# 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, 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. During this reporting period, we have successfully installed the Energy Harvester Tie (EHT) on revenue service track. The new tie includes design modifications to remedy a minor failure that occur during earlier installation of the tie in revenue service. The re-designed tie has been in service for nearly six months with no failures. We have been making power measurements to ensure the tie's proper function and also add to a large set of power data that we have collected on this innovative design.

Additionally, we have started an effort intended to design a power circuit for storing the harvested power. This effort was delayed because of the COVID Pandemic. The one-year extension on the project has provided us the ability to complete this essential subsystem, hence completing the first-ever successful design and revenue service implementation of an energy harvester tie for railroad applications.

VT-2: Application of Doppler LiDAR Sensors for Assessing Track Gage Widening in Curves and Locations with High-lateral Forces. The effort for this project continues. We have been challenged by the lack of availability of revenue-service track for our field testing. The revenue service tests are intended to complement the laboratory tests reported in our earlier reports, and some that were done during this reporting period. We are hoping that we can regain access to revenue service tracks in the next few months to complete a few rounds of tests that are planned for verifying the effectiveness of the LiDAR system that has been developed at the Railway Technologies Laboratory (RTL) during this project.

We have also undertaken an effort to develop a detailed model of the track structure, using elastic beam on elastic foundation concept. The model has been used to simulate conditions that leads to gage widening, such as reduced track vertical and lateral stiffness. The model's results are remarkable like the field data that we were collected. The agreement between the modeling results and field data confirms the effectiveness of Doppler LiDAR systems for early assessment of track gage widening in curves and high-lateral force locations.

VT-3: High-precision Evaluation of the Effect of 3rd Body Layers on Rail, Including Top of Rail Friction Modifiers. We have made a significant amount of progress on this project. Multitude of laboratory and field tests were done during this period. The test results were used to further fine tune the lubricity measurement system and develop a second Laser system to enable measuring lubricity status of both rails, simultaneously. The added system has been successfully tested in the

lab and in the field successfully. The field data includes measurements on a spur line near Blacksburg, VA, as well as revenue-service testing with one of the Class I railroads that has been our industrial partner on this project. All field tests were extremely successful. We plan to conduct additional field tests on revenue service tracks near Blacksburg, VA in the next few months to assess the reparability of the field measurements and increase the test database.

Additionally, we have undertaken an effort to develop a new track cart for future field tests. The new track cart is more dynamically stable that the earlier cart used for the tests and can travel faster. The extensive track tests we have conducted with the new cart has proven its utility for this project as well as the gage-widening project, mentioned earlier in VT-2.

The results of this project 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.

Major progress has been on modifying the imaging systems to make the images more stable during the high-speed operation of the TCR on rough terrain (i.e., ties and ballasts). These efforts have included an improved isolation system that has been incorporated into the TCR and improved settings on the GoPro® cameras. We have setup a test course in the lab that closely emulates the dynamics on operating on ties and ballasts. The TCR with the new image setup and isolation system has been run on the test course with increasingly encouraging results. We have been able to obtain clear images of overhead patterns to test the clarity of imaging train's undercarriage in revenue service. After some additional laboratory tests, we are planning to evaluate the inspection system in revenue service under an actual train, during the next reporting period.

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. Transverse rail profile data were collected for over 10 years from annual inspections for approximately two miles of track. The data were used to develop two-dimensional wear rates, and algorithm to predict the evolution of the profile based strictly on its past performance was developed. This approach treats the transverse Cartesian data as time series with adjoining weighting functions that constrain adjacent growth. 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 a third paper was published by the Journal of Rail and Rapid Transit in October 2023. Student is also preparing her PhD thesis for submittal in Fall 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. This project was completed, and a final report submitted in October 2023. Final Report entitled: Predicting track geometry using machine-learning methods. 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, the rail was repaired with several compositions of minerals at the ESAB Welding and Cutting Equipment company in Pennsylvania and these repaired rails were tested at UNLV. At the same time, a technical paper was submitted to a technical journal.

UNLV-2: High-speed Rail Access Charge for the XpressWest of Nevada. In this reporting period, a recommendation from the drafted report was investigated, which is evaluating the deterioration of railroad track due to different speed of trains, which directly influence the access charge.

UNLV-3: Development of Acoustics Technology to Detect Transverse Defects in Rail at High-speed (220 mph). The research team acquired the Xarion ETA 250 optical microphone in July. Subsequently, the team initiated pencil lead break (PLB) tests to evaluate the microphone's performance in detecting AE signals in various environments. Initially, the team focused on understanding signal attenuation with increasing distance from the defect. To achieve this, the sensor and pencil were placed on the steel rail surface, and PLB signals were recorded at intervals

ranging from 0 to 5 inches. Following this, the team investigated signal attenuation in the air. In this setup, the pencil remained on the rail surface while the sensor was positioned in the air, with distances ranging from 0 to 5 inches. The results demonstrated that the optical microphone effectively detected AE signals within 2 inches with acceptable attenuation in both scenarios. Based on these findings, the team decided to position the sensor approximately half an inch from the rail for the upcoming field tests.

The team then conducted field tests at the Nevada Railroad Museum. Considering the risk of damaging the sensor head, the team opted not to install the sensor on the train without a comprehensive assessment of the vibrations when mounted on the train. Instead, the team placed the sensor a half inch under the rail head and on the rail web at pre-damaged locations without contacting the rail in current setups. The tests were repeated ten times for each sensor installation location. At present, the team has completed the field tests and is working on the data processing. Meanwhile, the team is exploring methods to install the sensor on the train securely.

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. Our team has achieved successful implementation of the Data Acquisition and Processing (DAQP) system, comprising an Intel NUC, Tektronix RSA-306B, and antenna. This system facilitates iterative scanning of radio frequency (RF) signals spanning the range of 100 MHz to 3 GHz. The DAQP system is proficient in recording the scanned signal data in IQ streams and summarizing spectrum information, including center frequency and power spectrum, which is then stored in r3f files. These r3f files can be decoded into CSV files containing raw data in the time domain. The DAQP system has undergone rigorous testing and verification, showcasing its capacity to capture signals at 315 MHz and 2.45 GHz Bluetooth signals, even at power levels as low as -30 dBm, all within a one-foot range. Furthermore, our team has recently acquired a broadband arbitrary waveform generator (AWG) and an oscilloscope, both covering a frequency range of 100 MHz to 2 GHz. Current experiments are aimed at utilizing the AWG to generate suitable signals for testing and validating the DAQP across a wide frequency spectrum. In parallel, we are exploring the design of signal attenuation circuits to ensure impedance compatibility between the AWG and RSA-306B. Meanwhile, ongoing efforts are directed towards optimizing the program to enhance its reliability and robustness.

UNLV-5: Non-Propriety Ultra-High-Performance Concrete (UHPC) for Ballast-Track High-speed Railroad Sleepers. During this reporting period, preparation for third phase (last phase) of the test were made. Our planned carbonation test deals with the evaluation of carbonation attacks on railroad ties made using ultra high performance concrete. Carbonation attack on exposed concrete structures, such as railroad ties, is one of the causes of concrete deterioration and failure. At the present time the test set up is being built at the College machine shop.

UNLV-6: Development of UAV-Based Rail Track Irregularity Monitoring and Measuring Platform. Our team has achieved successful registration of LiDAR PCD frames with the assistance of IMU, enabling the registered point clouds to provide a broader field of view of rail tracks. When compared to onsite measurements of rail geometry (ground truth) at the Nevada State Railroad Museum in Boulder City, Nevada, the current rail gauge measurement using LiDAR attains a

precision level of approximately 1 cm. We believe this represents the limit achievable with the current hardware, including UAV and OS1-128 LiDAR. However, determining the absolute level plane of the scene remains a challenging task.

At present, our team can calculate only the relative super-elevation. Furthermore, the registration process opens up possibilities for calculating rail curvatures. Nevertheless, the accuracy of curvature calculations may be significantly influenced by various factors, including data sparsity of cloud points on the rails and distortions and noises introduced during the reconstruction of 3D rail models. To address these challenges, our team is exploring two different approaches:
(1) Utilizing generative adversarial networks (GANs) to generate complementary cloud points that fill the 3D model of rail tracks as they ideally should be. This enhancement of the point cloud data quality has the potential to improve calculation and measurement accuracy.
(2) Investigating data fusion from both LiDAR PCD and high-speed RGB camera images/video frames. By doing so, the RGB camera can complement the rail track reconstruction and geometry measurement, potentially providing a more comprehensive and accurate representation

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

**Initiating new research programs**

None to report in this period.

**Upgraded education opportunities**

At Virginia Tech, 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. More than 25 undergraduate and graduate students attended each course at UD.
At UNLV, two courses were offered in the Spring semesters of 2023 and the Fall semester of 2023, i.e., CEE 470/670 High Speed Rail and CEE 462/662 High Speed Rail. Their enrollments are 21 and 23, respectively.

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

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 2023. 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.

## Results disseminated

A major presentation on the results of one of the UTC projects was made at the International Heavy Haul Railways Conference in Rio de Janeiro Brazil in August 2023. It was entitled "Effect of Failing Adjacent Crossties on Tie-Life: A Machine Learning Model". A journal publication was published by the Proceeding of the Institution of Mechanical Engineering, Part F: Journal of Rail and Rapid Transit, September 2023 https://doi.org/10.1177/09544097231203275' entitled "Forecasting Crosstie Condition Based on the Dynamic Adjacent Support Using a Theory-Guided Neural Network Model". University of Delaware has issued one new UTC final report "Predicting Track Geometry Using Machine-Learning Methods" and expects to have a second UTC report completed by the end of the Fall 2023 semester "Effect of Failing Adjacent Crossties on Tie-Life: A Machine Learning Model". 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 13-14, 2023 in live format, and will include presentations concerning the UTC projects that are being conducted at 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 July 2023, 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.

UNLV completed one Masters' thesis and a Ph.D. dissertation which were presented at UNLV.

### Plan for the next reporting period

Virginia Tech's efforts in completing the current four projects it is undertaking will continue to completion in 2024, 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, our extensive interaction with NS continued, 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). We have initialed collaboration with ENSCO toward field testing the gage widening measurement system in VT-2 and Lubricity Assessment system in VT-3 at its test facility in Pueblo, CO. The idea of testing the VT's energy harvester tie remains on hold; considering the success we have had with testing the system in revenue service track.

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.

A Memorandum of Understanding (MOU) with the Nevada Railroad Museum was signed for three years.

### Other collaborators or contacts involved

None to report during this reporting period.

## 3. OUTPUTS

### Output performance measures

In this reporting period, nine papers were published which exceeds our expectation:3-4 papers. We do not file any invention disclosures or provisional or utility patent applications, which are below our annual expectation, i.e., 1-2 and 1, respectively. UNLV has a patent application in the last year which is still under review. UNLV will file at least one patent application next year.

## Publications, conference papers, and presentations

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

*Publications*

1. Huang, M., Ahmadian, M., Rahimi, A., and Steiginga, L., Dynamics Performance of Long Combination Vehicles with Active Control Systems, Vehicle System Dynamics, Vol. 61, No. 7, May 2023, pp. 1829 - 1878. (https://doi.org/10.1080/00423114.2023.2194545). UTC support acknowledged. (Virginia Tech)
2. Ali, G., McLaughlin, S., and Ahmadian, M., The Surface Accelerations Reference — A Large-Scale, Interactive Catalog of Passenger Vehicle Accelerations, IEEE Transactions on Intelligent Transportation Systems, April 2023 (online). (https://doi.org/10.1109/TITS.2023.3267844). UTC support acknowledged. (Virginia Tech)
3. Radmehr, A., Mirzaei, M., Larson, I., Holton, C., and Ahmadian, M., Railroad Track Gage Widening Assessment Using On-board Doppler LiDAR Velocity Measurements and Unsupervised Machine Learning Technique, The 2023 International Association of Vehicle System Dynamics (IAVSD) Bi-Annual Conference, Ottawa, Canada, August 21 – 25, 2023. UTC support acknowledged. (Virginia Tech)
4. Chen, Y., Neighborgall, C., Zheng, X., and Ahmadian, M., Field Testing and Performance Evaluation of Roll Stability Control System of Double-trailer Trucks, The 2023 International Association of Vehicle System Dynamics (IAVSD) Bi-Annual Conference, Ottawa, Canada, August 21 – 25, 2023. UTC support acknowledged. (Virginia Tech)
5. Zhang, Z., Chen, Y., and Ahmadian, M., Interconnected Roll Stability Control System for Semitrucks with Double Trailers, 2023-01-0906, ISSN: 0148-7191, e-ISSN: 2688-3627, WCX SAE International World Congress Experience, Detroit, MI, April 18 – 20, 2023. UTC support acknowledged. (Virginia Tech)
6. 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" Proceedings of the Institution of Mechanical Engineers, Journal of Rail and Rapid Transit, September 2023 https://doi.org/10.1177/09544097231203275. UTC support acknowledged (University of Delaware)
7. Olubode, O., Pantograph Carbon Strip Degradation Monitoring – Pulsed Power Application Using Electromagnetic Dot, Dissertation, Department of Electrical and Computer Engineering, University of Nevada, Las Vegas. August, 2023. UTC support acknowledged (University of Nevada Las Vegas)
8. Hasnat,A., Development of Non-Proprietary Ultra-High-Performance Concrete and Railway Tie Application Ph.D. Dissertation, Department of Civil and Environment Engineering and Construction, University of Nevada, Las Vegas, June 2023. UTC support acknowledged (University of Nevada Las Vegas)
9. Hasnat , A. and Ghafoori, N., Transport Properties and De-icing Salt Resistance of Blended Ultra High-Performance Concrete. ASCE Journal of Cold Regions Engineering, 2023, DOI:

10.1061/JCRGEI/CRENG-724. UTC support acknowledged (University of Nevada Las Vegas)

*Books or other non-periodical, one-time publications*

None

*Other publications, conference papers and presentations*

1. Ahmadian, M., Dynamics Performance of Long Combination Vehicles with Active Control Systems, Keynote Presentation at The 2023 International Association of Vehicle System Dynamics (IAVSD) Bi-Annual Conference, Ottawa, Canada, August 21 – 25, 2023. UTC support acknowledged. (Virginia Tech)
2. Ahmadian, M., Railroad Track Gage Widening Assessment Using On-board Doppler LiDAR Velocity Measurements and Unsupervised Machine Learning Technique, Presentation at the 2023 International Association of Vehicle System Dynamics (IAVSD) Bi-Annual Conference, Ottawa, Canada, August 21 – 25, 2023. UTC support acknowledged. (Virginia Tech)
3. Ahmadian, M., Field Testing and Performance Evaluation of Roll Stability Control System of Double-trailer Trucks, Presentation at the 2023 International Association of Vehicle System Dynamics (IAVSD) Bi-Annual Conference, Ottawa, Canada, August 21 – 25, 2023. UTC support acknowledged. (Virginia Tech)
4. 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)

## 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:

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 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 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 once again will hold its annual Career Dinner, an exclusive event for bringing together the most qualified students with railroad companies, on October 18 and 19. This mark one decade of the event, except for a lapse during the COVID Pandemic. This year, six rail companies and suppliers will attend the event, which includes extensive engagement from the VT-AREMA student chapter. Some 16 representatives from the six companies and 35 pre-selected undergraduate and graduate students (from 50+ resumes submitted to the event's announcement) will attend this year's 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.

## 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 are continuing their field testing of prototype systems in revenue service or on test tracks, with great success. During this reporting period, we reinstalled the VT energy harvester tie (VT-1) on NS revenue service track in Christiansburg, VA. Thus far the harvester has performed flawlessly in one-of-dozens of trackside data collection sessions that we have held. The results have been exceeding successful and are promising the successful technology development from a concept to a proven, field-tested prototype that is made possible by the RailTEAM's funding. With other projects, we are continuing to make grounds on some of the lost field-testing opportunities that occurred because of COVID. Anticipate completing all planned field tests by the end of the projects in 2024.

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).

### Outcome performance measures

During this reporting period, our research papers in technical journals and conference proceeding were cited 39 times, much more than the targeted measures, 6-10 annually. Our UTC was covered by news media four times, exceeding the expectations 2-3 time annually. The topics covered in these news media range widely from freight train details in Ohio to high speed rail in the world.

# 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. On October 12, 2023, UPRR gave a seminar at UNLV introducing their railroad company to the students. On October 10, 2023, Stacy and Witbeck, Inc. gave a seminar on their design of the high speed rail from Las Vegas to Southern California. Both seminars draw a great audience who are interested in railroad engineering.

### Impact performance measures

During this reporting period, we have three cases where stakeholders requesting RailTEAM expertise in the application of research products, which is exceeding the yearly expectation (1). Virginia Tech and UD have one of their products transferred to a company, respectively, which is also exceeding our annual expectation (1).

## 6. CHANGES/PROBLEMS

No changes in approach.

Actual and anticipated problems or delays

We are making grounds on the delays caused by the COVID Pandemic. We anticipate that all the projects will be completed by the end of the funding period in September of 2024.

## 7. SPECIAL REPORTING REQUIREMENTS

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