UTC-Semi-Annual Progress Report

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

Rail TEAM

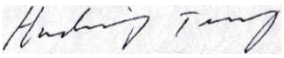
University of Nevada Las Vegas
Virginia Polytechnic Institute and State University
University of Delaware

Submitted to

Denise E. Dunn, Grant Manager
University Transportation Centers Program (RDT-30)
Office of the Assistant Secretary for Research and Technology (OST-R)
U.S. Department of Transportation
1200 New Jersey Avenue, SE, Work Station E33-436
Washington, DC 20590-0001
Phone: 202-366-4985
Fax: 202-493-2993
Email: denise.e.dunn@dot.gov

Submitted by

Hualiang (Harry) Teng, Professor



Department of Civil and Environmental Engineering and Construction
University of Nevada, Las Vegas
4505 S. Maryland Parkway, Box 454015
Las Vegas, NV 89154-4015
Phone: 702-895-4940
Fax: 702-895-3936
Email: hualiang.teng@unlv.edu

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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, the 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 all developed and developing countries around the world. High-speed rail 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 that are 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 the 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 the research to industry and academia. Examples of these activities are organizing and attending conferences, seminars, and workshops. We will 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, i.e., four at Virginia Tech, seven at the University of Delaware, and seven at the University of Nevada Las Vegas. Significant advances have been made in each project. The progress of the projects is described below.

VT-1: Energy Harvester Tie for Providing Access to Electric Power in Remote Locations. The primary purpose of this project is to develop an effective and practical energy harvester tie that can be used to provide power for trackside usage in places that power is not available. As reported in our last semi-annual report, we have successfully prototyped an energy harvester tie that was successfully installed on revenue service track in collaboration with our industrial partner, Norfolk Southern (NS) railroad. Due to a minor track failure, we successfully field tested the prototype energy harvester tie (EHT) that was removed and evaluation in the lab. The EHT was disassembled, the cause of the failure was identified, and a fix was implemented. The improved tie was re-tested in the lab multiple times to ensure that the design fix proves as intended. Subsequently, the tie was installed at the same location as earlier on the NS track, and it has been undergoing periodic evaluation of its functionality and measurement of the harvested power, to augment the data we have collected earlier.

VT-2: Application of Doppler LiDAR Sensors for Assessing Track Gage Widening in Curves and Locations with High-lateral Forces. The evaluation of the test data collected during track testing at the Transportation Technology Center (TTC) in Pueblo, CO, which was reported previously continues. We have evaluated the data using Fast Fourier Transportation (FFT), wavelet analysis, and other suitable means. The outcome has been encouraging, although the analysis is continuing. Thus far, the results show that the LiDAR system can measure gage widening on tangent tracks, but the measurements in the curves remain inconclusive. Further analysis and tests are needed to further confirm the current findings. Returning to TTC for another round of testing would be ideal but have not yet received a commitment such testing. We hope to have an update on the possibility of another round of TTC testing in our next semi-annual report.

VT-3: High-precision Evaluation of the Effect of 3rd Body Layers on Rail, Including Top of Rail Friction Modifiers. The primary goal of this study is to evaluate the effect of 3rd body layers on reducing rolling traction and braking. Testing on the high-precision Virginia Tech-Federal Railroad Administration (VT-FRA) roller rig at the Railway Technologies Laboratory (RTL) continues. We have identified the effect of friction-reducing agents such as flange grease on traction. The results indicate a long-lasting effect due to the seasoning of the rail and wheel that prolongs for a period far longer than original anticipated. We are currently in the process of identifying and testing with traction enhancing agents, such as certain composition of iron oxides, silica, and others. Where it is known qualitatively that such 3rd body layer agents would increase traction, it is not known by much. We intend to provide a quantification to the effect of such agents. We anticipate completing the planned tests and reporting on the findings in the next report.

The findings of this effort are expected to contribute significantly to practices that can be adopted by the U.S. railroads for reducing wheel-rail rolling resistance in dry conditions and increasing traction and braking in grades on wet rails.

VT-4: Automated Inspection of out-of-sight Under-train Equipment. The primary goal of this effort is to develop a remotely controlled Track Crawler Robot (TCR) that can be easily transported to various locations for inspecting the undercarriage of a stopped train in locations such as railyards. sidings, or spurs. As reported earlier, the TCR is fitted with GoPro® cameras and can travel the length of a train in between the rails without interference. The testing with TCR indicates that even though it is powered for travelling at speeds of 10 mph or higher, the onboard cameras experience too much shaking due to vibrations caused by travelling on rough terrains, i.e., the crossties and ballasts. Consequently, at more than 2 mph, the images become to blurry to be useful.

To reduce the vibrations transmitted to the cameras, we have designed and implemented an isolation platform that separates the cameras from the TCR frame. The isolation platform uses wire mounts that have the appropriate isolation frequency range and damping for our needs. The damping and isolation prosperities of the mounts are determined based an extensive vibration analysis and bench testing of a prototype platform. The TCR has been retrofitted with the isolation platform. The modified unit is currently awaiting additional track testing to determine the improvements in operating speed due to the added isolation platform.

UD-1: Development and Validation of a New Generation Rail Wear Model Using Emerging Big-Data Analytic Techniques. This project is ongoing and work continues on Phase II of the rail wear model. Amtrak has restated their interest in this rail wear model and will be providing additional data for the analysis activity. This includes transverse rail profile data that were collected for over10 years from annual inspections for approximately two miles of track. The data were used to develop two-dimensional wear rates, and we are now working on predicting the evolution of the profile based strictly on its past performance, after a delay due to the coronavirus (during which Amtrak was not able to provide data support). Work is now progressing on the prediction of the transverse rail profile, based on historic changes in the transverse profile using the 2DARIMA modeling approach developed previously under this activity. This approach treats the transverse Cartesian data as time series with adjoining weighting functions that constrain adjacent growth. Data are now being used to train an AI based analysis model. Amtrak has resumed active cooperation and the team is working with Amtrak on this activity. A paper based on this research was presented at American Railway Engineering and Maintenance of Way Association Annual Conference, Denver, CO, August 2022.

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

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

UD-4: Effect of Adjacent Poor Ties on the Life of Wood Crossties. This research activity is ongoing, and has published several papers and presentations. These include a journal paper in the Journal of Transportation Infrastructure Geotechnology published in November 2022, a conference paper accepted for International Heavy Haul Railways Conference, Rio de Janeiro Brazil, for presentation in August 2023, and this paper was submitted to the Journal of Rail and Rapid Transit in March 2023. These are in addition to the previously noted papers to include a paper published in the May 2021 edition of the Journal of Transportation Infrastructure Geotechnology as well as an article on the research published in Railway Track & Structures in October 2021. A presentation was also made at the Big Data in Railroad Maintenance Planning conference of December 2022. This activity continues in order to study the effect of adjacent tie conditions on the life of a railroad cross-tie using automated crosstie inspection taken from the same track over multiple years. This approach takes into account the dynamic changing of the conditions of adjacent ties to more accurately predict the life of the rail and develop improved models of the ties' longevity. The project currently focuses on the interaction of the degradation rates over time, as well as the iterative process that describes how changing the support condition impacts the middle and adjacent ties. The development of a closed-form expression that describes the deterioration behavior of wood ties as a function of the degradation rates of adjacent ties is underway. Then, a data science approach will be used to develop the relationships identified in the closed form solution, to include the relationship between tie condition and load distribution, and the corresponding relationship between load distribution and degradation rate. Additional tie condition data has been obtained to now include data from approximately 100,000 crossties over the five-year period from 2016 to 2021. This data is now being used to look at the effects of replacing individual ties on the rate of degradation of adjacent cross-ties. This activity aims to provide a method to predict and model the lives of ties based on dynamically changing support conditions as defined by the changing conditions of adjacent cross-ties.

UD-5: Risk Modeling of Grade Crossing Accidents. This project has been completed, and a follow-up activity is being considered. This activity utilized the national grade crossing inventory database and other readily available demographic data to develop a Bayesian Network to predict optimal crossing protection and accident/collision risk. An exposure metric was developed based on the densities of both train and highway traffic. This metric, along with other variables, was employed in the development of the Bayesian Network to define the protection level required for an individual crossing based on the historic performances of similar crossings, and it predicts the probability of collisions between trains and vehicles on the road.

UD-6: Random Forest-Based Covariate Shift in Addressing Non-Stationarity of Railway Track Data. This activity has been completed, and a paper was published in the ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering, 2021. This project addresses the accuracy issue for automated track geometry measurement vehicles, specifically the limitations due to the likelihood of the 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. In this study, supervised Machine Learning (ML) methods were used to detect the geometric data's non-stationarity. The methods included Random Forest, Logistic Regression, and Support Vector Machine. The researchers varied the train-test and validation ratio in phases to ascertain the accuracy of each of

the Machine Learning methods and their adaptability to different distributions. In the first phase, both the Random Forest and the Support Vector Machine had accuracies of 97.1%, and the Logistic Regression had an accuracy of 96%. In the second and third phases, the Random Forest method produces better results than the other supervised learners, with 97% and 97.1% accuracy, respectively. Similarly, for validation, the Random Forest performed better than the other classifiers with a 98% accuracy rate. Conclusively, the application of the developed models indicated that the Random Forest model provided a more effective approach for detecting the non-stationarity of track geometry data.

UD-7: Topological Data Analysis and Track Geometry Data. Topological data analysis (TDA) is a data-driven approach that involves studying high-dimensional data without assumptions or feature selections. For many complex data sets, especially monitoring railway tracks, the number of possible hypotheses is large, and generating useful hypotheses becomes difficult. The data can be streamed in high dimensions, which can cause the "curse of dimensionality" problems. There is a need to extract robust, qualitative information and gain insight into the processes that generates the data initially. Compared with traditional principal component analysis (PCA), t-distributed stochastic neighbor embedding (t-SNE), and cluster analysis, TDA more effectively detects large and small patterns in data. Thus, the main objective of the project is to apply TDA to various track geometry data and to develop a new approach, i.e., an invariant approach to traditional TQI, that can be more effective.

UNLV-1: Mobile 3D Printing of Rail Track Surface for Rapid Repair. In this reporting period, tensile test and bending test were performed on a segment of repaired worn rail. At the same time, a technical paper was prepared for submission to a technical journal.

UNLV-2: High-speed Rail Access Charge for the XpressWest of Nevada. A final report has been prepared for this project in this reporting period.

UNLV-3: Development of Acoustics Technology to Detect Transverse Defects in Rail at High-speed (220 mph). The research team has been modifying the inspection system to meet the requirement of the air-coupled-based defect detection. Initially, the team attempted to obtain an air transducer from a Canadian vendor for our specific amplifier. However, after an extensive investigation with lab tasting, the amplifier is found to be not fully compatible with the transducer. Following this, the team has been in communication with the PCB developer to develop an air-coupled transducer-based inspection system. During the development progress, the research team identified that the inspection frequency range and the signal amplification gain needed improvement to ensure system functionality properly. After extensive discussions with the team members and the PCB developer, the team decided to replace the conventional ultrasonic transducers with an optical microphone. This would better meet our detection requirements, and as a result, the team terminated the contract with the PCB developer. The team has been currently working with an Austrian vendor to acquire an optical microphone for our specification needs. After careful evaluation, the team is in the process of creating contracts for purchase of the Xarion ETA 250 model as a transducer of the new inspection system. Once the new device arrives, the team will conduct lab tests to verify the system's performance with the new sensor.

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. The team has successfully employed the data acquisition and processing (DAQP) system (i.e., Intel NUC, Tektronix RSA-306B and antenna) to iteratively scan radio frequency (RF) signals from 100 MHz to 3 GHz. The DAQP can record the scanned signal data in IQ streams and brief spectrum information (the center frequency, power spectrum, etc.) into a r3f file, which can be decoded into a csv file that contains raw data in time domain. The DAQP system has been tested and verified with a 315MHz signal and a 2.45GHz Bluetooth signal over -30 dBm within one-foot range. The team is looking for potential test sites and collaborators with facilities (e.g., transformers, etc.) for strong PD signal detection and DAQP system testing to prove the feasibility of detecting PD from distance. Meanwhile, the team is still in the process of clearing up and optimizing the program, and also considers adding cloud service into the system for remote accessibility, so that users are able to monitor signals off-site and receive an alarm during a triggerable event.

UNLV-5: Non-Propriety Ultra-High-Performance Concrete (UHPC) for Ballast-Track High-speed Railroad Sleepers. During this final quarter, five UHPC ties with an overall nominal length of 2362 mm (93 in), in accordance with the AREMA requirements for standard railway ties were tested. Two specimens were used to evaluate the center negative moment capacity with variations in the strength grade of the main/longitudinal reinforcing rebar. Corresponding specimens were also subjected to cyclic loading conditions. Finally, one specimen was tested to evaluate the rail seat moment capacity. Two types of loading schemes were used in this full-scale testing program.

UNLV-6: Development of UAV-Based Rail Track Irregularity Monitoring and Measuring Platform. The team has been working to fuse data from IMU and GPS/GNSS with LiDAR PCD frames for image registration. This is to stitch consecutive PCD frames to create a larger field of view so as to measure the radius of curve, and also to restore/correct the potential tilt/inclining angles that might be introduced during the unideal horizontal movement of the UAV; the pose/stance of the UAV is not absolutely level or fixed when there is a speed change, it turns and/or even it is hovering. The incorrect inclination value may affect the geometry measurement of super-elevation, profile, etc. The team has tried multiple algorithms for inclination recovery, and so far we can reduce the angle error to approximately 1 degree in a lab environment, which corresponds to about 2cm differences in altitude between the two rail tracks. The next step is to test all the algorithms on rail site for verification. Once this is done, the team may have accomplished all the geometry measurements (e.g., gauge, curve radius, super-elevation, etc.) within a reasonable level of precision.

UNLV-7: Efficient Railway Analysis Using Video. Graduate Assistant, Paul Stanik (CS), successfully defended his M.S. Thesis from this topic in November 2022. He decided to remain at UNLV and is now enrolled in the CS Ph.D. program focusing on machine learning (ML) and computer vision (CV). A journal paper based on the thesis has been prepared and will be submitted in May (target publication is the IEEE Transactions on Intelligent Transportation Systems). Key contributions of Mr. Stanik's work include state-of-the-art performance on the RailSem19 rail segmentation benchmark and the collection of the first public rail anomaly dataset which includes overgrown vegetation, mud pumping, and individual ties from a locomotive camera view. The team met with the Data Engineering team from BNSF Railways to develop a follow-up project

using their vast amounts of caboose images and real examples of anomalies. Conversations need to be restarted after the difficult last six months for the rail industry

Initiating new research programs

None to report in this period.

Upgraded education opportunities

We continue to have plans to offer a distance learning graduate course, entitled "Rail System Dynamics." The research involvement, however, has proven to make the planning and development of the course more challenging than initially anticipated. Upon its implementation, the course will be made available to the University of Delaware and UNLV graduate students in an online format. The students at each university will receive credit toward their graduate degrees from their home institutions.

The University of Delaware offered four railroad courses one in the Fall of 2022; CIEG 418/618 Railroad Engineering and three in the Spring of 2023; CIEG 317 Introduction to Railroads, CIEG 414/614 Railroad Geotechnical Engineering and CIEG 417/617 Railroad Safety and Derailment Engineering. At UNLV, two courses were offered in the Fall semesters of 2022 and the Spring semester of 2023, i.e., CEE 460/660 Introduction to Railway Transportation and CEE 470/670 High Speed Rail. More than 20 undergraduate and graduate students attended each course.

Opportunities for training and professional development

Virginia Tech participated in the "Big Data" in Railroad Maintenance Planning conference in December of 2022 and presented some of its research findings related to VT-2 to a large audience of railroad practitioners and researchers, in a presentation entitled "Can Machine Learning Methods Improve the Identification of Unstable Tracks?" Additionally, the VT's energy harvesting tie received a significant amount of media publicity, including The VT-News, NPR, Popular Mechanics, and other reputable publications.

The University of Delaware's Professional Engineering Outreach provides professional courses for practicing railroad and transit professionals. These professional development courses include the new Continuous Welded Rail-Rail Neutral Temperature course (July 2021), with other recent professional development courses, such as Rail Grinding and Rail Maintenance, and Rail Industry Growth for Increased Long-Term Profitability. A short course on Application of Emerging Data Science Techniques for Railway Maintenance Planning is scheduled for May 2023 and is fully booked with no spaces remaining.

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. The 2022 conference was held on December

14-15, 2022 at the University of Delaware, Newark DE campus and was well attended with close to 200 attendees. The 2023 conference will be held on December 13-14, 2022 at the University of Delaware, Newark DE campus

Results disseminated

VT continues to be active in publishing its research results in various technical journals, trade magazines, and railroad conferences.

At the University of Delaware, we are currently preparing three reports on our past projects that we will share with the DOT through the lead university, UNLV. A new presentation is scheduled for the 2022 Big Data at the University of Delaware on December 14-15, 2022. Additionally, we made three presentations at the ASME Joint Rail Conference that took place virtually on April 20-21, 2022. 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 and AAR's Transportation Technology Center, Inc. (TTCI).

The University of Delaware conducted two major activities to disseminate results to industry and academia. The next Big Data conference will take place December 14-15, 2023 in live format, and will include presentations concerning the UTC projects that are being conducted at Virginia Tech and the University of Delaware. The University of Delaware maintains contact with industry partners and its own railway advisory board to present the results of the UTC project. In the UD Railway Advisory Board meeting in December 2022, the results of the UTC project were presented from several UTC sponsored projects. The next UD Advisory Board is scheduled for December 2023.

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 paper based on this wear project was presented at the August 2022 AREMA technical conference.

Plan for the next reporting period

Virginia Tech's efforts in completing the current four projects it is undertaking will continue to completion in 2023, as noted earlier. The University of Delaware and UNLV will also plan to continue their research and educational activities through the end of the current UTC contract. Both universities offered railroad-related courses in the fall 2023 and spring 2024 semesters.

2. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

Organizations involved as partners

Norfolk Southern (NS), MxV Rail, and ENSCO Rail currently serve or have served as industrial partners in our research projects. During this reporting period, we had a great amount of interaction with NS, resulting in planning, installing, and successfully testing of the VT's energy harvester tie on the NS track at a location in Christiansburg, VA (VT-1). We have also worked with NS for some of the field testing of VT's gage widening and track stability system on revenue service track (VT-2). Additionally, we had extensive collaboration with MxV Rail, the R&D arm of the Association of American Railroads (AAR), resulting in extensive tests at their test facility in Pueblo, CO in August. As reported in the past, AAR is providing $154,300 of matching funds for VT-2. The requested information about AAR's matching funds is:

- Organization Name: MxV Rail or Association of American Railroads (AAR)
- Location of Organization: Pueblo, Colorado
- Partner's contribution to the project (identify one or more): Financial Support for $154,300. Extensive engineering support (approximately ½ man-year in total during this reporting period)

We have initialed collaboration with ENSCO toward designing and fabricating a new generation of railcar energy harvesters. ENSCO will assist VT in testing the energy harvester at its test facility in Pueblo, CO.

At the University of Delaware, Phase II of the rail wear project will have new data and technical support from Amtrak's Engineering Department (Philadelphia, PA) as well as ongoing support and data from CSX Transportation in Jacksonville, FL. Results will be presented to Amtrak upon completion for incorporation in their maintenance management activities.
The requested information about Amtrak's matching funds is:

- Organization Name: National Railroad Passenger Corporation (Amtrak)
- Location of Organization: Philadelphia, PA
- Partner's contribution to the project (identify one or more): Financial Support for $95,437 plus engineering support and provision of data for use in the activity.

The Nevada Railroad Museum and UNLV were preparing a Memorandum of Understanding (MOU) for cooperation in future. This preparation process halted all the field work at the Museum.

Other collaborators or contacts involved

None to report during this reporting period.

3. OUTPUTS

Output performance measures

In this reporting period, our performance in the number of publication, invention disclosures and patent applications are three, zero and zero, respectively, all lower than expected annual measures: 6, 1, 1. It is a reasonable random fluctuation and they would be better in the next reporting period.

Publications, conference papers, and presentations

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

Publications

1. Pan, Y., Zuo, L., and Ahmadian, M., A Half-wave Electromagnetic Energy-Harvesting Tie towards Safe and Intelligent Rail Transportation, Applied Energy, 313(4):118844, May 2022. (https://doi.org/10.1016/j.apenergy.2022.118844). UTC support acknowledged. (Virginia Tech)
2. Soufiane, K., Zarembski, A. M., and Palese J. W., The Contribution of Crosstie Condition as Represented by Local Track Stiffness to the Wheel Load Distribution", Journal of Transportation Infrastructure Geotechnology, November 2022. https://doi.org/10.1007/s40515-022-00263-1. UTC support acknowledged (University of Delaware)
3. Soufiane, K, Zarembski, A. M. and Palese, J. W., Forecasting Crosstie Condition Based on the Dynamic Adjacent Support Using a Theory-Guided Neural Network Model, submitted to Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit, March 2023. UTC support acknowledged (University of Delaware)
4. Stanik, P. III, Real-Time Semantic Segmentation for Railway Anomalies Analysis, MS Thesis, Department of Electrical and Computer Engineering, University of Nevada, Las Vegas, May 2023. UTC support acknowledged (University of Nevada Las Vegas)

Books or other non-periodical, one-time publications

None

Other publications, conference papers and presentations

1. Radmehr, A. and Ahmadian, M., Can Machine Learning Methods Improve the Identification of Unstable Tracks?" Big Data in Railroad Maintenance Planning 2022, Newark, DE, December 14 – 15, 2022. UTC support acknowledged. (Virginia Tech)
2. Soufiane, K., Zarembski, A. M. and Palese, J. W., Effect of Failing Adjacent Crossties on Tie-Life: A Machine Learning Model, International Heavy Haul Railways Conference, Rio de Janeiro Brazil, August 2023. UTC support acknowledged. (University of Delaware)

3. Palese, J. and Mohamed, O., University of Delaware, "Development of a Multi-Dimensional Time-Based Track Safety and Quality Index" Presentation at Big Data in Railroad Maintenance Planning Conference, December 2022, Newark, DE. UTC support acknowledged. (University of Delaware)
4. Zarembski, A. M. and Soufiane, K., The Effect of Adjacent Tie Condition on Wood Cross-tie Life, Presentation at Big Data in Railroad Maintenance Planning Conference, December 2022, Newark, DE. UTC support acknowledged. (University of Delaware)

Policy Papers

None 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 can continue to provide service. This technology will save significant maintenance costs for the railroad industry. Another technology that UNLV is developing is the inspection of track irregularities such as gauge and curves using LiDAR and UAV technology. This technology can replace the labor extensive track inspection using the current inspection cart. 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. We also found that PTV Vissim, a highway traffic simulation software, can simulate the operation of high-speed rails, which provides a way to evaluate them.

Inventions, patent applications, and/or licenses:

Virginia Tech has filed a patent, entitled “Kinetic Energy-Harvesting Device for Powering and Charging Railway and other Applications,” USPTO Application No. 17719971, filed on April 13, 2022, which has resulted from the energy harvesting tie project funded by the RailTEAM UTC.

UNLV’s application for a patent on 3D printing: Additive Manufacturing System and Method for Railroad Rail and Wheel Repair is under review.

4. OUTCOMES

Passage of new policies, regulation, rulemaking, or legislation

The University of Delaware is working 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 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 to become 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.

We do not know whether LiDAR on UAV can measure track irregularities that required high accuracy. Our UAV projects demonstrates that track irregularities can be measured with LiDAR mounted on UAV, which is a knowledge breakthrough, providing a direction for a new way to inspect track effectively.

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 CWR on bridges, which represent critical cost, maintenance, and safety areas.

Our project at UNLV on 3D printing technology can reduce maintenance cost significantly.

Enlargement of the pool of trained transportation professionals

Virginia Tech's Railway Technologies Laboratory hosted six rail companies and suppliers on November 9 and 10, 2022, in a special recruiting event for the rail transportation industry, in conjunction with the VT-AREMA student chapter. This event that was attended by 30 pre-selected undergraduate and graduate students from a group of 90 students is held annually for the primary

purpose of providing direct access to some of the most talented undergraduate and graduate students at Virginia Tech. Over the years, the event has resulted in many successful recruitments (potentially 100) to rail transportation 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 Company (UPRR) visited UNLV for recruiting in November 2022. In addition, UPRR provided scholarship for railroad education at UNLV. In March 2023, UPRR gave a seminar at UNLV as well. They were amazed at the diversity of the student body attending our railroad class.

Adoption of new technologies, techniques, or practices

All of our projects use new technologies, techniques, and practices. We are at the leading edge of the application of many of these technologies in practice. Although interesting 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 successfully undertook field testing of prototype systems in revenue service or on test tracks. During this reporting period, we reinstalled the VT energy harvester tie (VT-1) on NS revenue service track in Christiansburg, VA. The prototype harvester that had been removed earlier for the purpose of redesigning and improving was tested extensively in the lab prior to its track installation approximately six weeks ago. The VT team has visually inspected the installed tie in several times and on each occasion has measured the amount of energy that can be installed with each passing axle. The results have been encouraging, in line or exceeding the amount of energy harvested during the tie's initial installation more than a year ago.

track testing of the LiDAR system (VT-2), and rail yard testing of the track crawler robot (VT-4) was in an attempt to cover some of the lost ground in field testing our systems during the Covid Pandemic era in 2020 and 2021, as reported in our past semi-annual reports. We remain somewhat behind with our field testing, and it is expected that one or two years of extension will be needed for the current program at Virginia Tech to fully recover the lost time due to the Covid shutdown.

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 University of Delaware's methodology to predict the rate of wheel wear and identify "bad actor" cars that generate excessive wear (and possibly excessive levels of lateral force) 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 (safety).

UNLV has developed a few technologies that have the potential to be adopted in practice. For example, the 3D printing technology to repair worn rails may be quickly adopted, evidenced by the high citation rate of the relevant papers produced from our project.

Outcome performance measures

In this reporting period, our research work was cited 39 times, much more than the target 6-10 annually. Our center was covered by the news 22 times. The VT's energy harvester tie has received extensive media coverage in well-known outlets such as the NPR, and Popular Mechanics. University of Delaware was extensively interviewed more than 10 times about the derailments in Ohio that has HAZMAT involved. UNLV was interviewed for the railroad strike. These coverages are far more than the expected.

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, hence 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 collect with current and future track inspection methods, hence 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 results 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 society's perception regarding the safety of using new and emerging technologies. The impact of technologies under development at the RailTEAM UTC is related directly to improving track-maintenance practices. The U.S. railroads collectively spend billions of dollars on track and rolling stock maintenance. Even small improvements (say 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.

UNLV's access charge project will directly impact the construction decision of XpressWest, which is considering building a high speed rail from Las Vegas to Los Angeles. XpressWest did not consider this access charge when initiating their project.

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 continue to provide 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 education of 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 November 2022.

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. Some new employees at the current high speed rail projects have been seeking professional development related to their projects.

Impact performance measures

In this reporting period, our UTC was requested five (5) times by stakeholders for RailTEAM expertise in the application of research products and/or results, which is far more than our annual target one (1). These stakeholders are Norfolk Southern Railroad Company, ENSCO Inc., Federal Railroad Administration, Amtrak, and KSNV Channel 3 in Las Vegas, Nevada. A major international tie manufacturer is interested in licensing and manufacturing energy harvester tie made by Virginia Tech, which makes our center impact performance better than our expected in this time period.

6. CHANGES/PROBLEMS

No changes in approach.

Actual and anticipated problems or delays

We continue to play catch up to the interruptions and delays caused by the COVID-19 Pandemic, mainly as they relate to our field testing with the railroads. Although the revenue service testing and test track evaluations that we have been able to do during this and the previous reporting period have enabled us to gain grounds on the delays caused by the shutdown during 2020 and 2021, we fully anticipate that more time beyond the current conclusion of the RailTEAM contract will be needed to complete the tests. We intend to request a no-cost extension (NCE) to the end of September 2024, preferably September 2025.

The change in our testing schedule has had some impact on expenditures by delaying them. There have been no significant changes in the use or care of human subjects, vertebrate animals, and/or biohazards. In addition, no change has occurred in the location of the primary performance site from the original proposal.

7. SPECIAL REPORTING REQUIREMENTS

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