UTC-Semi-Annual Progress Report

Tier 1 University Transportation Center on Improving Rail Transportation Infrastructure Sustainability and Durability

Rail TEAM

University of Nevada Las Vegas
Virginia Polytechnic Institute and State University
University of Delaware

Submitted to:

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UTC Semi-Annual Progress Report

1. ACCOMPLISHMENTS

Major goals and objectives of the program

The goals of this program are to conduct research, promote education, and facilitate technology-transfer activities to improve the sustainability and durability of railroad infrastructure in the United States. Forecasts call for the U.S. economy to continue to grow and for freight travel to remain steady or increase slightly. Thus, railroads will have an even larger role in the future in meeting this demand. In turn, this increased use will expedite the deterioration of railroad systems. The need for faster transfer of goods and people will necessitate high-speed rail transportation, as has occurred in developed and developing countries around the world. High-speed rail (HSR) transportation will place far higher demands on maintaining and sustaining the rail infrastructure, which can only be accommodated through advanced technologies, such as those detailed within the goals and objectives of this DOT-UTC.

The first objective of this program focuses on four research areas critical to railroad system operations and safety:

- Asset management and performance assessment
- Condition monitoring, remote sensing, and use of GPS
- Application of new materials and technologies
- High-speed rail (HSR) construction methodologies and management

Virginia Polytechnic Institute and State University (Virginia Tech) focuses on condition monitoring, remote sensing, and the use of laser-based and GPS-based systems. The University of Delaware (UD) focuses on asset management and performance management using big data (data analytics) techniques and on the application of new materials, analytic models, and technologies. The University of Nevada Las Vegas (UNLV) is engaged in technologies and construction methodologies to better enable further development and implementation of HSR in the U.S.

The second objective of the program is to improve the development of workforce and rail education in the U.S. by 1) offering related undergraduate and graduate courses for engineering students; 2) establishing certificate programs suitable for the new generation of engineering students and young professionals who wish to engage in the rail industry; and 3) providing short courses suitable for practicing engineers who wish to hone their skills. All three partnering universities are thus engaged in complementary activities that range from STEM activities to the introduction of railroad-specific undergraduate and graduate courses, workshops, and professional development seminars.

The third objective of this program is to develop and conduct professional activities to disseminate the results of research to industry and academia. Examples of these activities are organizing and attending conferences, seminars, and workshops. We also write and submit articles for publication in various journals.

Goal accomplishments

Continuing active research projects

Our consortium universities have continued 18 research projects in this reporting period: four at Virginia Tech, seven at the University of Delaware, and seven at the University of Nevada Las Vegas. All these projects have been completed in this reporting period. The progress of the projects is described below.

VT-1: Energy Harvester Tie for Providing Access to Electric Power in Remote Locations. The Energy Harvester Tie (EHT) remains installed on revenue service track with the research team inspecting its operation periodically. During the last inspection of the tie, we noticed the output voltage has reduced significantly. This indicates an internal failure of one or more elements of the harvester that requires the removal of the tie and inspection in the lab. We intend to remove the tie from revenue service track in the next few weeks for trouble shooting the failure.

This project has been quite successful. A recent presentation of the project at the Annual AREMA Conference in Louisville, KY generated great interest by the industrial audience. One Class I railroad indicated an interest for further testing of the tie in their railyard for operating switches. Two companies indicated an interest in partnering with the Rail Technologies Laboratory (RTL) to commercialize the system. We intend to pursue these leads and possibly transfer the technology to a company for commercialization.

VT-2: Application of Doppler LiDAR Sensors for Assessing Track Gage Widening in Curves and Locations with High-lateral Forces. We performed additional work to improve our data analytics methods. The new methods better automate the data analysis process and increase the efficiency of removing noise and other unwanted dynamics from the measurements. We also performed a limited number of tests on an industrial branch line near Blacksburg VA to determine how well the system can detect various rail and tie dynamics in lateral and vertical directions. The test results were successful. We were able to identify seven different combinations of vertical and lateral rail and tie movements (vibrations).

The earlier efforts to develop a track model as a beam on an elastic foundation continued. During this period, we improved the interface between the rail and tie to better represent the compliant interaction that exists between the two. We also replaced the point load used in earlier models with a moving load that represents the load applied to the track by rolling wheels. The results of this project have pointed the way for other efforts that may be pursued by RTL in the future. They have also brought an increased understanding of how the rail and ties respond to the dynamic model due to the rolling stock.

VT-3: High-precision Evaluation of the Effect of 3rd Body Layers on Rail, Including Top of Rail Friction Modifiers. Most of our effort during this reporting period was devoted to analyzing the test results from earlier periods. We were able to summarize the effect of friction modifiers on curving forces and wheel-rail force on a tangent track. We have taken steps to share the results of

the tests and the findings of the study with one of Class I railroads and a leading U.S. supplier. The project has resulted in bringing a better scientific understanding to the effectiveness of friction modifiers in practice. The results are expected to lead to better lubrication practices beyond the anecdotal knowledge that the industry has been relying on.

VT-4: Automated Inspection of out-of-sight Under-train Equipment. The remotely controlled Track Crawler Robot (TCR) developed by RTL was extensively tested in the lab and various types of tracks in the field. The onboard video system was significantly improved to reduce blurring and shadows. The structure was modified to enable the positioning of the cameras for a wide field of view of the train undercarriage to enable capturing a full image with one pass. Finally, the unit was tested at the Southwest Virginia Transportation Museum underneath various types of railcars. It was also tested on two types of revenue-service tracks with RE115 andRE136 rails. The test proved the successful completion of the design and functioning of the TCR.

We intend to explore the application of the TCR with Class I railroads and security agencies such as the Transportation Security Authority (TSA) for situations that train undercarriage inspection is essential. We will also explore possibly commercializing the system.

UD-1: Development and Validation of a New Generation Rail Wear Model Using Emerging Big-Data Analytic Techniques. Phase II of the rail wear model research is complete and final report is being produced. Discussions with Amtrak on implementation have been conducted.

UD-2: Load Transfer from Track to Bridge Structure on Curves. This project was completed in this reporting time period.

UD-3: Track Geometry Models Using the "Small Data" Algorithm. This project was completed in this reporting time period.

UD-4: Effect of Adjacent Poor Ties on the Life of Wood Crossties. This research activity was completed, and a final report was submitted together with several published papers and presentations.

UD-5: Risk Modeling of Grade Crossing Accidents. This project was completed.

UD-6: Random Forest-Based Covariate Shift in Addressing Non-Stationarity of Railway Track Data. This activity was completed.

UD-7: Topological Data Analysis and Track Geometry Data. This project was completed, and a final report was submitted in October 2023. Final Report entitled:

UNLV-1: Mobile 3D Printing of Rail Track Surface for Rapid Repair. During this reporting period, six sets of 3D printing for heavy rails (136-lb/yd) and eight sets for light rails (75-lb/yd) were printed at Elektriska Svetsnings-Aktiebolaget (ESAB), an Electric Welding Limited company. Lab test results indicate that 3D printing train rails can achieve AREMA requirements for both yield and tensile strength in light rails, but only the yield strength exceeds the requirement

for heavy rails. The tensile strength is slightly below the requirements. However, rail hardness in both cases for heavy and light rails is above the AREMA standards, and the elongation rate is below requirement. To solve the hardness and elongation problems, heat treatment was applied to some of the printed rails, improvements were observed, but satisfactory procedure and parameters are yet to be developed before the project comes to an end. During this reporting period, one research paper was accepted and published on the International Journal of Transportation Science and Technology, and another paper was submitted to the Journal of Rail and Rapid Transit.

UNLV-2: High-speed Rail Access Charge for the XpressWest of Nevada. In this reporting period, a software, VIAS3D Academia, to estimate the cost of the deterioration of railroad track due to different speeds of trains was purchased and used in this study.

UNLV-3: Development of Acoustics Technology to Detect Transverse Defects in Rail at High-speed (220 mph). The research team conducted a series of field tests at the Nevada Railroad Museum and MxV Rail in Colorado to investigate acoustic emission (AE) attenuation in rails and characterize AE signals associated with rail defects. At the Nevada Railroad Museum, the team performed both on-rail and on-vehicle tests where the sensors were placed on the track with different longitudinal and lateral distances from the internal defects. Additional field tests at MxV Rail in Colorado were conducted. In addition to repeating the same test plan as in Nevada, the team added a bending test for a defective rail segment and an on-rail test for an internal defect at a testing speed of 40 mph. Due to sensor damage during the MxV Rail field tests, the team conducted an on-rail test at another internal defect while their fleet continuously ran overnight. This test recorded AE events for over six hours as the fleet was running, aiming to evaluate changes in AE characteristics during defect development. The team has completed the data analysis, and the results revealed patterns of AE signals and energy distributions across the frequency range. A final report has been written to document the research results.

UNLV-4: Development of a Platform to Enable Real-Time, Non-disruptive Testing and Early Fault Detection of Critical High Voltage Transformers and Switchgears in High-Speed Rail. In this phase, the project team integrated Internet of Things (IoT) functionality into the platform to enable remote accessibility for partial discharge (PD) monitoring. The system consists of an RF antenna and a data acquisition and processing (DAQP) system that continuously senses and collects RF signals within the frequency range of 100 MHz to 3 GHz. When signals exceed a configurable power threshold (set to -50 dB in this study), the system automatically records events, capturing both the raw signal data and spectrum snapshots. This data is then transmitted to a cloud server (or Google Drive) for storage. Additionally, an Android app was developed to allow users to access the updated data in the cloud. The app also provides notifications when new data is uploaded from the DAQP system. A comprehensive project report has been prepared to summarize the development of the platform and detail the testing results achieved throughout the project.

UNLV-5: Non-Propriety Ultra-High-Performance Concrete (UHPC) for Ballast-Track High-speed Railroad Sleepers. A final report was submitted for this project during this reporting period.

UNLV-6: Development of UAV-Based Rail Track Irregularity Monitoring and Measuring Platform. Building on our previous success in measuring rail dimensions with centimeter-level

accuracy, this phase focused on further improving precision. Despite utilizing various advanced techniques, such as 2D and 3D data fusion, Neural Radiance Fields (NeRFs), and registration, the results did not significantly enhance the accuracy of 3D modeling for rail track geometry measurement. However, the platform continues to measure rail dimensions with centimeter-level precision, providing reliable assessments of key parameters such as track gauge, curvature, and profile. A detailed project report covering critical aspects of the platform's development has been prepared.

UNLV-7: Efficient Railway Analysis Using Video. This project was completed during this reporting period.

Initiating new research programs

Nothing to Report.

Upgraded education opportunities

The plans for offering "Rail System Dynamics" class as a cross-listed multi-university course are on hold. The logistical issues of cross-listing students must be resolved between the partnering universities before this vision can be implemented. We intend to pursue this opportunity outside of the RailTEAM UTC program. The discussions that we have had because of the collaboration between Virginia Tech, UNLV, and University of Delaware will be helpful in pursuing this effort further.

The University of Delaware offered four railroad courses, one in the Fall of 2024; CIEG 418/618 Railroad Engineering and three in the Spring of 2024; CIEG 317 Introduction to Railroads, CIEG 414/614 Railroad Geotechnical Engineering and CIEG 417/617 Railroad Safety and Derailment Engineering. More than 25 undergraduate and graduate students attended each course at UD.

At UNLV, three courses were offered in the Spring semester of 2023 and the Fall semester of 2024: CEE 471/671 Public Transportation Systems, CEE 470/670 High Speed Rail, and CEE 726 Railroad operation. Their enrollments are 36, 10, and 6, respectively.

Opportunities for training and professional development

Virginia Tech participated in the Annual AREMA Conference in Louisville, KY during September 15 – 18, 2024. Five undergraduate and graduate students were part of the delegation of VT researchers attending the conference. The VT team presented two papers at the conference, to disseminate the research information from earlier mentioned project. Both papers were well received by the audience, mostly from the U.S. Class I railroads and major suppliers.

The University of Delaware's Professional Engineering Outreach provides professional courses for practicing railroad and transit professionals. These professional development courses include a new Professional course entitled "Introduction to Data Science for Railways" which was given during May 2024. Over 30 professionals attended this in-person course.

The Big Data in Railroad Maintenance Conference takes place in December each year at the University of Delaware, and the Conference is co-sponsored by the RailTEAM UTC. This Conference addresses the growing use of data analytics in the planning and management of railroad maintenance, and it usually has more than 200 attendees from railroads, transit systems, railway suppliers, data analytic companies, and academia.

Three undergraduate students from UNLV attended the Annual AREMA Conference in Louisville, KY during September 15 – 18, 2024.

Results disseminated

As mentioned earlier, VT researchers attended the Annual AREMA Conference and presented two papers to disseminate the results of their research. The AREMA conference is the most major gathering of the U.S. railroad practitioners and engineers. The papers are chosen by AREMA committees of industrial experts. The presentations are accompanied by peer-reviewed publications.

A presentation was made by Joseph Palese of University of Delaware at the Cyber and Digital Information in Railway Engineering and Operations Workshop at University of Maryland, College Park, MD in March 2024. Three papers are in the final stages of preparation to be submitted to journals within the next 30 to 60 days. We have also had Zoom and in-person meetings with researchers and engineers from FRA and some of our industrial partners, such as Amtrak, Norfolk Southern, CSX, BNSF etc. In addition, Amtrak has rejoined the rail wear project and is again supporting that activity with rail wear data and is interested in utilizing the results in their rail maintenance management program. This Amtrak activity was suspended for almost two years due to COVID but has recently been reinstated.

A presentation on 3D printing for repairing worn rail was given by a UNLV student at the International Conference on Transportation and Development on June 13, 2024, Atlanta, George.

Plan for the next reporting period

Our research efforts have been successfully completed. We expect most of the projects we have pursued lead to discussions for commercializing the research concepts or pursuing additional industrial or government funding.

2. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

Organizations involved as partners

Our partnership with Norfolk Southern (NS) and MxV Rail continues. We have also received significant support from companies such as L.B. Foster. We intend to use the fruitful collaboration

that has resulted from the RailTEAM efforts during the past few years toward future research and educational programs that we intend to pursue in the future.

At the University of Delaware, Phase II of the rail wear project will be completed and a final report prepared. Results will be presented to Amtrak upon completion for incorporation in their maintenance management activities.

UNLV conducted field tests twice in the summer of 2024 at MxV. Extensive tests on 3D printing for repairing worn rails were conducted at ESAB, a welding company in Pennsylvania, In August 2024, Union Pacific Railroad provided a $20,000 gift to UNLV for railroad education.

Other collaborators or contacts involved

Nothing to Report.

3. OUTPUTS

Output performance measures

In this reporting period, we have had 16 papers produced that are accepted by, submitted to and in preparation for submitting to technical journals. This number of publications exceeds the expected number of 3-4 per half year. We have no invention disclosures filed in this reporting period, which is within our expectations of 0-1 in a half year. UNLV is in the process of applying a patent for their research on detecting internal defects in rail using acoustic emission technology, which makes our performance measure within our expectation of 0-1 per half year.

Publications, conference papers, and presentations

The presentations and publications developed by our UTC team in this reporting period are listed below.

Publications

1. Mirzaei, M., Radmehr, A., Holton, C., and Ahmadian, M., In-Motion, Non-Contact Detection of Ties and Ballasts on Railroad Tracks, Applied Science, September 2024, Vol. 14, Issue 19, pp. 8804 – 8823. https://doi.org/10.3390/app14198804 UTC support acknowledged. (Virginia Tech)
2. Kasch, J. and Ahmadian, M., Design and Operational Assessment of a Railroad Track Robot for Railcar Undercarriage Condition Inspection, Designs, July 2024, Vol. 8, Issue 4, pp. 70 – 100. https://doi.org/10.3390/designs8040070 UTC support acknowledged. (Virginia Tech)
3. Kumar, N., Radmehr, A., Ahmadian, M., Experimental Evaluation of Effect of Leaves on Railroad Tracks in Loss of Braking, Machines, April 2024, Vol. 12, pp. 301 – 318. https://doi.org/10.3390/machines12050301 UTC support acknowledged. (Virginia Tech)

4. Chen, Y., Mirzaei, M.., Holton, C., Ahmadian, M., Development of An Optical Sensing System for the Detection of Lubricity Conditions on the Rail Gage Face, International Journal of Rail Transportation, February 2024. (https://doi.org/10.1080/23248378.2024.2309618) UTC support acknowledged. (Virginia Tech)
5. Chen, Y., Chatterjee, R., Ahmadian, M., Electromagnetic Energy Harvester Tie: Design, Implementation, and Field Testing, the AREMA 2024 Annual Conference and Exposition, Louisville, KY, September 15 – 18, 2024. UTC support acknowledged. (Virginia Tech)
6. Kumar, N., Radmehr, A., Ahmadian, M., Assessment of contact patch on curving forces in two-point contact condition, the AREMA 2024 Annual Conference and Exposition, Louisville, KY, September 15 – 18, 2024. UTC support acknowledged. (Virginia Tech)
7. Ahmadian, M., Chen, Y., and Pan, Y., Laboratory and Field Evaluation of an Energy Harvesting Tie for Energy Generation on Railroad Tracks, Railways 2024, Prague, Czech Republic, September 1 – 5, 2024. UTC support acknowledged. (Virginia Tech)
8. Mohammed, O., Palese, J., Zarembski, A., Development of a 3D track quality index incorporating machine learning techniques and a multivariable normal distribution" to be submitted to a peer-reviewed professional journal, September 2024. UTC support acknowledged (University of Delaware)
9. Ahmed, M., Palese, J., Zarembski, A., Predicting Track Geometry Using Machine-Learning Methods, to be submitted to a peer-reviewed professional journal, September 2024 UTC support acknowledged (University of Delaware)
10. Palese, J., Zarembski, A., A Stochastic Approach to Rail Wear Rate Assessment and Forecasting Using Mixture Density Networks, to be submitted to a peer-reviewed professional journal, September 2024 UTC support acknowledged (University of Delaware)
11. Mohammad, A.A., Wang, Z. Teng, H., Mechanical and Metallurgical Assessment of a Submerged Arc Welded Surfaced Rai, accepted by International Journal of Transportation Science and Technology, October 2024 UTC support acknowledged (University of Nevada Las Vegas)
12. Mohammad, A.A., Wang, Z. Teng, H., Finite Element Modeling and Validation of Submerged Arc Welding for Repairing 136re Heavy Rails, Part F: Journal of Rail and Rapid Transit, January 2024. UTC support acknowledged (University of Nevada Las Vegas)
13. Mohammad, A.A., Wang, Z., Teng, H., Finite Element Modeling and Validation of Submerged Arc Welding for Repairing 136re Heavy Rails, Proceeding of International Conference on Transportation and Development 2024, June 13, 2024, Atlanta, George, United States. UTC support acknowledged (University of Nevada Las Vegas)
14. Jia, L. Park, J.W., Zhu, M., Jiang, Y. Teng, H., Evaluation of On-Vehicle Acoustic Emission Detection for Rail Defects, submitted to the Journal of Transportation Technologies, September 2024 UTC support acknowledged (University of Nevada Las Vegas)
15. Fan, J., Zhu, M., Jiang, Y., Teng, H., Development of a Platform to Enable Real Time, Non-disruptive Testing and Early Fault Detection of Critical High Voltage Transformers and Switchgears in High Speed-rail, submitted to International Journal of Transportation Science and Technology, September 2024 UTC support acknowledged (University of Nevada Las Vegas)
16. Qiu, L., Zhu, M. Park, J.M., Jiang, Y., Teng, H., Non-Interrupting Rail Track Geometry Measurement System Using UAV and LiDA, submitted to International Journal of

Transportation Science and Technology, September 2024 UTC support acknowledged (University of Nevada Las Vegas)

Books or other non-periodical, one-time publications

Lei Jia, Non-Contact Acoustic Emission Approach for Rail Health Monitoring, Dissertation of Civil and Environmental Engineering, University of Nevada Las Vegas, Fall 2024 (UNLV)

Other publications, conference papers and presentations

1. Chen, Y., Chatterjee, R., Ahmadian, M., Electromagnetic Energy Harvester Tie: Design, Implementation, and Field Testing, the AREMA 2024 Annual Conference and Exposition, Louisville, KY, September 15 – 18, 2024.
2. Kumar, N., Radmehr, A., Ahmadian, M., Assessment of contact patch on curving forces in two-point contact condition, the AREMA 2024 Annual Conference and Exposition, Louisville, KY, September 15 – 18, 2024.
3. Ahmadian, M., Chen, Y., and Pan, Y., Laboratory and Field Evaluation of an Energy Harvesting Tie for Energy Generation on Railroad Tracks, Railways 2024, Prague, Czech Republic, September 1 – 5, 2024.
4. Ahmadian, M., Southward, S., Mantovani, G., Shaju, A., In-motion Detection, Isolation, and Classification of Wheel Cracks using Air-coupled Ultrasonic Acoustic Emission (UAE) Methods, MxV Rail University Day, August 6 – 7, 2024.
5. Mantovani, G., Kumar, N., Ahmadian, M., Virginia Tech-Federal Railroad Administration Roller Rig Measurement Capabilities and Efforts to Improve its Capabilities, 2024 Pacific Southwest Region 9 UTC Annual Congress, Las Vegas, NV, March 11 – 12, 2024.
6. Kumar, N., Mantovani, G., Radmehr, A., Ahmadian, M., Experimental Evaluation of Loss of Braking due to Leaves on Railroad Tracks, 2024 Pacific Southwest Region 9 UTC Annual Congress, Las Vegas, NV, March 11 – 12, 2024.
7. Chen., Y., Mirzaei, M., Holton, C., Ahmadian, M., Application of Laser-induced Fluorescence Technique for Measuring Lubricity Conditions on Rail Gage Face, 2024 Pacific Southwest Region 9 UTC Annual Congress, Las Vegas, NV, March 11 – 12, 2024.
8. Mirzaei, M., Radmehr, A., Holton, C., Ahmadian, M., Leveraging Non-contact Doppler LiDAR Sensors and Unsupervised Algorithms for In-motion Assessment of Railroad Track Stability, 2024 Pacific Southwest Region 9 UTC Annual Congress, Las Vegas, NV, March 11 – 12, 2024.
9. Ahmadian, M., Radmehr, A., Mirzaei, S. M. H., Condition Monitoring of Railroad Tracks in Revenue Service using Doppler Lidar Systems, the 8th International Conference on Condition Monitoring in Non-Stationary Operations (CMMNO 2024), Wenzhou, China, May 10 – 13, 2024.

10. Palese, J. Mohammed, O., Ahmed, M., Using Long-Short-Term-Memory Networks and Mixture-Density Modeling to Predict and Classify Track Geometry at Cyber and Digital Information in Railway Engineering and Operations Workshop, University of Maryland, College Park, MD, March 2024

11. Mohammadi, A.A. Wang, Z. Teng, H., Finite Element Analysis of Submerged Arc Welding Process for Surface Repair of Heavy Rails, Presentations at ASCE International Conference on Transportation and Development, Atlanta, June 17, 2024.

Policy Papers

Nothing to Report.

Website

We have purchased the "railteam.org" web domain for the RailTEAM UTC. It was first used for the RailTEAM Symposium in May 2022, and continues to be available to us for future events. Additionally, Virginia Tech's Railway Technologies Laboratory (RTL) maintains its website for publicizing its research activities. Many of the DOT-UTC initiatives have been included at the Center for Vehicle Systems and Safety's new website (https://www.cvess.me.vt.edu), the RTL website (https://www.me.vt.edu/rtl-2/), as well as RailTEAM's webpage (https://www.unlv.edu/railteam).

The University of Delaware has continued to highlight the railway research and educational activities in its Railroad Engineering and Safety Program website (railroadengineering.engr.udel.edu/). UNLV routinely updates the RailTEAM website with information from partnering universities.

Technologies or techniques

Several technologies have been developed with RailTEAM funding, including a patented energy harvester, non-contacting LiDAR track geometry measurement system, and track robot that can be used for train undercarriage inspection. Virginia Tech's energy harvesting tie presents a novel and innovative technology that can bring railroad transportation many benefits. This novel technology was developed due to RailTEAM's efforts. Similarly, the Track Crawler Robot (TCR) developed by Virginia Tech provides a unique all-terrain platform that is being tested for the first time for its intended railroad safety and security applications. Finally, as documented in the past, Virginia Tech's efforts have resulted in significant advances in the application of LiDAR technology for railroad applications. The advances made in LiDAR technology have not only raised the industry's awareness but have also made them more comfortable with adopting LiDAR systems for their way practice maintenance.

The University of Delaware has developed noteworthy maintenance models. One is the method/model for predicting the wear life of railway rails, and it was presented at the 2022 American Railway Engineering and Maintenance of way Association Annual Conference, Denver

CO, August 2022. A second model is a new approach to predicting the development of rail defects and the associated fatigue life of rail, recently published (2021) in *The Jo*urnal of Rail and Rapid Transit, an internationally recognized railway journal. A third model determines life of timber cross-ties as a function of varying support condition, presented at the American Railway Engineering and Maintenance of Way Association Conference, September 2020, the Railway Tie Association's annual technical conference in November 2021, and was published in The Journal of Transportation Infrastructure Geotechnology in 2021. A new paper, with more recent research results has been submitted to The Journal of Transportation Infrastructure Geotechnology in September 2022.

UNLV has been developing a 3D printing technology to repair worn rail on site. Instead of replacing the worn rail, it can be repaired and continue to provide service. This technology will save significant maintenance costs for the railroad industry. The other technology monitors the pantograph strip that receives electricity from overhead wires to high-speed rail trains. This strip constantly touches the wire and wears out quickly. This monitoring technology can tell the extent the strip is worn out in real time, which provides information as to the time to replace the strip.

Inventions, patent applications, and/or licenses:

UNLV is applying for a patent on detecting internal defects in rail using acoustic emission technique.

4. OUTCOMES

Passage of new policies, regulation, rulemaking, or legislation

The University of Delaware continues to work with Amtrak to develop new tools for improved management of rail maintenance, particularly in the area of worn rails, because it is a major maintenance cost area.

Increases in the body of knowledge

Many of the technologies that we are developing are expected to have tangible outcomes that will make rail transportation safer and more operationally efficient. For instance, the field-tested energy harvesting tie in VT-1 provides the ability to integrate sensors and monitoring electronics in the track to continuously monitor its condition and alert track engineers when there are track anomalies or failures that could cause derailments. Similarly, for VT-4, the Track Crawler Robot will be able to monitor train undercarriage conditions and assess any deficiencies or pending failures that require intervention, to eliminate unscheduled maintenance that could cause major interruptions to train schedule and traffic flow. The VT's LiDAR system in VT-2 can provide an earlier indication of track lateral instability and gage widening so that the track crew has more time to schedule maintenance to circumvent the track deficiency. This not only causes less interruption to the traffic flow but also prevents the deficiency to progress becoming a costly catastrophic

failure. These are all examples of how RailTEAM's research projects are expected to create actual outcomes to benefit U.S. rail transportation.

The research at the University of Delaware addresses new generation data analytic tools to increase the amount of railroad inspections and operations data and the development of new relationships between performance, component degradation, and safety. Current research activities already address this in the following areas, i.e., degradation of crossties (sleepers), wear of railway wheels, wear of railway rails, railway rail fatigue, track geometry degradation, and forecasting derailments.

Using acoustic emission from internal defects in rail to detect internal defects was proposed several decades ago. UNLV's study tested a sensor that can detect the acoustic emission from the defects in rail, representing a significant breakthrough in technology.

Improved processes, technologies, techniques, and skills in addressing transportation issues

All RailTEAM's projects are undertaken with the intention of improving processes and technologies that will address one of the most critical rail transportation issues: track and train maintenance. For instance, Virginia Tech's VT-3 project is developing better lubrication processes that can improve track friction management toward more fuel efficiency and less wheel/rail wear. The energy harvesting tie in VT-1 and LiDAR system in VT-2 will lead to more advanced track maintenance monitoring and diagnostic technologies.

The research performed by the University of Delaware provides new analytical tools to address key issues in rail transportation. These include degradation/failure mechanisms for both track and vehicle components, specifically ties, wheels, rails, track geometry, and Continuous Welded Rail (CWR) on bridges, which represents critical cost, maintenance, and safety areas.

The 3D printing technology project at UNLV to repair worn rail on site can reduce maintenance costs significantly.

Enlargement of the pool of trained transportation professionals

Virginia Tech's Railway Technologies Laboratory held its annual Career Dinner on September 24 – 25, 2024. This is an exclusive event for bringing together the most qualified students with railroad companies. The event resulted in 15 professionals from six companies joining 25 students from various engineering disciplines that had been pre-selected by the VT-AREMA Officers based on their qualifications. We anticipate that more than 10 offers will be placed by the attending companies to the students. Many of the attending students mentioned that they would not have considered employment with railroad companies had it not been for this event. Over the years, the event has resulted in many successful recruitments of 100 students or more to the rail companies.

The railroad program at the University of Delaware trains working professionals who earn UD's Graduate Certificate in Railroad Engineering. The program includes professionals from WMATA,

Amtrak, SEPTA, BART, Maryland MTA, the U.S. Navy, and numerous consulting groups and international railways.

Union Pacific Railroad has attended the UNLV career fair continuously for several years while providing funding to the university for railroad education. Each semester they present at our railroad classes for career education and recruitment. Our students attend the AREMA annual conference every year for railroad professional activities.

Adoption of new technologies, techniques, or practices

All RailTEAM projects use new technologies, techniques, and practices. We are at the leading edge of the application of many of these technologies in field situations. Although innovative technologies are often studied in the laboratory, they fall significantly short of practical solutions that help the industry. Our projects have successfully bridged this gap.

Three of the RailTEAM's projects at Virginia Tech continued their field testing of prototype systems in revenue service or on test tracks, with great success. For example, the VT energy harvester tie (VT-1) performed nearly flawlessly on the NS revenue service track in Christiansburg, VA. The tie harvested energy for more than a year in revenue service, a major achievement for a prototype system in an extremely demanding environment.

The University of Delaware's rail wear forecasting methodology is shared with Amtrak, which is currently working with UD to apply this methodology to its current rail wear analysis and rail replacement planning tools as part of the maintenance planning programs at UD. The forecasting methodology predicts the rate of wheel wear and identifies "bad actor" cars that generate excessive wear (and possibly excessive levels of lateral force) and has been shared with New York City Transit (NYCT), the largest transit system in the United States. NYCT is examining how it can be incorporated into their maintenance and safety programs. The work has significant potential for both maintenance and safety since it addresses railway wheels and the point at which they are removed from service for either maintenance or replacement.

Outcome performance measures

In this reporting period, our research work was cited 86 times, which is far greater than our expectation of 3-5 times per half year. UNLV was interviewed three times in this period for their involvement in high-speed rail research and education, which is bigger than the expected 1-2 times each year.

5. IMPACTS

The RailTEAM projects directly and materially have been improving railroad safety, increasing the knowledge of technologies that contribute to operational efficiency of railroads, and training the next generation of railroad professionals. Examples of our efforts include:

- Development of LiDAR systems that are capable of detecting gage widening and early stages of track instability that can lead to derailments.
- Invention of an energy harvesting system that can bring energy where it is not available, enabling integration of sensors and devices that can intervene when needed to warn or correct for track deficiencies.
- Promotion of Machine Learning (ML) and Artificial Intelligence (AI) methods that can significantly increase the speed and accuracy of large volumes of data that are often collected with current and future track inspection methods, making future railroading both more intelligent and cost effective.
- Hosting railroad-specific recruiting efforts to promote the rail industry to students and students to railroad companies, which have resulted in many students starting their career in the rail industry.

Impact on the effectiveness of the transportation system

Most of the research conducted under this UTC has resulted in field-proven and tangible results that will result in safer and more reliable rail transportation in the U.S., mainly reducing the likelihood of costly derailments and accidents. As accidents in the railway industry draw public attention, improvements in approaches to safety have a direct impact on the society's perception of the railroad industry. The impact of technologies developed by the RailTEAM consortium of universities is related directly to improving track-maintenance practices. U.S. railroads collectively spend billions of dollars on track and rolling stock maintenance. Even small improvements (e.g. 4 or 5%) in maintenance practices yield significant cost savings, beyond saving lives and raising the public's confidence and reception of rail transportation. The technologies in which we are engaged at Virginia Tech (LiDAR, energy harvesting, train inspection robots, and others) promise to bring significant cost savings and improved railroad safety. The cost savings are due to the improved fuel efficiency that result from the better understanding and management of friction, the ability to detect failed components and malicious out-of-sight packages, and early detection of any pending track failures before it is too late.

The University of Delaware's UTC sponsored research on rail wear is being applied on Amtrak, and specifically Amtrak's Northeast Corridor, in rail replacement planning, a key part of Amtrak's track maintenance program. The University of Delaware is working with Amtrak to collect additional rail profile data for continued efforts on Phase II of the rail wear research project. Amtrak also provides guidance on the practical application of the methodology, as well as data limitations. As this model becomes fine-tuned and validated, we expect implementation on many major U.S. rail systems, including freight railways, passenger and commuter railways, and rail transit systems.

As reported previously, the University of Delaware extended the method it developed to predict the rate of wheel wear. The railways can directly apply models to predict the wearing of railway wheels and predict when to perform maintenance to extend life (e.g., wheel truing) or replace them. NYCT is examining how to incorporate this information in the company's maintenance and safety programs.

A new method of predicting the development of rail fatigue defects by the University of Delaware examines the use of Parametric Bootstrapping for the Weibull Analyses. This bootstrapped method provides reasonable estimates track segment defect rates with no prior defect data, allowing for far more data analysis and accounting for in-maintenance planning efforts, thus increasing the rail forecasting effectiveness.

A model has been developed for the determination of lateral thermal forces on curves, including curves on bridges, and this will allow the accurate prediction of these forces that can affect the load on bridge structures due to constrained thermal expansion in continuously welded rail. The Journal of Rail and Rapid Transit has recently published a paper concerning this information (February 2021).

Finally, a model has been developed that addresses the issue of the accuracy of data for automated track geometry measurement vehicles, specifically the limitations due to the likelihood of non-stationarity of the gathered data due to external influences. The effect of non-stationarity may lead to the wrong representation of track conditions, thereby increasing the possibility of false outputs from the model. This work thus results in increased data accuracy from track geometry car measurements.

Impact on the adoption of new practices

Virginia Tech's 's revenue-service-track and test-track and field testing of the LiDAR system, the energy harvesting pre-production tie, and the Track Crawler Robot prototype have all contributed to increasing the confidence in the commercial success of these technologies, beyond the immediate research by the RailTEAM UTC. If successfully deployed, these technologies will have a significant impact on improving railroad engineering practices. For instance, the LiDAR system in VT-2 can be adopted for in-situ measurement of track gage widening onboard a locomotive or Hyrail truck. This would enable detecting and fixing sections of the track with low lateral strength before they lead to costly derailments. Similarly, the commercialization of the energy harvester tie in VT-1 will enable a seamless and practical means of accessing power in places where such power is currently unavailable. This will be a critical and enabling technology for integrating sensors and smart devices on the track, which will have several significant advantages. The track Crawler Robot in VT-4 would yield means of train inspection that is currently only available through highly sophisticated and costly systems.

It is expected that 3D printing technology that can repair worn rails onsite will change railroad maintenance practice. Currently, worn rails are removed from the railroad track and replaced with new ones. Due to the 3D printing technology that can repair worn rails on site, the worn rails will not need to be removed from the track. This practice will save the cost of removing and discarding the worn rail, thereby reducing the railroad operating cost significantly.

Impact on the body of scientific knowledge

The knowledge gained in VT-3 regarding the effect of contaminants on traction has had measurable improvements in the basic science of how a railroad wheel interacts with the rail. The scientific knowledge gained in this regard has been significant enough that leading peer-reviewed journals have accepted our publications.

Some of the technologies we are working on have scientific and practical applications beyond rail transportation. For instance, LiDAR technology can assess roadway surface conditions. The Track Crawler Robot can also be used for under-train inspection by the Department of Homeland Security and the U.S. Army. The learnings from the energy harvesting tie in VT-1 are directly applicable to units that can be used for road and highway applications; for example, an "energy harvesting road bumps" for powering a mobile LED sign and gently alerting drivers to slow down in road construction zones.

The University of Delaware has developed approaches and methodologies to maintain the railroad infrastructures that are readily adaptable in the areas of highway pavement and airport runway research and analysis.

Impact on the development of transportation workforce development

The RailTEAM projects have provided the education and training necessary for careers in the rail transportation industry, producing highly sought-after undergraduate and graduate students. As mentioned earlier, we not only provide the courses needed for training and educating our graduates for the rail transportation industry, but also provide career planning and recruiting events that connect them with the leading rail companies, such as the career fair at Virginia Tech in September 2024.

UNLV has been teaching courses on railroad and high-speed rail. The undergraduate and graduate students who took these courses have opportunities to join the work forces to plan, design and construct high speed rails in the U.S. On October 8, 2024, Siemens Mobility came to UNLV to present on the Brightline West project, which drew hundreds of attendees.

Impact performance measures

In this reporting period, we were requested four times by our stakeholders for the expertise in the application of research products, which is more than our expectation (one time per year). During the 2024 Annual AREMA Conference, one of the Class I railroads requested installing the VT energy harvesting tie (EHT) on their yard truck. Additionally, two companies indicated an interest in engaging in a dialogue for licensing the technology and possibly commercializing the EHT. Amtrak has been using research by the University of Delaware and applying it to their rail maintenance management. UNLV is applying a patent for their research on detecting acoustic emissions generated by internal defects in rail. These metrics make our performance within our expectations.

6. CHANGES/PROBLEMS

Nothing to Report.

No delays or programmatic issues were experienced during this reporting period.

7. SPECIAL REPORTING REQUIREMENTS

Our UTC project complies with the Research Project Requirements and Submission of Final Research Reports.