IDEA

Innovations Deserving
Exploratory Analysis Programs

TRANSPORTATION SAFETY

New IDEAS for Rail Safety

Rail Safety IDEA Program Annual Report

January 2017

TRB TRANSPORTATION RESEARCH BOARD

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NEW IDEAS FOR RAIL SAFETY

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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.

January 2017

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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 and overseen 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 are:

- NCHRP 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; and
- Transit IDEA, which focuses on products and results in support of the Transit Cooperative Research Program.

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

The IDEA programs are open to all individuals, including entrepreneurs, small and large businesses, and institutions. The program provides an opportunity 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 to mentor 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 the 2016 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 2016 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: Jo Allen Gause), Transportation Research Board, 500 Fifth St. NW, Washington, DC 20001, Email: jagause@nas.edu.

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

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 15, 2005 - - Project Completed
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 Lightning 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 22, 2005 - - Project Completed
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 1, 2005 - - Project Completed

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 5, 2006 - - Project Completed

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 28, 2006 - - Project Completed

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.

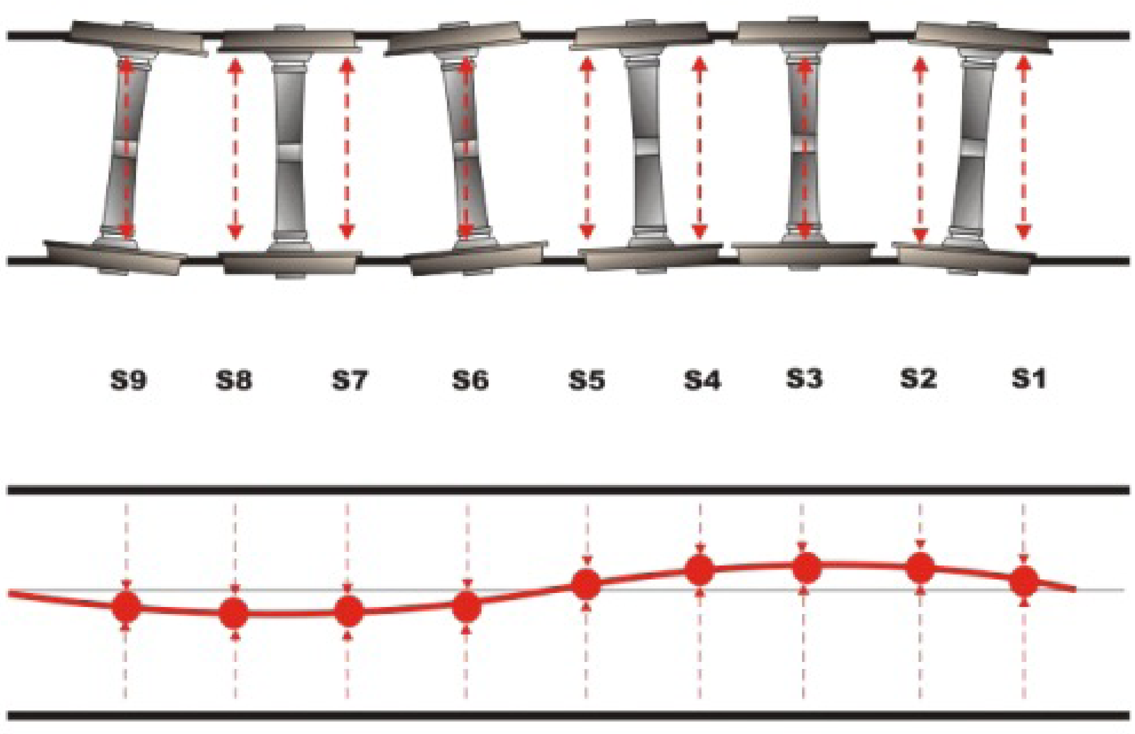


Figure 1: A wheelset's path captured by a multiple sensor array

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 4, 2006 - - Project Completed

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 31, 2006 - - Project Completed

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.

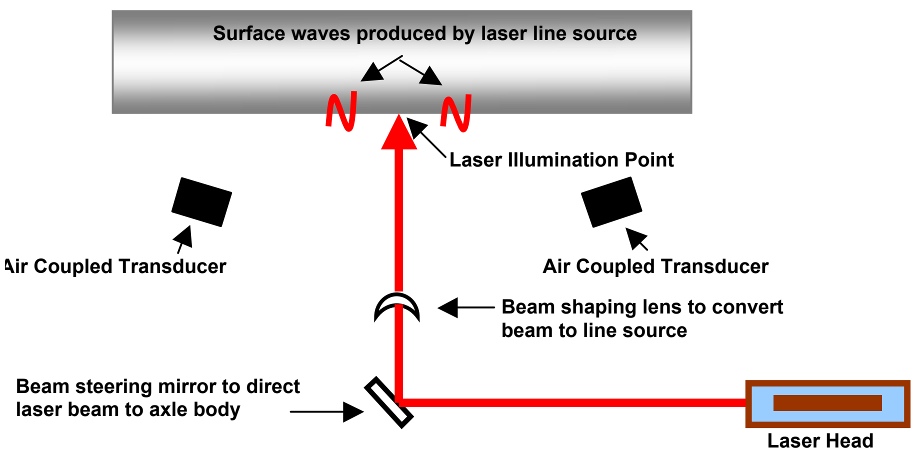


Figure 2: Axle inspection laboratory setup

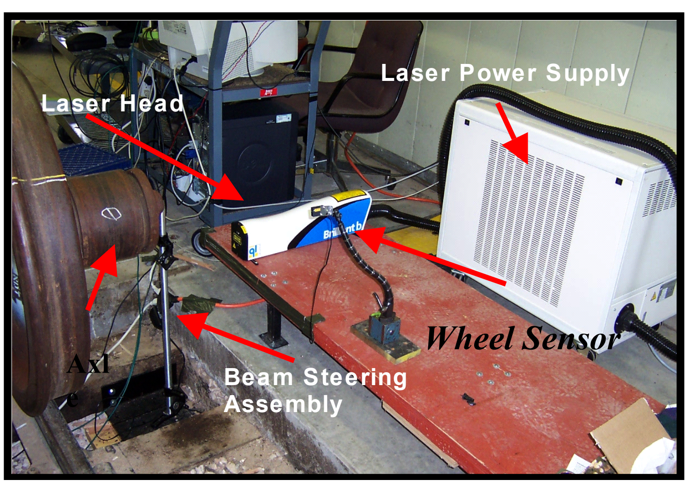


Figure 3: Proof of concept demonstration test setup

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 21, 2006 - - Project Completed

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 5, 2008 - - Project Completed

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 31, 2008 - - Project Completed
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 - - Project Completed
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 - - Project Completed
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

Principal Investigator: Dr. Stefan Hurlebaus

Completed: July 2011 - - Project Completed

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 - - Project Completed
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:	Project 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:	Project 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: Project 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: Department of Mechanical and Aerospace Engineering

Principal Investigator: Afsaneh Rabiei

Completed: Project 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 (MJ/m^3)
76 (MJ/m^3)	67 (MJ/m^3)

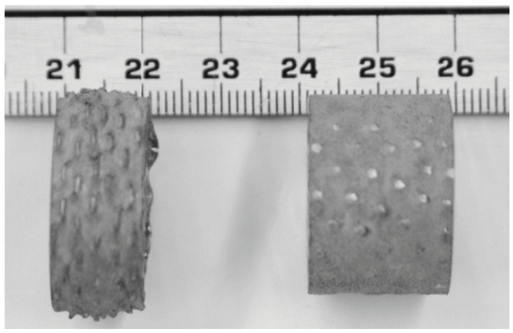


Figure 1: CMF samples with 4 mm steel spheres before and after high-speed impact.

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: Project 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 cladding. 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.

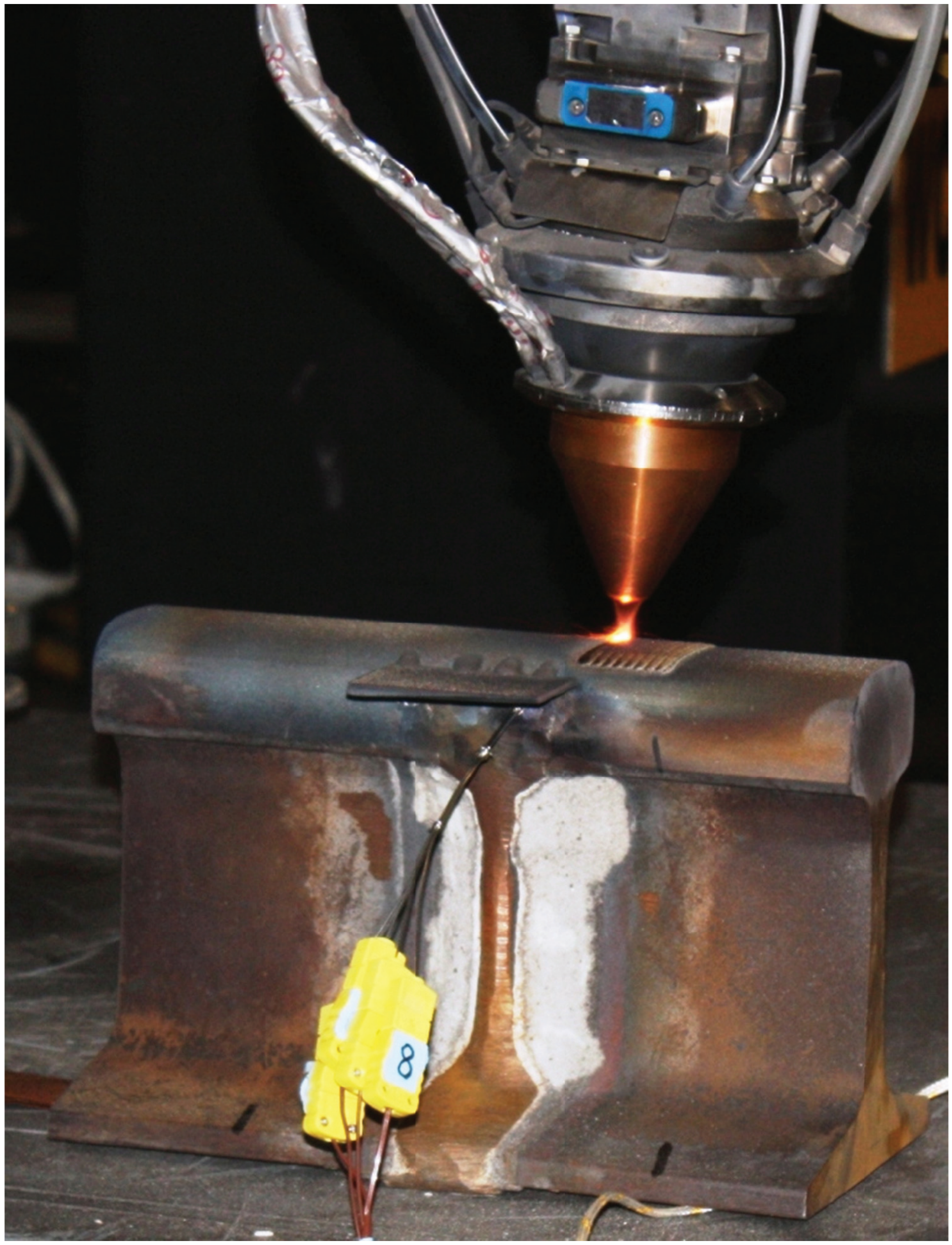


Figure 1: Laser cladding application showing thermocouples to record temperature.

Reducing Wheel Climb at Switch Points to Reduce Derailments

Safety IDEA Project 23

Research Agency: University of Delaware

Principal Investigator: Allan M. Zarembski

Completed: Project 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.

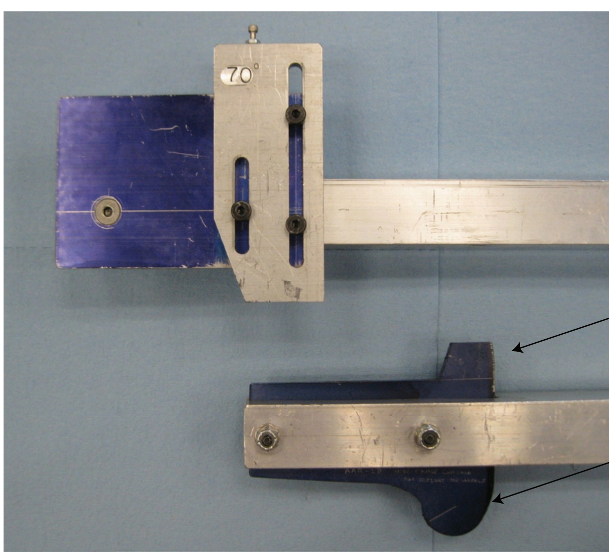
The researchers, working with an Expert Review Panel and Norfolk Southern research staff, developed a series of hand held measurement gauges to address these problem areas, based on European practice, and then modified to reflect U.S. conditions and practices. These gauges were then taken out into the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



Severe Profile Gauge with 70° flange angle

Chipped Point Gauge

TGAAR1B Gauge with 60° contact mark

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: Project 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.

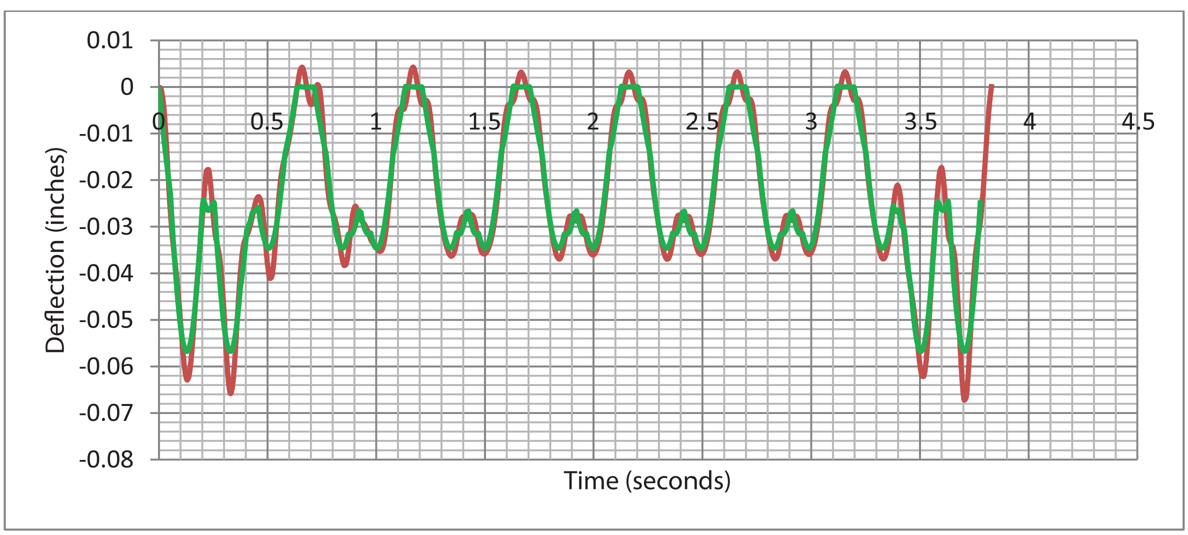


Figure 2: 120 mph train speed-induced girder deflections at midspan superimposed on the quasi-static 6 mph train.

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 14, 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.

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

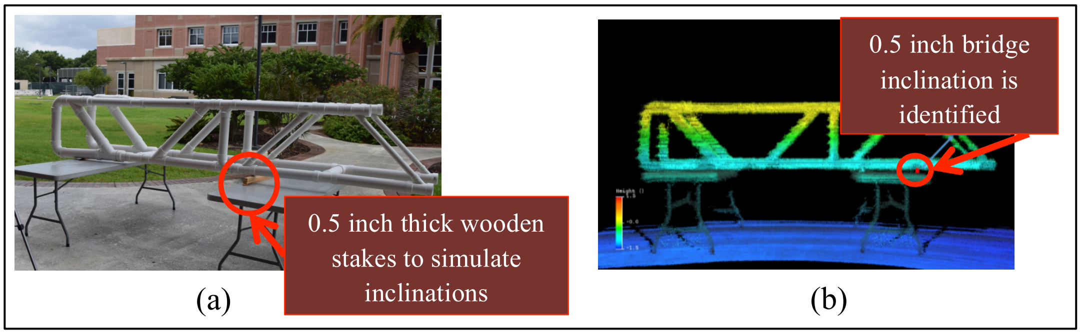


Figure 1: (a) PVC bridge for controlled experiments; (b) 3D model showing 0.5 inch structural deviation.

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 multipurpose 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.

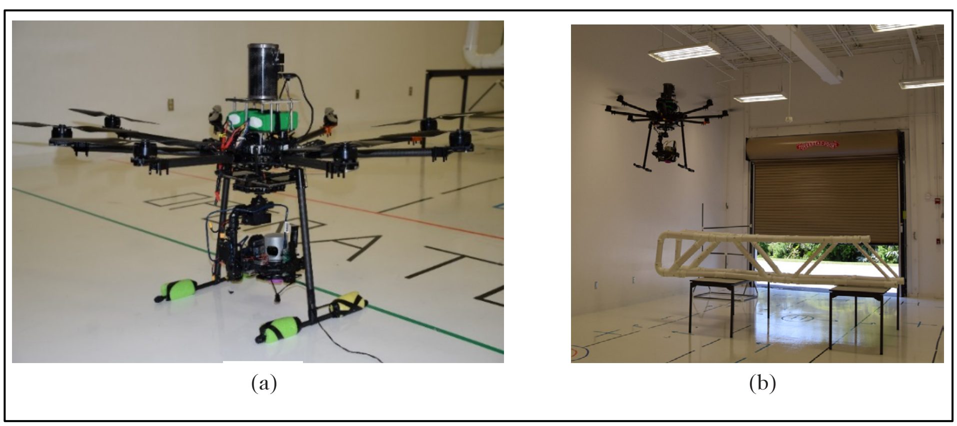
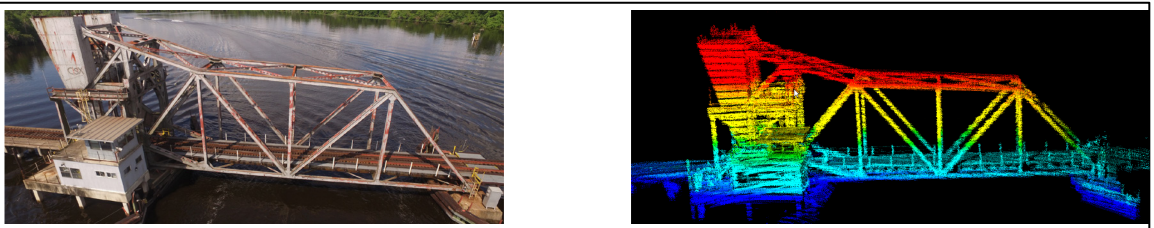


Figure 2: (a) Fully integrated UAS; (b) Indoor UAS flight around PVC bridge.

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.

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: Scheduled to be completed November 15, 2016

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 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 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

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

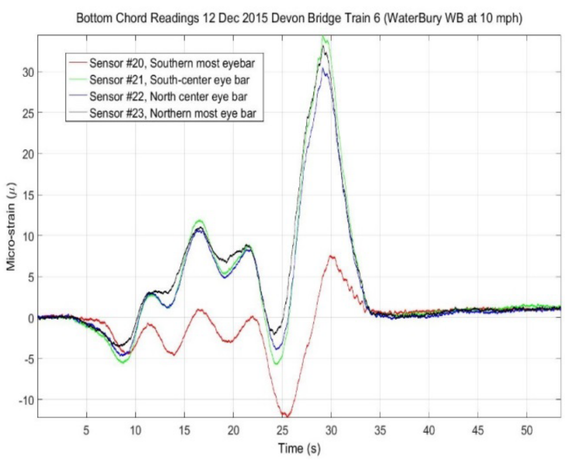


Figure 2: Strain readings on four eyebars, bottom chord L6-L8 South truss under Waterbury train westbound, on track 3 traveling at 10 mph.

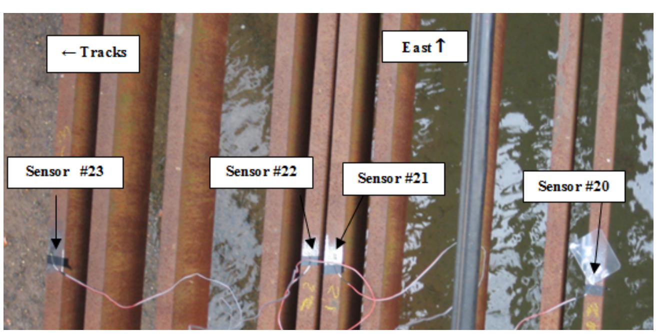


Figure 3: Plan view of bottom chord eyebars between nodes L6 and L8 (Figure 5) showing strain gages attached.

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.

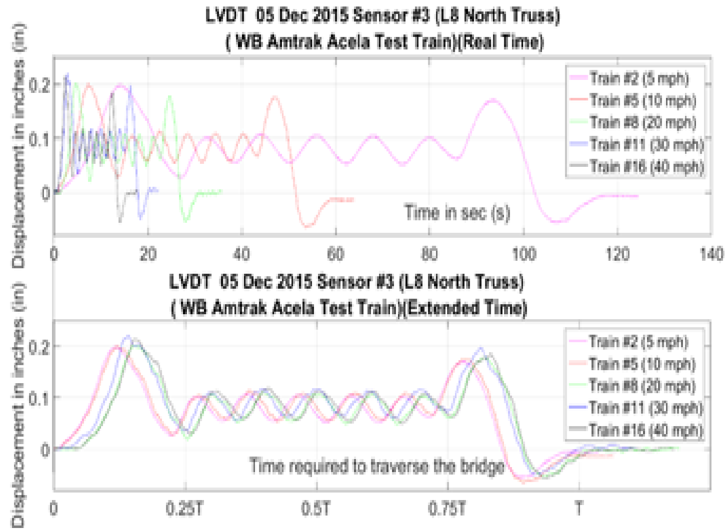


Figure 4: Vertical displacements at node 8 of Devon bridge north truss under Amtrak Acela train at various speeds.

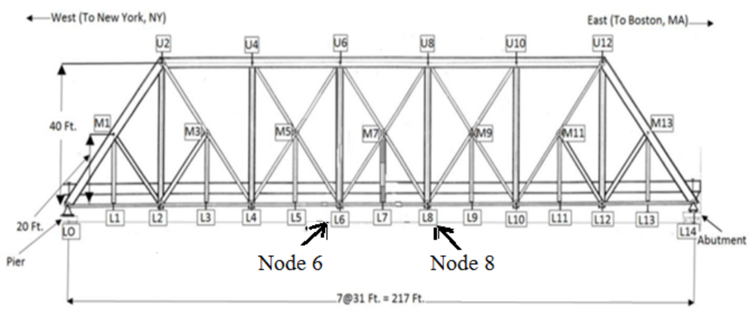


Figure 5: Elevation of the Devon bridge truss showing locations of various nodes.

Several representative conclusions were determined based on the study: (1) 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 (2) 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 finite element 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 the ability 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 bridges, 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, U.S.DOT 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.

Acknowledgements: The principal investigator acknowledges, with much gratitude and appreciation, the financial and/or in-kind support received for this research project from the following organizations: U.S.DOT Federal Railroad Administration, Transportation Research Board of the National Academies of Science, 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.

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:	Scheduled to be Completed March 2017
IDEA Contract Amount:	$100,000

IDEA Concept and Product

This research focuses on the development and future implementation of a technology for on-site characterization of railroad ballast using machine vision-based inspection systems for automated ballast quality evaluation and degradation condition assessment. A validated Imaging Based Fouling Index (IBFI) will be established as part of this technology development using the application of machine vision both in the laboratory and field environment. The new IBFI will be linked to the commonly used Selig's Fouling Index (FI), based on the sieve analyses of ballast samples, to provide meaningful degradation levels for researchers, practitioners, and track inspectors. The implementation of this technology, envisioned for installation onshoulder cleaners to automate collection of ballast images from the crib and shoulders, will provide rapid data collection and on-site quantification of ballast degradation trends in the field. The new IBFI can also be paired with ground penetration radar (GPR) applications to validate its processing methods and ballast fouling assessment. As a component of a comprehensive Ballast Management System (BMS), the developed technology will 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)

An innovative approach was used for ballast field sampling, as well as procedures for image acquisition of ballast cross sections both in the laboratory and the field. Field degradation trends of five ballast material types collected from in-service railroad track at five different tonnage (MGT) levels were studied in the laboratory using the imaging approach. An image processing algorithm with three main modules including pre-processing, segmentation, and post-processing was applied on the field collected ballast images. An imaging-based index called average Percent Degraded Segments (PDS) was defined and successfully implemented in this study to distinguish different levels of ballast degradation from the ballast images acquired.

Fourteen ballast samples and their images were collected from trench cross sections in Section 3 of the High Tonnage Loop (HTL) at the Transportation Technology Center (TTC) in Pueblo, Colorado. Particle size distributions and Selig's FI values were determined through laboratory sieve analyses and used as ground truth values to validate the image processing results. Regression analyses showed a significant correlation between the FI and average PDS values. A linear correlation was found to exist between the FI and PDS values from these preliminary data.

The objective of Stage II of this research project is focused on the development and demonstration of the PDS and the resulting IBFI concepts applied to ballast cross-section images captured by equipment monitoring the Ballast Shoulder Cleaners (SBC) during maintenance operations. In Stage II of this research project, additional ballast field images and ground truth values covering a full range of degradation levels will be collected.

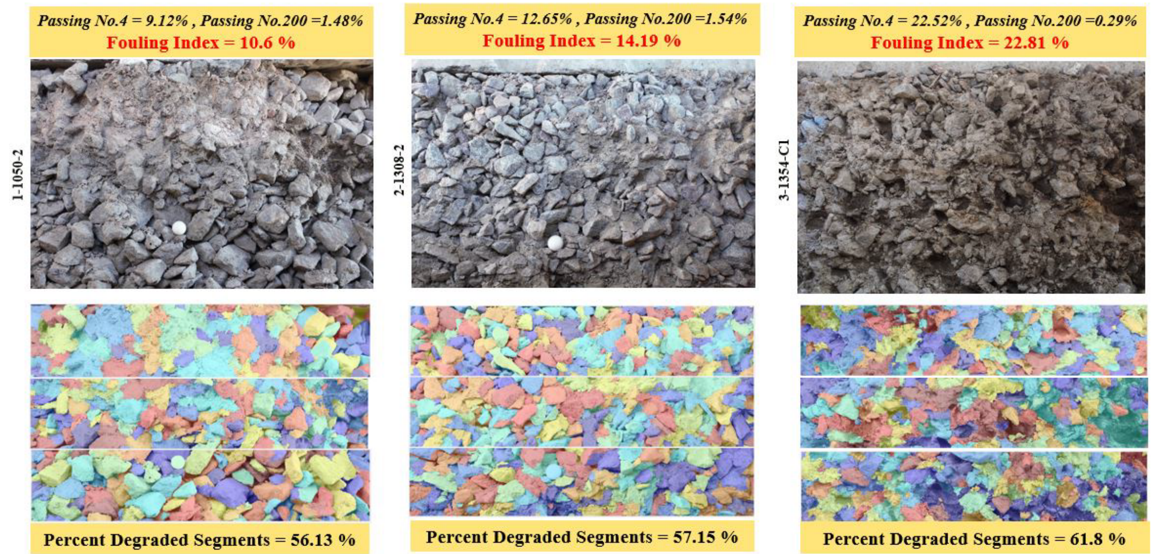
Product Payoff Potential

The routine application of the validated technology innovation will establish an IBFI database from an automated ballast inspection system, such as one envisioned for installation on a shoulder cleaner or undercutter. Accordingly, the IBFI data can be incorporated into a railroad company's information technology system combined with a geographical information system (GIS). As a result, ballast field deterioration levels can be continuously monitored over different periods at different locations along the track, such as in the shoulder or crib, and including special track work and transition zones. Additionally, spatial variation of fouling levels versus the ballast depth profiles associated with the use of different clean ballast types or other geographic and loading considerations can also be recorded. Not only safety concerns due to fouled track conditions could be predicted ahead of time, but also ballast service life and ballast performance models could be developed with the IBFI data collected from the machine vision-based inspection system.

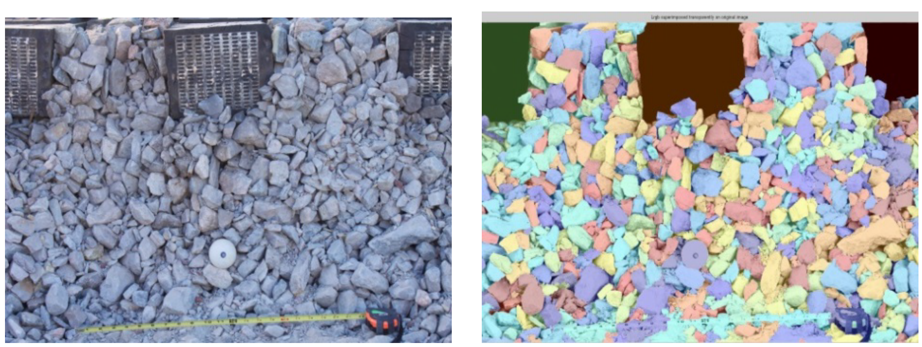
Product Transfer

This project will develop a machine vision inspection system for on-site collection of high resolution color images of railroad ballast and analyzing/classifying fouled zones as well as particle sizes and shapes using image processing techniques. Machine learning methods will be utilized to define and validate an IBFI that can be uniquely linked to the commonly used Selig's FI. The IBFI will have the potential to replace the prevailing subjective visual inspection and time-consuming sampling and mechanical sieve analysis practices. The proposed technology as an inspection tool can eventually be installed on current and future generations of SBC to automate the collection of ballast images from the cut shoulders below the ties. With this vision, ballast shoulder cleaners equipped with this proposed technology would become a continuous data collection device for automatic ballast inspection. In addition, this process could then be used to evaluate the recommendation of follow-up undercutting procedures to remove fouled ballast.

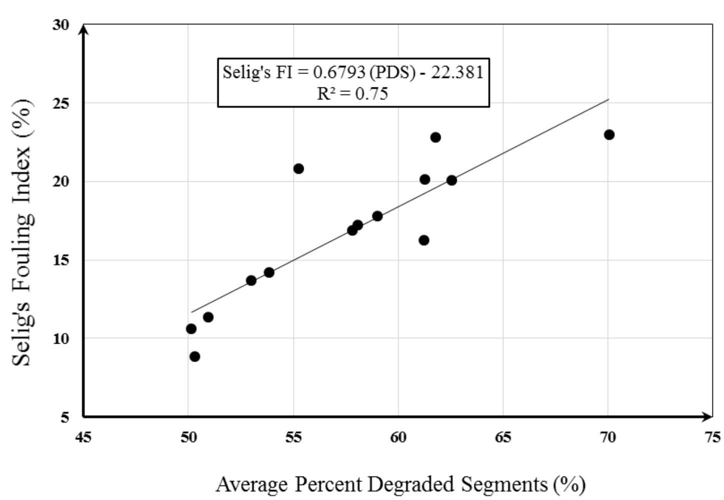
Although in some cases GPR technology has shown promising results, there are still many difficulties involved in implementation, such as data collection and interpretation of GPR scans. These include finding the right antenna with the proper frequency and a robust digital signal processing algorithm to analyze and interpret the received signals from different ballast layers, particularly under high moisture conditions. Therefore, trenching and ballast sampling are occasionally required to validate the GPR readings and interpretations. The automated machine vision-based tool can be paired with GPR technology to further validate the signal processing algorithms and enhance the efficiency and reliability of GPR interpretation for accurate ballast condition assessment.



Representative image segmentation results for three TTCI HTL ballast images indicating low, medium, and high degradation levels from left to right.



Shoulder cut section image and image segmentation results on a field cut section.



Linkage between Selig's FI and PDS values obtained.

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

Rail Safety Project 28

Research Agency: University of Delaware
Principal Investigator: Allan M. Zarembski
Completed: Scheduled to be Completed December 2016
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 noncondemnable) 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.

Results to Date

Tasks 1 and 2 have been completed and task 3 is ongoing. 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[1] who looked at a total of 285 switch points of different design configurations and conditions using the four study gauges. The tests were taken in more than 20 yards. The following table shows the number of switches inspected by railroad in the field validation activity.

	Switches inspected
NS	22
LIRR	45
CN	135
Wolf[1]	41
BNSF	42
Total	285

Analysis of the results show good agreement with the railroad inspectors and feedback from the railroad using these gauges has been extremely favorable. An example of a correlation analysis between the gauges and the inspectors on the Long Island railroad is shown in Table 1. There was 84% agreement between the inspectors and the gauges for this set of data.

	R+	R-	Y+	Y-	Total
Count	0	5	3	2	10

	Count	% of total (45)
Total with one or more indicator	10	22%
Positives	3	7%
Negatives	7	16%
Good condition agreement	35	78%
Total agreements	38	84%
Disagreements	7	16%

Table 1: Turnout Gauge Analysis Summary for LIRR

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 choose a "sufficient" gauge in the top of the tree followed by gauges that are less "sufficient" further down the decision tree. One such decision tree is illustrated in Figure 1.

[1] Gary Wolf is an independent railroad consultant who agreed to test the gauges on several local railroads.

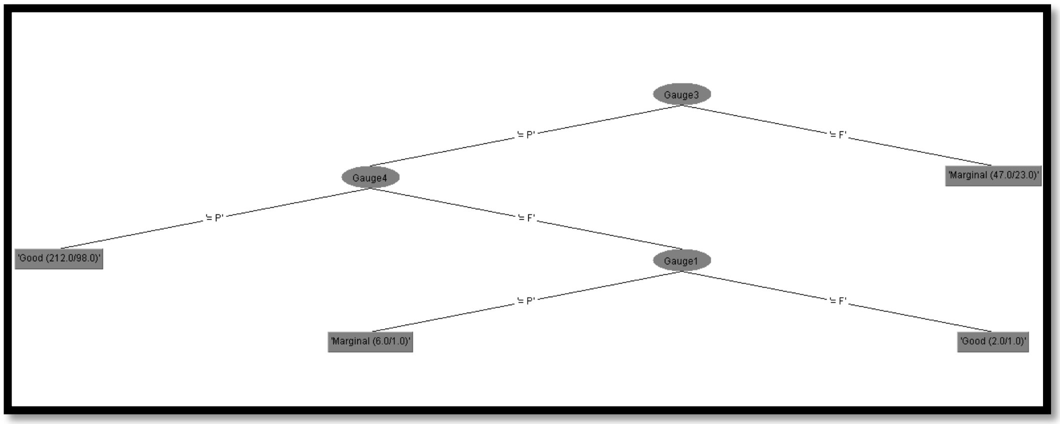


Figure 1: Decision tree diagram for the full data set.

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). Data collection with the new gauges is ongoing.

Potential Payoff for Practice

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."

Transfer to Practice

This activity will be readily transferable to practice with the expectation that the final set of gauges will be directly usable by railroads in the field as part of their switch inspection process. Such feedback has already been received from several railroads. The results of this project will be a set of hand held inspection gauges that can be used directly by track inspectors in identifying potentially unsafe switch point conditions.

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

Rail Safety Idea Project 29

Research Agency: University of Kansas
Principal Investigator: Hongyi Cai,
Completed: Scheduled to be Completed November 24, 2018
IDEA Contract Amount: $100,000

IDEA Concept and Product

This project will develop new 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 self-de-icing LED signals will adopt two novel architectures (Figure 1), including "Heated Lens Lighting Arrangement" (non-provisional patent application No. PCT/US14/53503, filed on August 29, 2014) that uses a single high-power LED, and "Heat Arrangement of LED Arrays in Low Profile" that deploys multiple LEDs. The heat generated by the LED(s) is harvested by the passive heat exchanger and stored to heat the lens for melting snow and de-icing in wintery

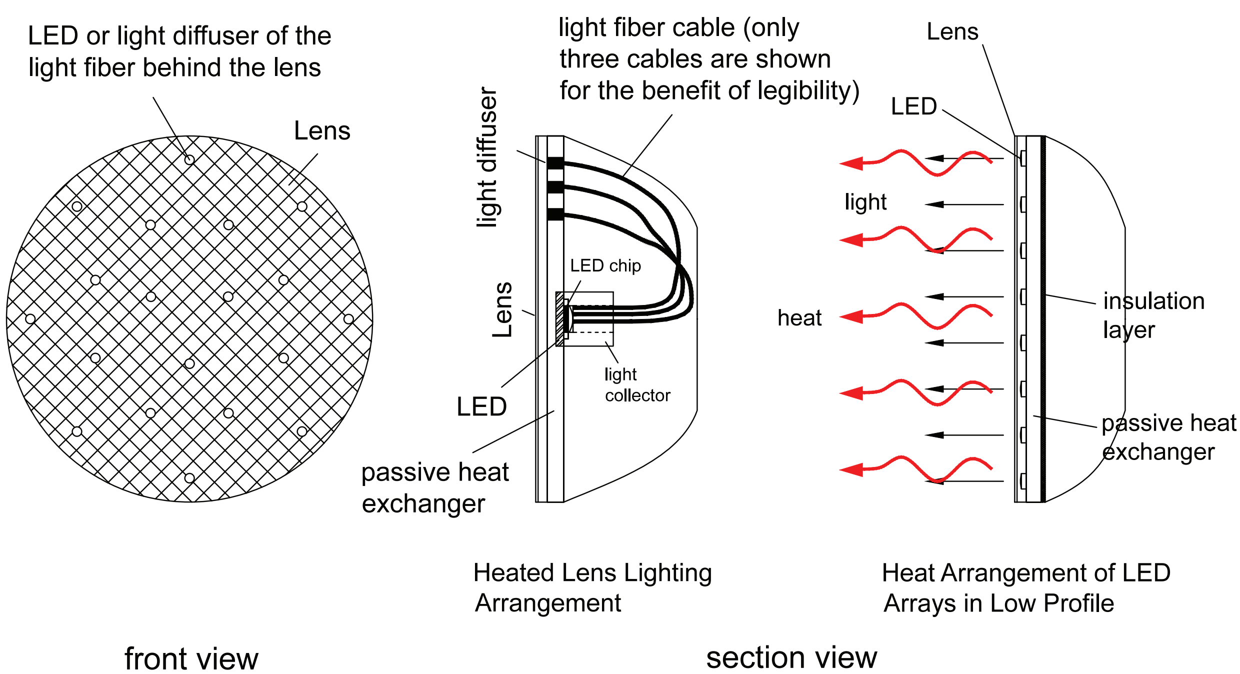


Figure 1: The concept of the self-de-icing LED signal light, which adopts new architecture of "Heated Lens Lighting Arrangement" or "Heat Arrangement of LED Arrays in Low Profile."

conditions. Three prototypes of the self-de-icing LED signals will be developed and tested on highway intersection and railroad wayside or at-grade crossing signal lights.

Project Results

The investigative approach for the proposed project is divided into the three stages. Work in Stage 1 that focuses on laboratory development and tests is underway. Necessary equipment, components, and materials are being procured to develop and build the prototypes and test for their thermal and lighting performance to meet all requirements. An expert panel meeting was held in early March. Discussions were held on desired specifications of the prototype signals and possible field test sites, as well as the field evaluation of the prototypes. A provisional patent of "Heat Arrangement of LED Arrays in Low Profile" was filed in April 2016. Appropriate color LED modules, which are not available in the market, were designed in-house and custom-made with the aid of the industrial partner. Three prototype signals (red, yellow, and green) have been developed in-house, each deploying 26 custom-made color LEDs mounted in an array via "Heat Arrangement of LED Arrays in Low Profile." They are under laboratory testing for improvements. The second type of signals that deploy a single high-power LED and multiple optical fibers via "Heated Lens Lighting Arrangement" are under development in-house. For the second type, appropriate high-power color LED modules are not available in the market; thus, are designed in-house and under development with the aid of the industrial partner. New lens, housing, light collector, and accessories have also been designed in house for the self-de-icing LED signal lights and will be custom made in fall 2016. In August 2016, six states (Kansas, California, Michigan, New Jersey, Wisconsin, and Pennsylvania) officially participated in this research for field tests and evaluation of the prototypes. Work in Stage 2 will focus on testing the three prototypes in a closed-course setting; for example, mounted on the roof of the University of Kansas engineering complex and powered by the signal controller cabinet. Work in the third and final stage will involve field testing of the developed prototypes on identified highway signalized intersections and rail track sections. On-site demonstration of the prototype signals will also be held for project partners and state DOTs to initiate the implementation process. A final report will provide all relevant data and results along with plans for implementation of the self-de-icing LED signals in affected states.

Product Pay-Off Potential

Once validated, the self-de-icing LED signal light is expected to be a viable replacement for the existing "cool" LED signal lights, the obsolete incandescent signal lights, and other emergent LED signal lights using additional heat generators and control sensors. 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. Once the self-de-icing LED signals are implemented in practice, significant benefits including safety and efficiency, cost savings, and environmental sustainability are expected to the transportation agencies, districts and cities, the railroad companies, and the driving public in the snow-belt states. The self-de-icing LED signal lights could save an annual maintenance cost of more than $30 per signal light. Replacing the existing "cool" LED signal lights with the new self-de-icing LED signal lights can gain an annual overall user cost saving of more than $28 per signal light, with a payback period of approximately 4.5 years.

Product Transfer

The research team and the University of Kansas Innovation and Collaboration (KUIC) 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 collaborative states (Kansas, California, Michigan, New Jersey, Wisconsin, Pennsylvania), the Union Pacific Railroad (UP), and the Burlington Northern and Santa Fe (BNSF) Railroad. The self-de-icing LED signals are expected to be installed at highway intersections, Class I railroads, commuter railroads, short line railroads, airport taxiway/apron lighting, and seaport applications in cold weather zones.