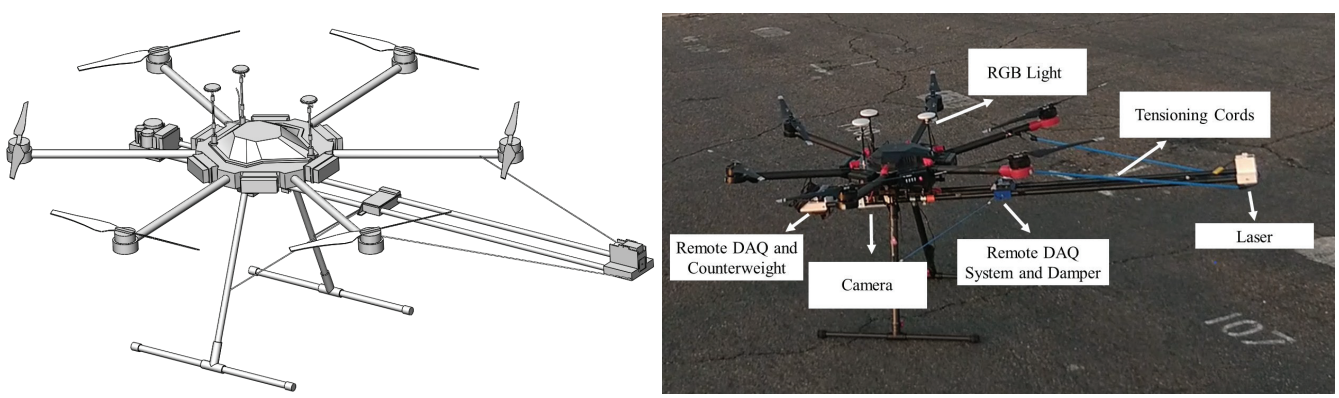
Research Agency: University of New Mexico

Principal Investigator: Fernando Moreu

IDEA Contract Amount: $98,997

IDEA Concept and Product

This research focused on developing an economical and reliable unmanned aerial vehicle (UAV)-Laser Camera system for the use of the railroad industry. Specifically, this IDEA product aimed to assist railroad bridge managers to obtain total transverse displacement of railroad bridges under trains. A new system was designed that integrated a UAV equipped with lasers, sensors, and other hardware to measure total displacements in the field (Figure 1). The system flies near the railroad bridge and obtains its displacement in a new non-contact and reference-free method. The intellectual innovation is the integration of two sensing approaches: laser and computer vision. A new algorithm was developed to collect various data signals from the system and obtain the desired total displacement values. The system was tested in the outdoor environment to prove its untethered performance. The results obtained were validated for accuracy and repeatability. Feedback from the railroad industry ensures its readiness for field use.



(a) (b)

Figure 1. New UAV developed for real bridge size testing: (a) design and (b) completion.

Project Results and Further Investigation

Work on the development of the UAV system's hardware and software was conducted in parallel. The two main sensors, laser and camera, were selected considering their accuracy, range, and price. An algorithm was programmed and tested for accuracy in 1 degree of freedom (1 df). Once the results were confirmed to be satisfactory by the railroad, the research team developed a new algorithm to obtain the 6 df motion of the camera. The camera and the laser signals were subsequently integrated to obtain the total displacement. Subsequently, indoor laboratory experiments were conducted to validate the algorithm prior to field implementation developments.

For field implementation, the research team selected a DJI Matrix 600 UAV system, Arduino platform, other low-costs data acquisition systems, and sensing hardware to ensure the affordability of this innovation. Several test flights were conducted in the Balloon Fiesta Park in Albuquerque. The results helped identify the challenges and shortcomings of the methodology and informed future steps to create a robust integration between the algorithm and the hardware. At the end of the project, the research team tested a full size bridge in Albuquerque, New Mexico) as an alternative to railroad bridges with traffic because of the restrictions applied due to COVID-19 (Figure 2). The possible uncertainties and challenges of the field experiment were investigated and addressed during this test, including the height of the UAV, computer vision, pilot control at real scale bridges, and data collection. The real scale test provided valuable information of the uncertainties expected in real train crossing events.

Figure 2. First real bridge test with untethered wireless outdoor UAV-Laser-Camera testing for measuring contact-free, reference-free displacements (Albuquerque, New Mexico): (a) pilot control and (b) drone laser solution lateral view.

Product Payoff Potential

This research was focused on the measurement of bridge displacements under freight traffic, but its application can be extended to displacement estimation in other structures. It enhances the accuracy of a new method to prioritize bridge repair and replacements, without the need of bridge access by inspectors, particularly for bridges located at inaccessible locations. The inspectors can use the product of this research to collect their data remotely without the need to climb the bridge to install sensors. The developed UAV-based methodology is affordable for railroad managers to adapt to their inspections to obtain non-contact reference-free displacements under train crossing events.

Product Transfer

This method can find the total displacement composed of both pseudo-static and dynamic components under freight load which was not possible before. Future improvements in cost and accuracy can be expected with the industry progress in UAV, sensors, and laser industry. The research team has met and discussed this technology and innovation with industry to explore technical improvements and deployment opportunities for their use in bridge management.

Minimization of Weld Failures by Means of Gas and Shrinkage Porosity Reduction

Safety IDEA Project 38

Research Agency:	University of Houston
Principal Investigador:	Francisco C. Robles Hernandez
Contract Amount:	$99,952

IDEA Concept and Product

This project developed a new methodology based on vibration technology to improve thermite welds (Figure 1). Thermite weld improvement is important because it is a major concern for the North American railways, and it is crucial to meet the network demands in terms of safety, reliability, and ridership operations. Specifically, the proposed innovative methodology improves fatigue performance (i.e., strength when subjected to cyclic stress) by minimizing the two most common types of porosity —gas and shrinkage. Gas porosity is the result of the precipitation of oxygen during solidification, and shrinkage pores are due to thermal contraction combined with a lack of melt feeding into the solidifying casting, which in this case is the thermite weld. The proposed vibration technology, applied during the solidification of the thermite welds, reduces the gas pores and refines the microstructure, resulting in an improved weld material with superior mechanical properties. The vibration can be induced into the weld by mechanical means as a non-direct contact method onto the weld. The vibration protocols were identified for mechanical vibration. The technology is almost ready for implementation by the railroad industry.

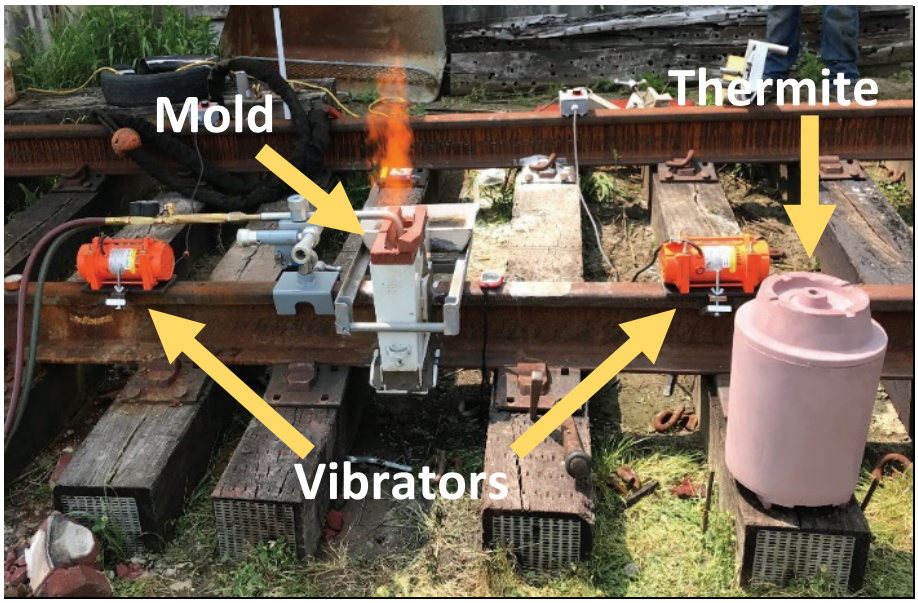


Figure 1. Experimental setup with vibrators during the thermite weld pre-heating process.

Project Results

The work was divided into three stages: (1) design of experiments and thermal weld casting, (2) mechanical testing, optical microscopy, and (3) analysis and reporting of results. Due to the expenses associated with performing first-time experiments on numerous thermite welds, a statistical method [design of experiments (DOE)] was employed to efficiently explore the process variables of the proposed vibration system. The purpose of DOE was to determine the specific variables that control a multi-variable process. In addition, a rail weld simulation device was developed for use in the laboratory to allow pre-testing the vibration device and explore the controlling variables. This information allowed for a more efficient exploration of the vibration process when applied to thermite welds. The operational variables considered for the design of experiments were vibration frequency, vibration force, vibration orientation and the distance of the vibrator from the weld. The first set of experiments was conducted in the laboratory scale simulator to understand the fluid mechanics of the vibration on a liquid. The experiments were performed using a water-containing marker. Water has very similar fluid properties (e.g., kinematic viscosity) to liquid steel. In addition, the added marker provided a method to track the specific motion of the water (or molten steel) when vibration is applied. The simulation results allowed the identification of the most important operating parameters to be tested in 16 experimental welds. Three additional welds were cast following current standard practices and used as controls.

The results indicated that the treatment was effective and improved the service life of the welds. Results from thermite welds treated with the vibration process show improvements in strength of up to 12% and a reduction in porosity. The porosity reduction has an expected improvement on the fatigue endurance limit of up to 30%. The treated welds were inspected using the protocols and recommended practices of the American Railway Engineering and Maintenance-of-Way Association (AREMA). These tests demonstrated that the vibration treatment was suitable for revenue service use as it had no negative effects on welds. The vibration parameter that provided the greatest benefit was the frequency, followed by the vibrating force. The other two parameters, which were orientation and distance between the vibrator and the weld, had less influence.

Product Payoff Potential

There is no porosity (gas and/or shrinkage) remediation treatment for thermite welds. The tests proposed here are aimed to identify the mechanical treatment of welds that best benefit the railroad industry. As such, this work has huge potential for future weld applications in railroad operations in the United States. The concept of having thermite welds treated by mechanical means will have a positive impact on efforts to reduce weld/rail maintenance and, at the same time, improve weld/rail life extension. An additional benefit will be the improvements in railroad safety. The eventual goal of this project is to introduce this technology to railroad systems to positively impact rail life extension and, most importantly, railroad safety. If successful, this approach will greatly improve fatigue life of welds and reduce not only rail breaks but also increase the overall safety.

Product Transfer

The improved thermal weld by mechanical vibration can be applied to railroad operations and will require minimum modifications for its successful implementation. The current setup can be used at the laboratory level; however, this research aims to extend its potential to the plant level, and, if successful, to the field. The technology will be proposed to weld manufacturers and the railways for real-life applications. There is now an initiative in place to test the welds at the Technology Transfer Center, Inc. If this is done, it could facilitate full implantation either independently or in collaboration with a railway or a thermite welding manufacturer. After the successful IDEA project, the welds are expected to be tested in-track in a Phase II project, funded by the railways or the Federal Railroad Administration. The goal is to make this technology a regular practice by the railways. Eventually, this technology could become the standard method to produce any thermite weld in the field.

Non-Contact Scour Monitoring for Railroad Bridges

Safety IDEA Project 39

Research Agency: Florida Atlantic University

Principal Investigator: Sudhagar Nagarajan

IDEA Contract Amount: $50,000

IDEA Concept and Product

This project developed an innovative platform independent non-contact scour monitoring technique for railroad bridges. This included developing methodologies and mathematical models for georeferencing and refraction correction to use green laser systems on static or mobile platforms like truck and unmanned aerial systems for railroad bridges over waterways.

The primary objectives of this research project were to (1) study the feasibility of using green laser for scour monitoring under varying turbidity conditions; (2) develop a procedure to apply refraction correction models for varying turbidity conditions for a static and mobile sensor platform; (3) perform laboratory experiments to obtain the scour hole dimensions using green laser under varying levels of water turbidity; and (4) perform experiments in the field to map the waterway/canal bed levels and the scour profile under the bridge piers.

Project Results

The project was implemented in two stages. Stage 1 of the project mainly focused on development of methodology to use a multi-platform-based bathymetric system for scour monitoring. This included deriving refraction correction procedures and development of registration methodology for a multi-sensor platform. 3-D concave-shaped scour hole models were fabricated and tested under varying depth and turbidity conditions using the developed methodology (Figure 1). The results were compared with original dimensions to validate the feasibility of green laser-based scour monitoring methodology. In Stage 2 of the project, the research team selected candidate bridges for field testing and experimented with the developed methodology to evaluate its feasibility.

Product Payoff Potential

Flood-related scour is the major cause of bridge failures across the nation that costs hundreds of millions of dollars in repair costs and also loss of human lives. Though most bridges can withstand typical water flows, long-term flood events like 50 years or more can cause scour-critical status or even bridge collapse. There are more than 100,000 railroad bridges in the United States. Bridge inspection is a crucial aspect of bridge management that detects the hazardous conditions to safely operate trains. *Federal Register,* Vol. 75, No. 135, July 15, 2010/ Rules and Regulations (Section 237.101) mandates that the track owner perform at least one inspection per calendar year, with not more than 540 days between successive inspections. Paragraph (b) of Section 237.101 further requires that the bridge management program shall

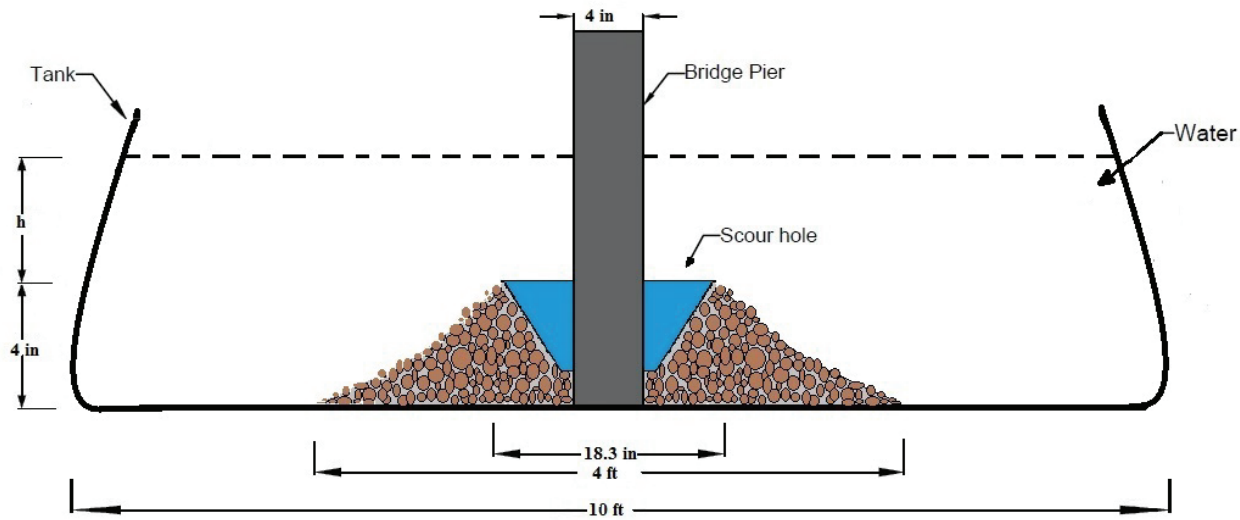


Figure 1: Scour hole model.

provide for the detection of scour or deterioration of bridge components that are submerged or subject to water flow. The required frequency for underwater inspections would be based on the particular river/stream conditions at each bridge. Underwater inspections are normally scheduled for every 2 years one month prior to the above water inspection. Interim underwater inspections are routine underwater inspections performed more frequently than every 2 years.

This project demonstrated methodologies to quantitatively evaluate the scour of bridge pier foundations by utilizing static or mobile platform-based green laser bathymetry measurements. The discussed methodologies have the potential to make scour mapping feasible, quick, safe and economical for railroad bridge owners.

Product Transfer

The implementation of the project was performed in CSX Transportation-owned railroad bridges. The research team will disseminate the knowledge to the railroad structural engineering community through publications and conference presentations. In addition, the codes and best practices procedures that resulted from this project will be shared with railroad agencies to identify/evaluate the substructure condition of railroad bridges using the developed non-contact scour monitoring technique.

Using Light to Reduce Fatigue and Improve Alertness in Railway Operations

Safety IDEA Project 40

Research Agency:	Rensselaer Polytechnic Institute
Principal Investigator:	Mariana G. Figueiro
Completed:	September 2020
IDEA Contract Amount:	$99,378

IDEA Concept and Product

With the advent and increasing prevalence of automatic train operation systems, dispatch centers are becoming more central to railway transportation worldwide. Railway operation is, however, highly susceptible to the detrimental effects of sleepiness that can cause severe nighttime fatigue and related impairment of work performance among dispatchers. A novel approach to mitigate the effect of sleepiness while on duty is the use of light, which can elicit an acute alerting response from humans at any time of day or night.

The primary objective of this project was to test and demonstrate the effectiveness and acceptability of combined red and white light for promoting alertness and improving performance in a simulated work-environment laboratory study using objective (i.e., electroencephalographic) and subjective (i.e., Karolinska Sleepiness Scale questionnaire) measures of alertness and objective measures of short-term performance (i.e., auditory–visual performance testing). This project lays the foundation for implementing lighting interventions in the railway environment and provides potential benefits that can support accident prevention strategies and policies.

Project Results and Planned Investigation

The research team exposed 18 (daytime) and 19 (nighttime) participants to four conditions: red light (λ_{max} = 630 nm, mean vertical illuminance [E_V] = 50 lx); white light (correlated color temperature = 2,700 K, mean E_V = 50 lx); red and white light combined simultaneously (E_V = 100 lux); and dim light (E_V < 5 lx) control. The red, white, and combined (simultaneous red and white) lighting conditions significantly reduced alpha, alpha-theta, and theta power compared with the dim condition, demonstrating the efficacy of light's alerting effects irrespective of time of day. These comparisons can be seen in Figure 1. Alpha power, specifically, was reduced significantly by the red and white lights during both daytime and nighttime, but the effect of the combined (simultaneous red and white) light was not statistically significant. Theta power was reduced significantly by the red and combined (simultaneous red and white) lights during the nighttime but not by the daytime. Alpha-theta power was reduced significantly under white light during the nighttime (see Figure 1). None of the conditions significantly increased beta power. The statistical effect of electrode site on electroencephalographic power was greatest at the Cz electrode. The results also indicated a trial effect that suggested participants' alpha, alpha-theta, and theta power increased over the course of the experiments.

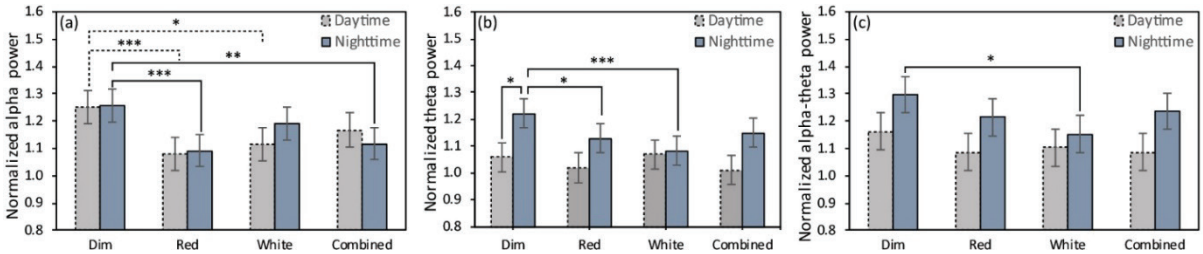


Figure 1: Normalized alpha (a), theta (b), and alpha-theta (c) power by lighting condition and time of day.
The error bars represent standard error of the mean: (*) $p < 0.05$, (**) $p < 0.01$, and (***) $p < 0.001$.

With respect to performance testing, a significant improvement in participants' hit rate (i.e., percentage of correct responses) was observed under the red lighting condition during the go/no-go (GNG) task. A significant interaction between lighting condition and trial for the GNG task also revealed that participants' performance scores (i.e., the speed of correct responses) were significantly higher under the combined (simultaneous red and white) light compared with the white light after 25 minutes of exposure. The results also indicated that nighttime participants' responses were significantly slower than daytime participants' responses, irrespective of condition, suggesting a strong time-of-day effect on response time. The research team did not observe significant improvements under any lighting condition in the psychomotor vigilance task. With respect to user visual comfort and acceptability for the performance of office work, the lighting appraisal questionnaire results revealed a preference for the combined (simultaneous red and white) light compared with red light alone among all participants (i.e., both nighttime and daytime).

Product Payoff Potential

Previous studies have suggested that red light can be used to promote alertness during the day and night, with red light being particularly beneficial at night because it does not cause circadian system disruption, which has been associated with sleep disturbances and major health risks. In the context of control center environments, however, it can be challenging to utilize only red light without falling short of facility lighting specifications and compromising dispatchers' visual performances. Because of this challenge, the transportation industry, and railways in particular, have not fully benefitted from the acute alerting effects of red light. The current IDEA project demonstrated that red light in combination with white light has potential as an effective countermeasure for promoting alertness and performance in the workplace, without compromising occupants' visual comfort. The research team believes that such experimental lighting solutions could be of great interest for railway operations, as their translation to real-world applications has the potential to support preventative strategies and policies for reducing the social and economic consequences of accidents.

Product Transfer

The research team will work with the project partner, New York City Transit, in seeking opportunities to test and demonstrate a prototype lighting system in an actual control center setting. The research team will also explore working with lighting manufacturers to develop simple, cost-effective lighting solutions that can be readily implemented in a variety of railway environments. In a potential follow-up field study, the research team will propose to test the effectiveness of lighting to promote alertness and reduce fatigue among train operation personnel, during both daytime and nighttime shifts.

Vibration-based Longitudinal Rail Stress Estimation Exploiting Contactless Measurement and Machine Learning

Safety IDEA Project 41

Research Agency:	University of Illinois at Urbana-Champaign
	University of Utah
Principal Investigators:	John S. Popovics and Xuan Zhu
IDEA Contract Amount:	$100,000

IDEA Concept and Product

This project developed new technology for on-site rail stress (rail neutral temperature or RNT) measurement combining contactless acoustic vibration sensing and machine learning. Such a system would predict in-situ rail stress or RNT and could rapidly assess a large inspection area once deployed on a moving platform enabled by the contactless sensors, which do not require any modification to track structures. The team interpreted the data using emerging machine learning technology to build a data-driven rail stress/RNT prediction model. Such innovations lead to the capability of continuously monitoring RNT along a track without the need for reference measurements nor modification to track structures.

Project Results

The tasks in this project were divided into two stages: Stage I, which was laboratory and field data collection using contactless measurement, and Stage II, which was machine learning for longitudinal stress determination based on field data. Figure 1 shows the overall technical approach for this project and prediction results.

Stage I activities centered on accurate rail stress and vibration data collection from an instrumented test site along a revenue service line. Strain gauges and temperature sensors were mounted directly on the web of the rail at two individual locations, and a set of gauges that monitor passing train loads was also attached. After rail de-stressing and sensor calibrations, rail vibration data were collected from the two locations. The vibration data were collected using a data acquisition system specially designed to carry out excitation and contactless sensing from an in-service rail structure. For both tests, frequency/mode-dependent sensitivities were identified in response to mechanical load and temperature variations, respectively, where the frequency spectrum variations are measurable. A total of 9 days' worth of vibration data were collected over 2 years to cover a wide range of temperature/stress conditions.

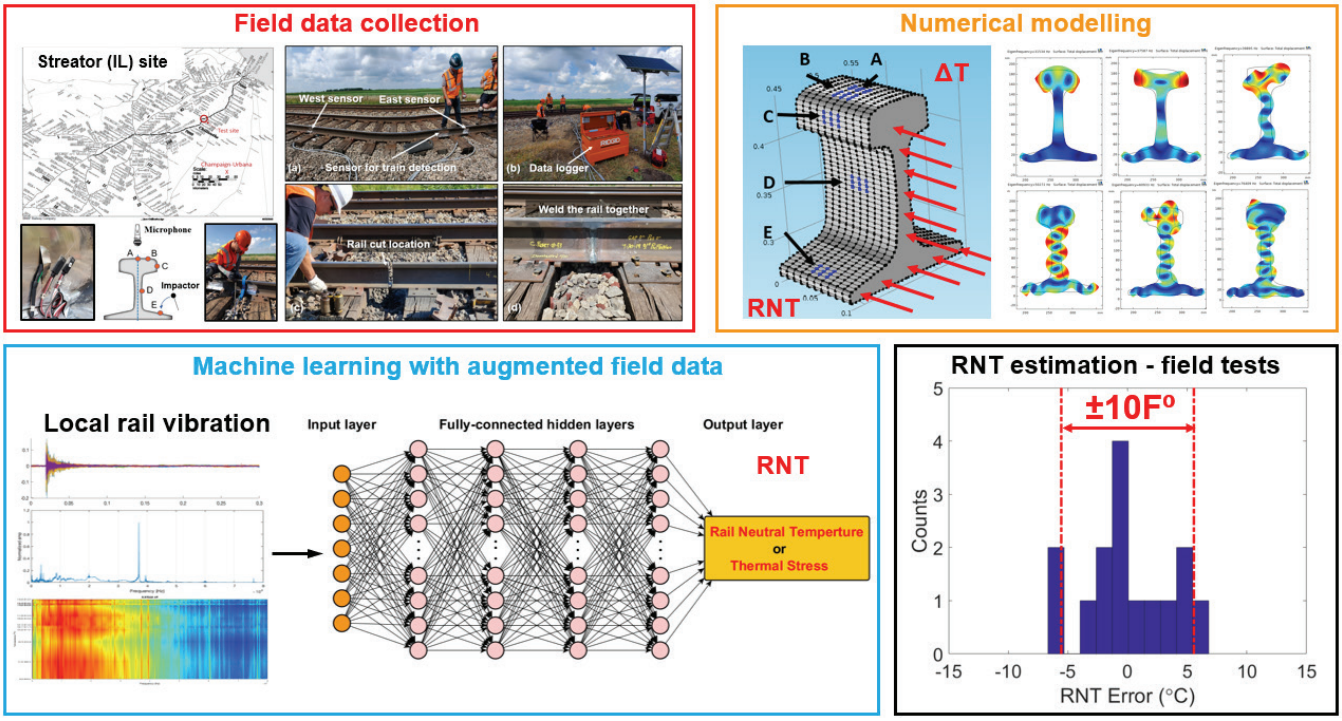


Figure 1: Illustration of the IDEA research approach using rail vibration data that are affected by stress and temperature to predict RNT.

Stage II activities focused on the development of a finite element model (FEM) and machine learning algorithms for RNT prediction using the field-collected and FEM data. Using FEM tools, rail track vibration behavior was predicted under mechanical and thermal loads; FEM predictions of resonance frequency were within 0.01% of those collected in the field. Using FEM frequency data from these specific modes under the influence of thermal load, a neural network was designed to predict RNT. The results from the neural network demonstrated that it is feasible to predict RNT using the identified high-frequency modes; the system performance with field data indicated that the proposed framework can support RNT prediction within ±5.5°C (±9.9°F) when measurement/model noise is low.

Product Payoff Potential

The mission of this project was to improve railway infrastructure safety and reliability. Accurate and practical in-place measurement of rail stress state or RNT was needed to achieve this objective. The currently employed VERSE technology provided accurate measurements but was time-consuming, labor-intensive, and not appropriate for autonomous measurement. Furthermore, VERSE technology must be applied when the rail is in a tensile state of stress, which is not applicable for operation in hot weather. Thus, a new technological development that provides accurate and more practical measurements will have a notable payoff for practice.

Product Transfer

The team's approach brings promise for effective implementation because the work was supported by in-service rail measurements with knowledge of true rail stress and temperature data. The team's work was enabled through close cooperation with our rail industry partner, which is BNSF Railway. The team has maintained regular communication with the technical contact at BNSF to increase the likelihood that the technology will eventually be implemented in the rail industry. Furthermore, the team's close partnership with the rail research group at the Rail Transportation and Engineering Center (RailTEC), University of Illinois at Urbana-Champaign, has enhanced the chances of the technology being implemented in practice because of the Center's extensive history and collaboration with the rail industry.

Railroad Tunnel Inspections for Maintenance and Replacement Prioritization Using Untethered Ground-Penetrating Radar and LiDAR Capable Unmanned Aerial Vehicles (UAVs)

Safety IDEA Project 42

Research Agency: ADOJAM, LLC

Principal Investigator: Michael Scott

IDEA Contract Amount: $99,685

IDEA Concept and Product

This project developed an innovative prototype system, Safe Automated Tunnel Evaluation System (SATES), for untethered, contact-free, and reference-free railroad tunnel measurements (surface and subsurface) to improve railroad safety. This unique concept can inform and optimize railroad tunnel asset life-cycle cost decisions. The product application provides ground-penetrating radar and light detection and ranging (LiDAR) measurement capabilities via an efficient, specialized unmanned aerial vehicle (UAV) deployment. The product application makes measurements of areas of moisture/water entrapment (behind the tunnel liner) and also provides insights into tunnel wall liner geometry, tunnel clearance dimensions, and tunnel material properties. Relevant metrics that SATES can evaluate are a function of moisture build up, geometry (tunnel clearance), and material properties affecting fire survivability, among other factors. The research team uniquely integrated, operationalized, applied, and field tested the SATES technology to produce relevant results. The outputs addressed key railroad needs, including safety and efficiency.

Project Results

The project work was carried out in two stages or phases. In Stage 1, the SATES system was configured and tested. Data was collected via SATES to support initial analysis and outputs. Prior to project inception, the researchers had worked to reduce fundamental SATES data acquisition and analysis processes to practice. Field conditions posed even greater challenges than anticipated but the obstacles were ultimately successfully addressed during data acquisition, including necessary refinements to perform in linear winds and optimize on board lighting. Key tunnel issues addressed by SATES to improve tunnel asset safety and performance life-cycle costs included (1) moisture build up behind tunnel walls/liners that impacts tunnel integrity/safety as well as tunnel function; (2) geometric clearances intruding on the railway vehicle kinematic envelope impacting safe railroad speeds and minimizing occurrences of operational damage; and (3) detecting tunnel liner defects (voids/cracks) and material property variations to advance mitigation of fire safety hazards in tunnels, extend tunnel asset life span, and minimize life-cycle costs. Work in Stage 2 involved refining SATES hardware and analysis to improve sensing and analysis based on Stage 1 results.

SATES technology demonstrated capabilities to provide comprehensive, three dimensional (3D) colorized tunnel liner measurements at high resolution to evaluate surface deterioration and subsurface moisture, including difficult access tunnel ceiling evaluation. Novel SATES UAV deployment and innovative sensors produced the world's first surface + subsurface UAV measurements in a tunnel. Among other features evaluated, SATES detected and located subsurface water behind concrete tunnel liners, surface concrete tunnel deterioration features (spalls or cracks), and virtualized 3D tunnel geometry as a dense, colorized point cloud. The custom SATES UAV airframe and purpose-built sensor deployments were integrated specifically for railroad tunnel inspection applications. The SATES UAV performed tunnel safety measurements untethered, contact-free, and reference-free, showcasing convenient scan capabilities at two field test sites. SATES sensing technologies accurately measured tunnel geometry within inspection tolerances, including difficult access features in tunnel ceilings, which are often dangerous and inconvenient to inspect via conventional means. SATES comprehensively documented tunnel deterioration features and provided information about excess water in concrete tunnel liners (linked to tunnel deterioration phenomena). In future research, Artificial Intelligence (AI) technology can be added to streamline the inspection process.

Product Payoff Potential

SATES has provided significant results, including detailed tunnel condition information. Additional benefits are reduced railroad worker injuries (by reducing railway worker exposure to the right-of-way), saving money by optimizing early sub-surface fault detection, quantifying rates of structural deterioration, and potentially saving lives. Specific benefits of the IDEA innovation include:

- The non-invasive and remote nature of the inspection makes the methodology economical and flexible.
- Detailed structural inspections can be carried out with minimal traffic interruption
- Results are presented in a standardized point cloud format that allows visualizations using industry standard software including computer-aided design. The data can be sliced and diced along any axis allowing ease of presentation and application of the collected data.
- The provisions in a recent past transportation legislation, Moving Ahead for Progress in the 21st century Act (MAP-21), resulted in the establishment of the National Tunnel Inspection Standards and publication of the Federal Highway Inspection manual (Tunnel Operations, Maintenance, Inspection, and Evaluation [*TOMIE Manual*], July 2015). SATES can streamline compliant workflows consistent with these new standards.

Product Transfer

Through collaboration and testing with the project's railroad partner Norfolk Southern, the researchers have gained valuable insights into how the SATES system (Figure 1) can be scaled up and enhanced to mesh with existing inspection and evaluation requirements and prepare the system for wider adoption. Beyond SATES testing, improving the speed of railroad asset evaluation, including 3D surface + subsurface measurements, metrics, and visualization (e.g., Figure 2) for rapid commercial deployment can enhance industry acceptance.

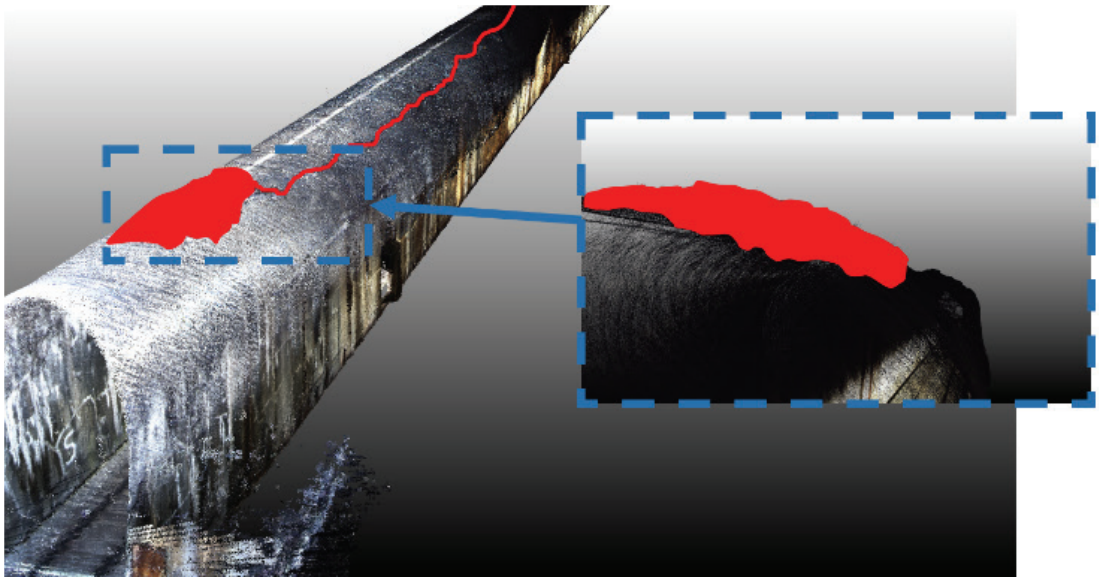


Figure 1. Initial SATES configuration reduced to practice by the ADOJAM Team.

Figure 2. SATES analysis output graphic highlighting water-induced concrete spall area and crack (both highlighted in red).

Laser-Based Non-Destructive Spike Inspection System

Safety IDEA Project 44

Research Agency: University of South Carolina

Principal Investigator: Yu Qian

IDEA Contract Amount: $100,000

IDEA Concept and Product

Spikes, together with tie plates and timber ties, are the dominant track components in North American freight railroads. Recent inspections have identified frequent broken spikes in certain tracks. Traditional track inspection methods can hardly identify any broken spikes without manually pulling each spike out, which is obviously not very practical. This IDEA project aimed to develop a low-cost, non-destructive, and contact-free inspection system to identify broken spikes in real-time. Numerical simulations were done to test the concept of using a laser to excite the spikes and estimate the reflection signals to distinguish broken spikes and good spikes. This was followed by a series of laboratory experiments using guidance from the numerical simulation results. Finally, a real-time pixel-level detection framework with improved real-time instance segmentation models was developed, based on a fully convolutional network.

Project Results

1. Finite Element Method (FEM) Heat Transfer and Wave Propagation Model for Spike: A numerical model of a spike based on the finite element method was established to simulate heat transfer from laser excitation and the corresponding thermal expansion and wave propagation within the spike. Three different types of spikes—good spike (new spike with no crack), partially cracked spike, and completely broken spike (hereafter referred to as broken spike)—were considered in the model. Laser excitation was simulated as a heat source at the spike head area to mimic different laser exposure times and focus areas. The wave caused by laser excitation at the spike head area could be reproduced by the numerical model to present the wave initiation and propagation within the spike. As shown in Figure 1, the research team found that the thermal acoustic responses of spikes with different lengths were different for the same excitation, which suggested the possibility of detecting the broken spike based on the acoustic emission patterns. The numerical model was used to perform a parametric analysis to guide potential laboratory setups to use the appropriate energy density.

2. Laser-Based Broken Spike Detection: Different spikes were excited with a laser directly at the spike head at different laser intensities. Both a microphone and an air-coupled transducer were used to detect the reflection waves away from the spike in a non-contact fashion to distinguish any difference between the signals from good spikes and broken spikes. Figure 2 shows a test setup with microphone. Figure 3 shows a test setup with air-coupled transducer. The specific laboratory setup with the air-coupled transducer developed in this project could pick up the differences between the signals from good spikes and broken spikes.

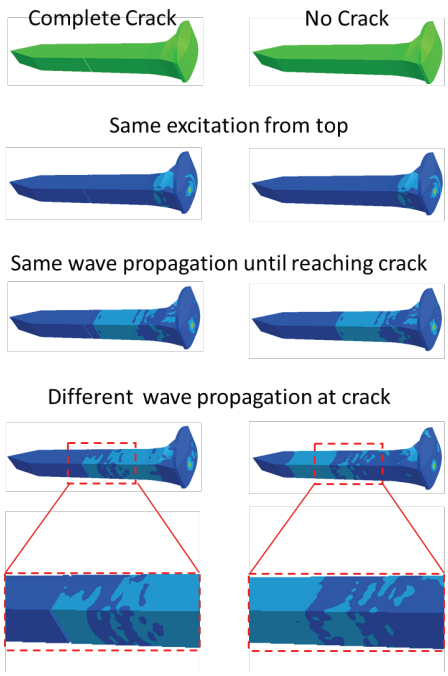


Figure 1. Numerical simulation results of different spike responses under the same excitation from the top.

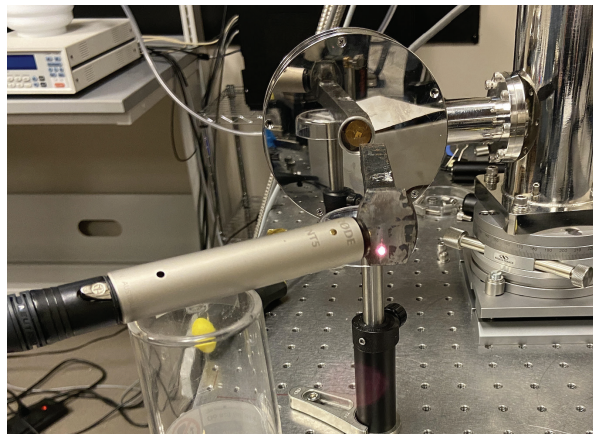


Figure 2. Laboratory setup of the laser excitation on top of the spike and acoustic collection system.

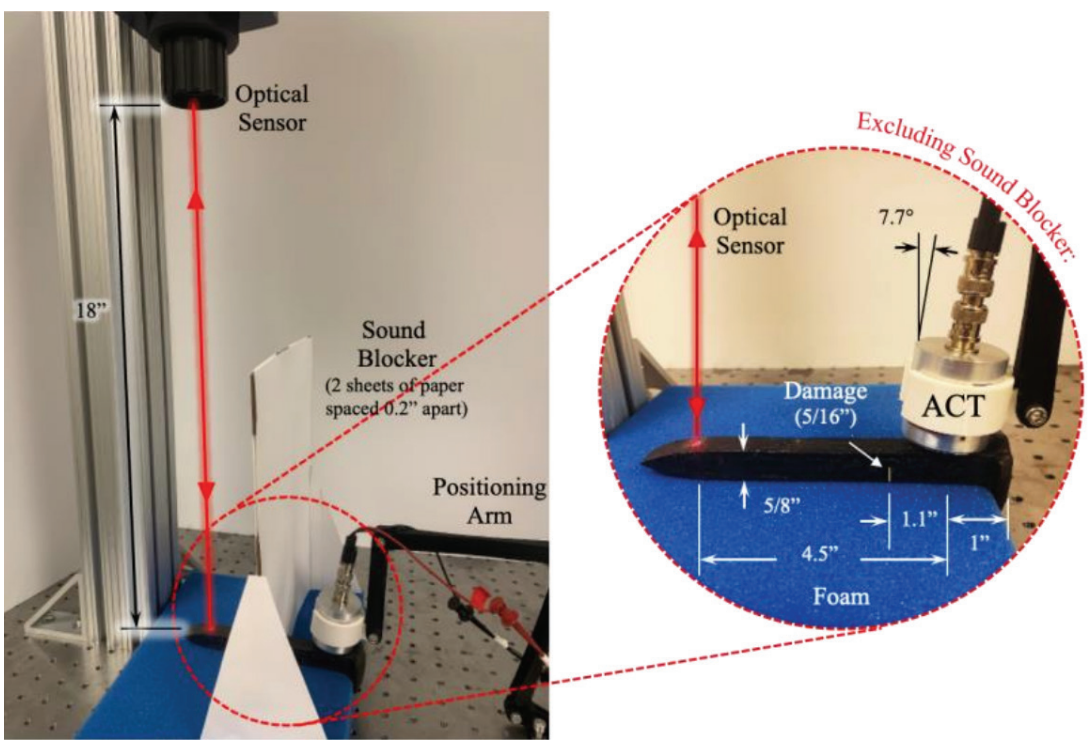


Figure 3. Laboratory setup with laser and air-coupled transducer.

3. Automatic Spike Detection Algorithm: A real-time pixel-level detection framework was developed based on a fully convolutional model including backbone, feature pyramid network (FPN), ProtoNet, and prediction head, as shown in Figure 4. The developed algorithm leverages fast object detection and highly accurate instance segmentation. Backbones with more granular levels and receptive fields were implemented in the proposed models. Track components such as spike, clip, and rail could be detected in real time (inference speed over 30 frames per second) with a single graphic processing unit. Under the different light conditions, the proposed models outperformed other models, proving the robustness on low visibility conditions.

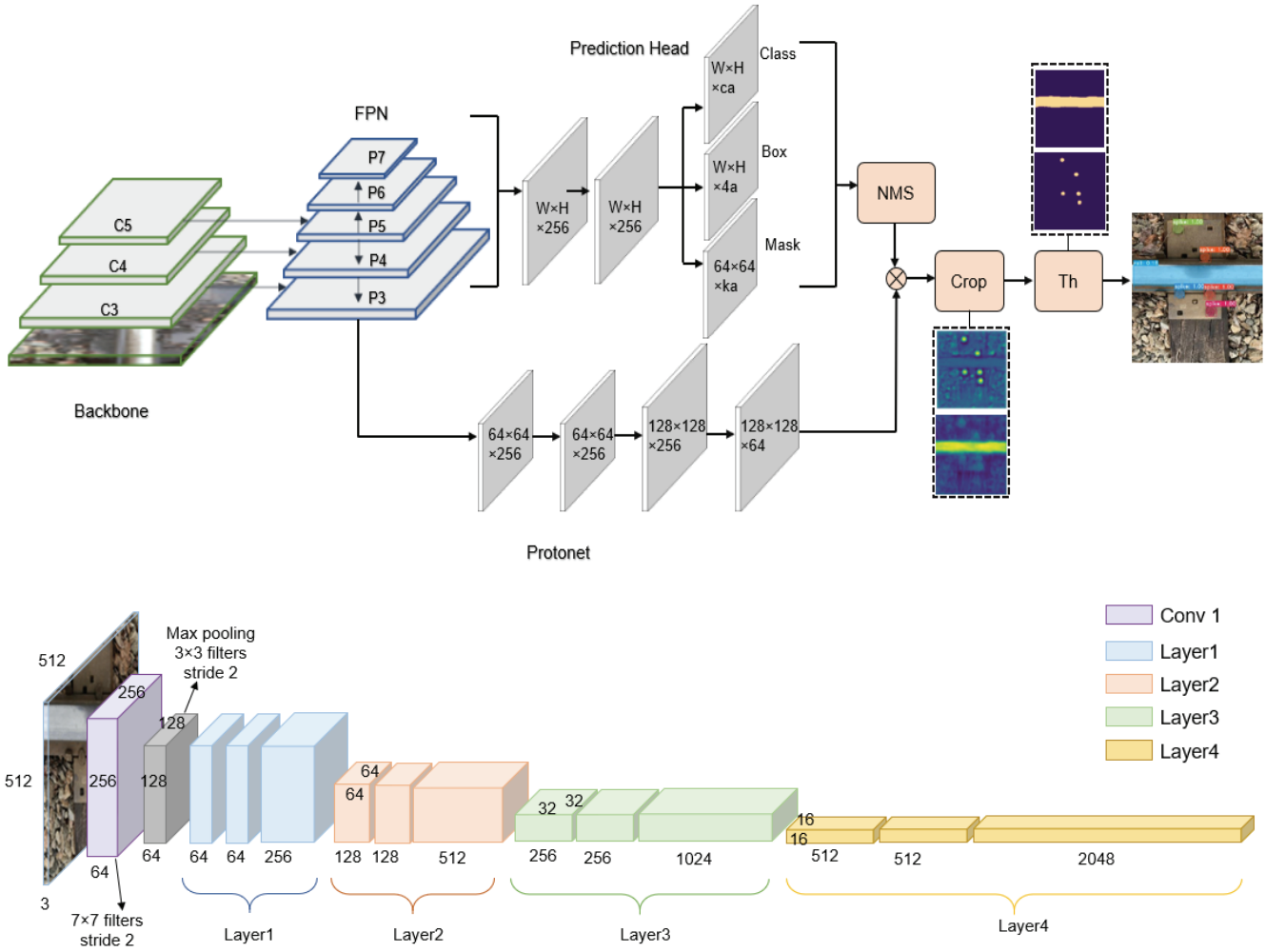


Figure 4. The main structure of the proposed model.

Product Payoff Potential

The proposed system is expected to serve as an unprecedented component for the next-generation, smart track inspection system, and could significantly reduce inspection costs and derailment risk, optimize maintenance strategy, and improve track safety. Instead of the current practice of using a sledgehammer to manually inspect every spike along the track, this proposed research attempted to develop a system that could be mounted on the existing track inspection platforms to automatically detect any missing or broken spikes. The reflected acoustic signal would then be used to evaluate the health condition of each spike in the field.

Product Transfer

Through collaboration and testing with the project's railroad partner Norfolk Southern and collaborator North Carolina State University, the research team has gained valuable insights into how to customize the proposed system to fit field practice needs. In the future, broken or intact spikes will be set up to represent field service conditions in the laboratory to test the accuracy of the developed system. Moving beyond this IDEA project, the team intends to work on developing a potential hand-held portable device for regular track inspection.

Development of a Fatigue Load for Railway Bridges

Safety IDEA Project 45

Research Agency: Purdue University

Principal Investigator: Robert J. Connor

IDEA Contract Amount: $100,000

IDEA Concept and Product

This project developed a fatigue load for design and evaluation of steel railway bridges. Current railway bridge design practice in North America uses the Cooper E80 Load as the design fatigue load. This is not optimal as the Cooper Load does not provide any real guidance for the number of anticipated active cycles, resulting in accumulation against the fatigue life. A fatigue design load that recreates the conditions of bending moment cycling generally provides a realistic approach to both design and rating of fatigue-prone details and beam sections. A successful load serves both purposes. A rating system can be instituted using the fatigue design load as the reference for the rating. The products of this IDEA research are software algorithms designed specifically for fatigue evaluation and a proposed fatigue design load for use in fatigue rating.

Project Results

This project was performed in two stages. The objectives of Stage I activities were (1) development of a computer program for calculation of bending moment and bending stress time histories for railway equipment at any point on a simple span of any length, (2) incorporation of rainflow cycle counting and root-mean-cube (RMC) stress calculations for fatigue cycle accumulation in those spans, and (3) application of this program to analyze fatigue behavior of virtual bridge beam and girder spans under past and current railway loadings. The results of the analysis were used to develop a proposed fatigue load.

The analysis used typical railcar equipment on virtually designed spans that conform to the different design recommendations published by the American Railway Engineering Association (AREA)/the American Railway Engineering and Maintenance-of-Way Association (AREMA) since 1906. The railcars used represented legacy and current types in a variety of configurations. The analysis is applicable to bending members (i.e., beams and girders) and can be performed on rolled or built-up sections at any point on a span.

Fatigue analysis has often focused attention at mid-span. Preliminary results show that the quarter points and cover plate cutoff regions are prone to active fatigue cycling, depending on the span length and the types of railcars loading the span. Figure 1 displays a typical bending moment time history at a quarter-point for a typical freight train on a medium-length span.

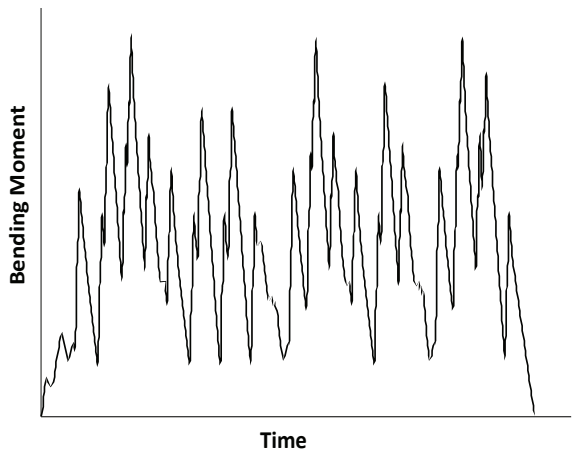


Figure 1. Typical Bending Moment Time History

Train configurations included ”unit trains” similar to a typical coal train, manifest (mixed) trains composed of any railcar equipment (either loaded or empty), and articulated equipment used in intermodal service. The axle weights can be adjusted to any desired level. The examination of mixed trains included a major Monte Carlo simulation development and analysis of random mixed train. This analysis had not been performed until this research. The results showed that mixed trains (empty and loaded cars together) produce fatigue cycling at greater levels than anticipated for affected span lengths and are a critical factor in fatigue life evaluation.

Stage 2 activities focused on the development of the proposed F80 fatigue load. The proposed fatigue loading used the results of different train types, including the mixed train, and was formulated to provide a combination of RMC stress and number of cycles sufficient to estimate potential future active cycles. The proposed F80 fatigue load has demonstrated that its effect on fatigue life is greater than the current loadings experienced on railroads, which is desirable for design and rating.

Product Payoff Potential

Fatigue design and evaluation of steel railway bridges use the same concepts as highway bridges. A fatigue design load exists for highway bridges that allows a uniform method of design along with rating of a bridge. However, no current “standard” exists for railway bridges. The main issue has been the availability of RMC stresses and anticipated cycles under various conditions. This research provides this data under a number of different loading conditions, which will be useful to railroads, public agencies, and the structural engineering community. A generally accepted fatigue load would be a major enhancement to railway safety, operations, and infrastructure planning, providing continuity between fatigue design and fatigue rating.

Product Transfer

Transfer of this product will include development of proposals for inclusion of the research material into the AREMA *Manual for Railway Engineering* published annually in April. The proposed fatigue load is directly applicable to fatigue design of new steel bridges and development of a fatigue rating for both bridges and railcars using the same configuration. The development of a fatigue rating system will provide the industry a common measuring tool for comparison of loads to a defined standard for fatigue, which will benefit any entity involved in operations and maintenance of a railroad property. The proposal for a fatigue load will require acceptance in the AREMA *Manual* in two locations of Chapter 15, where it will require vetting for both design and rating.

Additional research will continue using the software developed for this project, along with its results, for publication and dissemination of the methods described in the final report. Other conditions beyond the generalized conditions analyzed in the final report deserve examination. Fatigue life of riveted railroad bridges is an issue that will need more consideration as the inventory of these bridges continues to age.

SECTION 2
ACTIVE IDEA PROJECTS

This section reports progress on all Rail Safety IDEA projects that were active during the 2022 year.

Augmenting Reality for Safer Inspections of Railroad Infrastructure and Operations

Rail Safety IDEA Project 43

Research Agency: University of New Mexico

Principal Investigator: Fernando Moreu

IDEA Contract Amount: $100,000

IDEA Concept and Product

This research project is exploring the use of Augmented Reality (AR) to enhance the accuracy and efficiency of monitoring railroad inspections and operations. AR was utilized as a scaffolding tool, and a new framework was developed that accelerated information acquisition and improved decision-making capabilities during infrastructure inspection. The proposed approach included modeling human cognition and learning processes and programming them into AR. Additionally, to reduce decision-making biases, a real-time data access/accumulation system through AR platform was presented for field inspections for application to any railroad operation. Equipped with this new AR framework, railroad inspectors can access, collect, and share information in the field with higher efficiency. The new AR framework was tested at the American Railway Engineering and Maintenance-of-Way Association (AREMA) 2022 meeting with over twenty railroaders.

Project Results

The project tasks were divided into two stages: Stage I and Stage II. In Stage I, inspections with and without the proposed AR framework were compared. The software/hardware used was specifically designed/selected for track inspections and tested in collaboration with the Canadian National (CN) Railway (the industrial partner) at the CN campus at the start of the project. At the end of Stage I, new AR applications were developed, including robotic mediation with inspections as well as other applications that enhanced inspector safety with hands-off measurements.

In Stage II, activities included the training software that assisted novice workers in the indoor facility on how to conduct an efficient inspection with AR. Interest in training railroaders has been brought up by the project collaborator as a first step that can also inform later on the timeline of actual field implementations/solutions that would enable inspectors to do inspections faster. To achieve the goals of Stage II, activities the research team participated in the AREMA Conference & Expo 2022 to meet and present the AR developments to expert railroaders, in addition to demonstrating the new application on railroad tracks. New, young employees appeared more interested in the technology and could provide early feedback that could help improve the implementation of the AR applications in a context that has value for the railroad.

Product Payoff Potential

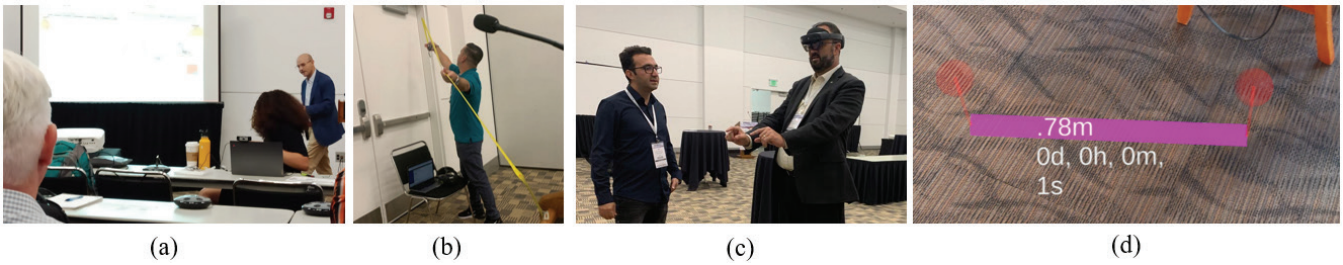
This research produced an AR application that was used to indicate the steps needed to conduct a better inspection with AR when compared with traditional tools (tape measurer) and which can be implemented in the field after testing and validation. The final report will include users' experience with both the new and the conventional methods and input for implementation of AR for faster training of railroad inspectors. A strong participation of industry in this research has ensured that the early steps on the development are directed toward real applications that are of value to the industry, with an emphasis on railroad inspectors who participated in the AREMA 2022 conference. External advisory panel members include the Volpe National Transportation Systems Center, Meta, CN Railway, Los Alamos National Laboratory, and the Air Force Research Laboratory.

Product Transfer

Working with industry partners ensures that the AR tools are transferred to practice for railroad inspections. The research team collaborated closely with CN to ensure this research identifies AR as a practical tool, and with AREMA Committees 10 and 24, dedicated to bridge management and education and training, respectively. Collaborations with the public and private sector leaders in AR, railroad, research, and industry ensures that the results of this research will have an impact on both the public and private sectors as well as on the infrastructure stakeholders. The research team has discussed both with CN and with Meta future opportunities to develop AR innovation to enable faster training for new railroad personnel. This information can also be shared in the form of applications, training programs, or different AR internships that prepare new employees to safely conduct their work in the field.

Figure 1 shows initial interface with CN Railway to understand priorities on safety during rail gage measurements in the field (informing the programming and development of AR application for Stage I). Figure 2 summarizes the Stage II progress collecting input from railroaders at AREMA 2022 Annual Conference, which will be included in the final report.

Figure 1. The research team is demonstrating the AR application for rail inspections to CN technical staff at the CN campus.



(a) (b) (c) (d)

Figure 2. AREMA 2022 AR survey from railroad industry to conduct inspections: (a) AR presentation to Committees 10 and 24, (b) participant's effort to use tape measure, (c) AR training, and (d) participants AR measurement results.

Adaptive Prestressing System for Concrete Crossties: Prototype Development

Safety IDEA Project 46

Research Agency: University of Illinois at Urbana–Champaign

Principal Investigator: Bassem Andrawes

IDEA Contract Amount: $100,000

IDEA Concept and Product

This project introduces an innovative technology that aims to resolve one of the most critical issues related to the safety, durability, and serviceability of railroad track systems, namely, cracking of prestressed concrete crossties. Conventional prestressing methods apply constant prestressing to the entire length of the crosstie to achieve desired strength, resulting in an inefficient system. This project explores an innovative and cost-effective concept for introducing, monitoring, and adjusting prestress forces within the tie, in the field, using an adaptive prestressing system (APS). With the use of innovative prestressing materials, it is believed that a method can be developed to introduce prestress in specific areas of concrete, as needed, by embedding shape memory alloy (SMA) fuses in the required region (Figure 1). This novel concept will enable users to control the level of prestress at certain regions of the crosstie and to accommodate the variations in support conditions, loads, and even climate conditions throughout the service life of the crosstie. The proposed technology will improve the safety and service life of the ties.

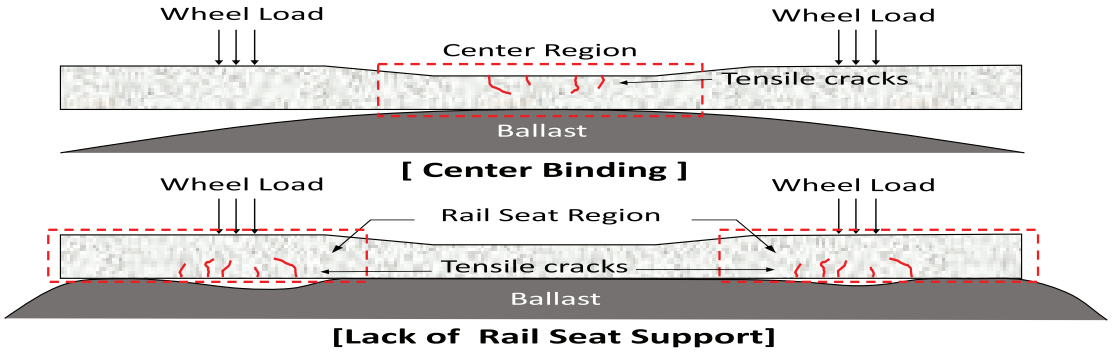


Figure 1: Schematic illustrating the use of SMA fuses to develop APS in concrete crossties.

Project Results

This project research is based on the success of the previous proof-of-concept Rail Safety IDEA Project Safety IDEA 33 and is aimed at designing and constructing full-scale prototypes of concrete crossties reinforced with the proposed APS. The work is being conducted in two stages. Stage I focuses on the design and fabrication of full-scale APS components for incorporation into the final prototype crosstie design. Work in Stage II focuses on assembling the APS components into a full-scale tie. Prototype designs with various APS configurations was considered as per the American Railway Engineering and Maintenance-of-Way Association (AREMA) Chapter 30 guidelines. The ties will then be tested in the laboratory and field to examine their performance under various loading conditions. The research team is collaborating with industry partners (crosstie producers) to optimize the design of the prototype crossties. The new prototype design of the crosstie with APS (Figure 2) shows a reduction in the amount of steel reinforcement used by over 40%. The design and experimental testing of the APS assembly (Figure 3) shows the ability of SMA fuse to effectively engage steel in prestressing using heating. This feature has proved to be reliable and repeatable during the service life of the crosstie, which will help mitigate the damage or cracking of crossties under service conditions.

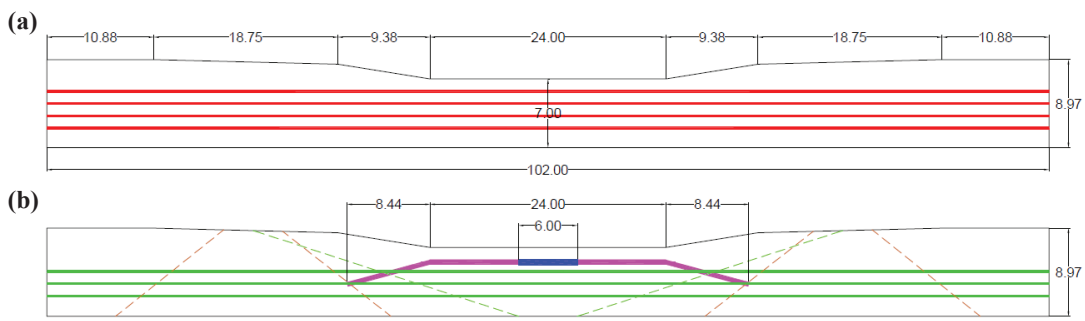


Figure 2. Crosstie design: (a) reference crosstie and (b) APS-optimized prototype.

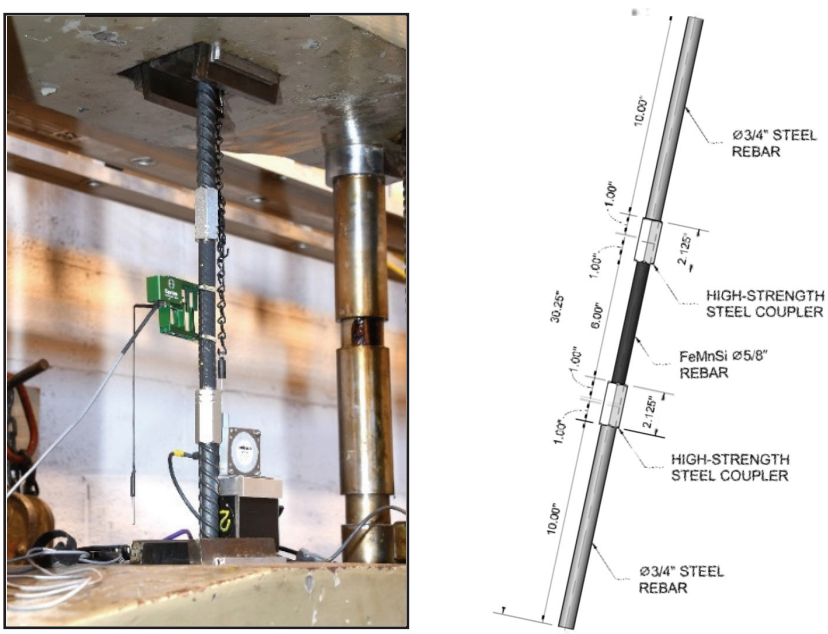


Figure 3. Design and testing of the APS, including SMA fuse, couplers, and steel reinforcement.

Product Payoff Potential

The proposed APS will provide designers the ability to easily adjust the crosstie design (i.e., location and amount of prestress force), based on track and load conditions. The current pretensioning technique provides designers with no control over the area of the cross-section where prestressing is being applied. The proposed APS will provide maintenance personnel with a tool to inspect/monitor the level of prestressing in the crosstie while in service and, if needed, to adjust the level of prestressing force at certain areas where understressing or overstressing has been observed. The delayed application of prestress in the proposed APS will help significantly reduce the level of prestress losses due to concrete creep/shrinkage and steel relaxation compared with that in the conventional pretensioning method, where prestressing is applied early (typically a few days after concrete casting).

Product Transfer

The project also entails the fabrication and casting of APS crosstie prototypes at crosstie plants in the United States. The research team is working with two crosstie producers on the design, fabrication, and testing of the developed prototypes. The early involvement of the industry in this new technology will play a key role in facilitating its transfer to the market. The patent that the principal investigator has filed for the APS technology is another important step toward the commercialization of the technology.

Autonomous Detection of Compressed Air Leaks on Trains

Safety IDEA Project 48

Research Agency:	Southwest Research Institute
Principal Investigator:	Christopher Stoos
IDEA Contract Amount:	$100,000

IDEA Concept and Product

Minimizing compressed air leaks on trains is one of the areas in which railroads can make significant gains toward reducing fuel consumption, which is necessary to meet the current greenhouse gas reduction goals. While some awareness of the cost of compressed air leaks exists, shop practices have generally not focused on fuel efficiency but rather focused on operability by allowing some level of leaks on certain compressed air systems on the train. Finding these leaks requires an employee to manually search by going over, under, or between rolling stock to listen or feel for leaks. This is an inefficient and time-consuming process, which is why the Federal Railroad Administration and railroad industry have defined acceptable leak rates. Automated detection of locomotive and train air leaks could reduce the time and labor necessary to find those leaks, reduce locomotive fuel consumption and exhaust emissions, and at the same time enhance the employee's safety. The purpose of this Rail Safety IDEA project was to develop a proof-of-concept wayside system that could autonomously detect compressed air leaks on trains and relay the location of the leaks to mechanical department personnel for repair, potentially reducing risk to the employees and reducing overall fuel consumption and emissions.

Project Results

During system development in Stage 1, hardware needed for the system was sourced. This included a visual spectrum camera and a thermal imaging camera as well as two Fluke SV600 fixed acoustic sensors. The Fluke sensor is a commercially available sensor that contains a 64-microphone array that, using technology developed by Fluke and their technology partner Sorama, provides an audio mask overlay on a visual spectrum image to show where sound sources are coming from. The sensor allows the user to define the upper and lower limits for decibel threshold as well as the frequency.

Initial testing determined the optimal sensor settings to detect air leaks while mitigating other sounds. A versatile stand to support the SV600 sensors and cameras was built, and various positions of the sensors in relation to the track were investigated (Figure 1). It was determined that air leaks were best captured with a minimum decibel threshold of 45dB and a frequency range of 30kHz-45kHz.

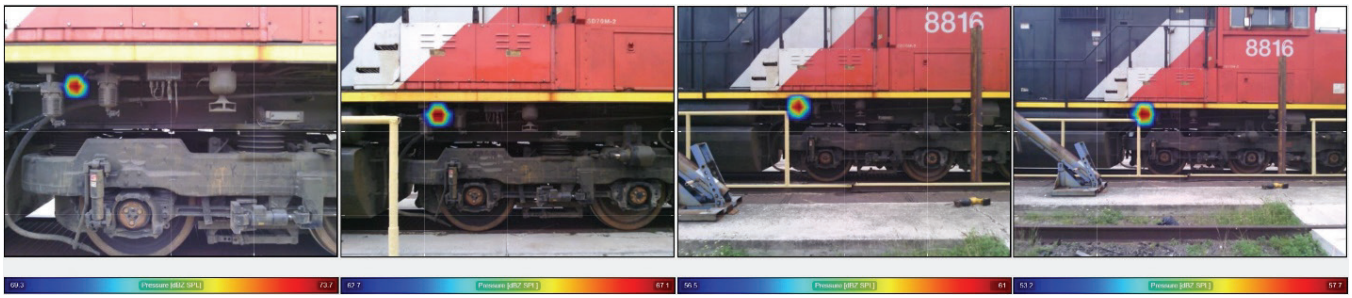


Figure 1. Air leaks at 3.0, 4.5, 6.0, and 7.5 meter distances.

Work in Stage 2 focused on implementation of the machine vision system. Various models were implemented to see which one was best suited to the task. The data was initially annotated using Computer Vision Annotation Tool, manually labeling known leaks and gladhands in the initial round, while reserving 20% of the initial data as a validation set. Two types of convolutional neural network were then trained and evaluated for the detection of air leaks. Both mobilenetV3 and YoloV5 models were assessed, with the YoloV5 model producing better overall results.

At this point in the development, the model was still triggering too many false positives. So a tracking logic was added that looked for leak persistence through time as it progresses through the field of view for the sensor. This spatial and temporal tracking allowed for the elimination of a large portion of false positives that were seen before by making sure that the signal tracked through the entire field of view.

Once detection (and false detection) was accomplished at an acceptable level, a basic notification system was developed. When a leak is detected, a composite image of the piece of equipment is created with the location of the detected leaks marked. Figure 2 shows an example of this composite image. In addition to the images, a notification is generated and sent to mechanical department personnel with the number of leaks, the leak locations, and the system confidence in each leak detected.

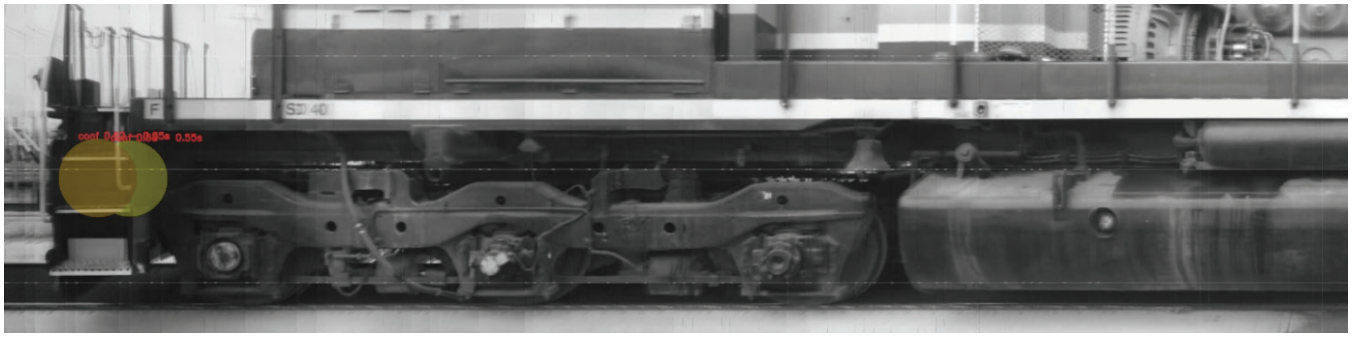


Figure 2. Example composite image with leak locations highlighted.

This Rail Safety IDEA project has successfully provided a proof-of-concept system that can autonomously detect compressed air leaks on moving trains and notify mechanical personnel of the exact leak location. At this point, the system accurately detects and flags air leaks 84.6% of the time, with false positives occurring only 0.03% of the time. With further field development and data collection, the system accuracy on air leak detection and the false positive rate is expected to improve significantly.

Product Payoff Potential

The proof-of-concept development of a wayside autonomous air leak detection system has shown great promise. The system was successfully able to detect air leaks at various locations with varying air leak rates with limited false positives and should greatly reduce the burden on mechanical personnel in finding air leaks on equipment. With further development, the system could be improved by integrating automatic equipment identification tag readers and implementing a machine learning system that can identify not just air leaks but also the individual components that are leaking, further reducing the burden on mechanical personnel.

As railroads strive to reduce their greenhouse gas emissions to meet their published targets, improving overall vehicle efficiency through net traction specific fuel consumption reduction and automatic engine start/stop system improvement is crucial. This system, if implemented correctly, could make significant improvements to both. This technology will also reduce the number of times employees must get on, under, or between rolling stock, which, in turn, will reduce their injury risks. Additionally, knowing where the leaks are on the equipment can allow for doing repairs in the shop environments during periodic maintenance, reducing the need for field repairs and further reducing potential injury risk.

Product Transfer

Through TRB and the project's expert advisory panel members representing freight railroads, passenger railroads and locomotive original equipment manufacturers, the research team received excellent feedback throughout the process on how such a system could be implemented as a tool for railroads. It is anticipated that the Southwest Research Institute will work with railroads and suppliers to further develop the technology from the proof-of-concept prototype designed in this project to a field-ready wayside detection system.

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