UTC-Semi-Annual Progress Report

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

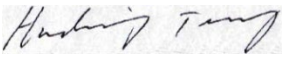
University of Nevada Las Vegas
Virginia Polytechnic Institute and State University
University of Delaware

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 field testing the VT Energy Harvesting Tie (EHT) continues, successfully. During this reporting period, we conducted data in two more occasions; each time from two to three freight trains. The tests confirmed that the continued working of the EHT. The amount of energy harvested from each axle of the freight trains is similar to the tests performed in earlier reporting periods. We plan to remove the porotype EHT from the track and examine it for any signs of internal wear and tear.

The efforts for designing a power circuit for storing the harvested power had to be abandoned because the graduate student who was working on the project run into academic difficulties and had to withdraw academically from Virginia Tech. Because of the limited amount of time to the end of the project (September 30, 2024), there are no plans to hire a new student to continue the effort. The learning curve for a new student would extend beyond the remaining time.

VT-2: Application of Doppler LiDAR Sensors for Assessing Track Gage Widening in Curves and Locations with High-lateral Forces. He performed more testing and data analysis for this project during the reporting period. The additional field data as well as the data that we had from past tests were analyzed using methods that extended the past analyses of our test data. The improvements to the analysis methods mainly involved machining learning methods that increases the confidence in gage widening estimations. We intend to spend the remaining time we have before the end of the project to further improve the machining methods. We also intend to further improve the elastic-beam modeling effort that we reported in our last progress report. Ultimately, the model and new field data analysis will be merged together to creative a comprehensive estimation of early assessment of track gage widening in curves and at high-lateral force locations.

VT-3: High-precision Evaluation of the Effect of 3rd Body Layers on Rail, Including Top of Rail Friction Modifiers. The efforts for this project continued during this reporting period, using the VT-FRA Roller Rig (VT-FRA). We have further established the effect of leaf residue as a 3rd-body agent at the wheel-rail interface. This study has significantly advanced the empirical and anecdotal information regarding braking and adhesion reduction because of leaf continuation in the fall season. The results of the study show that not all leaves have the same effect. Also, there is a strong nonlinear relationship between the volume of leaves and the resulting traction reduction. Small amount of leaves can cause large traction reduction, which does not increase in the same proportion as the increase in leaf volume. The findings of the study have been submitted to a journal and the annual AREMA conference for publication.

VT-4: Automated Inspection of out-of-sight Under-train Equipment. Many aspects of the remotely controlled Track Crawler Robot (TCR) designed and fabricated by the VT Railway Technologies Laboratory (RTL) were improved during this period. Notably, the structural design was revised to increase the field of view of the on-board cameras. Extensive FEA was performed to ensure that the new structure can sustain the large impacts during the operation, including climbing the rail to reach the running area in between the tracks and the jolts caused by impacting a raised tie. The video system was also improved to enable the GoPro® cameras to capture clearer images at higher speeds. The shutter speed and camera settings proved to be the most effective means of improving the recorded video images while allowing operating the TCR at high speeds. Another improvement involved increasing the onboard battery capacity to enable a minimum of one hour of contiguous operation at the maximum operational speed.

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 together with several Journal papers. Amtrak is currently evaluating the rail wear modeling results for implementation. 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. A fourth paper was submitted to the Journal of Infrastructure Systems in November 2023. Student completed and defended her PhD thesis in December 2023. A presentation was also made at the Big Data in Railroad Maintenance Planning conference of December 2023. This activity studied 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 looked at 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. A data science approach was 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. This activity provides 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. This project is completed in this reporting time period.

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. A journal paper is being prepared based on this research. A presentation was also made at the Big Data in Railroad Maintenance Planning conference of December 2023. 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 contractual procedure with ESAB as clarified. At the same time, two technical papers were submitted to two technical journals and a paper submitted to an ASCE conference which was accepted.

UNLV-2: High-speed Rail Access Charge for the XpressWest of Nevada. In this reporting period, the research on the deterioration of railroad track due to different speed of trains was continued.

UNLV-3: Development of Acoustics Technology to Detect Transverse Defects in Rail at High-speed (220 mph). The research team evaluated the system's performance in two distinct test setups by using the field test data collected the pre-damaged rail defects at the Nevada Railroad Museum. This data was employed to assess the performance of the sensor system in detecting acoustic emission (AE) signals. The first setup only utilized the system integrated amplifier at 20 dB, and the second setup utilized an external amplifier to obtain a total 40 dB gain. The results of these two comparable tests have indicated that the 40 dB gain setup has the potential to detect real-world AE signals with an acceptable increase in background noise levels. Conversely, the 20 dB gain setup missed a significant portion of the AE signals, although no background noise was detected. Therefore, the 40 dB gain setup was deemed as the better option for effective AE signal detection. Meanwhile, the mounting frame that installed the sensor for dynamic tests on moving trains was evaluated in the field tests. After multiple improvements to the design, the frame was able to carry the sensor safely during the tests and ensure signal detectability as well. Therefore, in the next step, the team plans to conduct dynamic tests by mounting the sensor on moving trains, aiming to validate the sensor's capability to identify rail defects on the moving trains.

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 built up a configurable radio frequency (RF) signal generator with a frequency range between 100MHz to 2GHz. Both mono- and mixed/multi-tone signals are tested, with a combination of Bluetooth (about 2.45GHz) signals. In summary, the team has confirmed that the developed data acquisition and processing (DAQP) system can iteratively capture the RF signal (potentially stimulated by partial discharge) within the range of approximately 10MHz to 2.5GHz. In the end, the team will be preparing the project report.
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UNLV-5: Non-Propriety Ultra-High-Performance Concrete (UHPC) for Ballast-Track High-speed Railroad Sleepers. All supplies were ready to assemble the test set up. Currently, the research team is doing carbonation test for UHPC ties.

UNLV-6: Development of UAV-Based Rail Track Irregularity Monitoring and Measuring Platform. The team has been engaged in an exploration aimed at reconstructing the 3D modeling of rail infrastructure based on consecutive multi-angle RGB images/videos. The rationale in complying this approach is to leverage the relatively high pixel resolution inherent in RGB imagery to enhance the precision in geometric measurement. Multiple image 3D remodeling (e.g., Gaussian Splatting, instant NeRFs, etc.) and data fusion algorithms have been employed and tested. Despite these efforts, the precision of the generated 3D models has fallen short of anticipated levels, primarily attributed to the

inherent sparsity of features within the rail and its surrounding environments. In response, the team has initiated an inquiry into potential factors that may contribute to the suboptimal precision observed in the 3D modeling process. Key considerations under investigation include issues related to scaling and registration, among others. Through a systematic analysis of these factors and their respective impacts on modeling outcomes, the team endeavors to devise strategies to refine and enhance the precision of the reconstructed 3D models, thereby advancing the efficacy and reliability of rail infrastructure assessments and related applications.

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. A meeting was held with UNLV's College of Engineering leadership to further discuss the logistics of offering joint courses at the two universities (VT and UNLV) in support of the educational missions of the RailTEAM UTC.

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 Fall semesters of 2023 and the Spring semester of 2024, i.e., CEE 462/662 Railroad Engineering and CEE 471/671 Public Transportation Systems. Their enrollments are 24 and 35, respectively.

Opportunities for training and professional development

Virginia Tech continues to interact with its industrial partners to provide professional development in support of RAILTeam's outreach missions. We also continue to be prolific in publishing our research results in journals and at technical conferences. We participated and presented four papers at a DOT-UTC conference held in March at UNLV. Two of our abstracts have been accepted for publication and presentation at the 2024 AREMA annual conference that will be held in September in Knoxville, TN. Additionally, three of our rail papers have been accepted in peer-viewed journals and three more are in review.

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

Beyond the efforts mentioned in. the previous section, three of our projects were selected to be showcased at the annual FRA Review in November 2023 in Pueblo, CO. A new journal paper was submitted to Journal of Infrastructure Systems in November 2023. "Assessing the Impact of Deteriorating Adjacent Crossties on the Future Condition of a Central Crosstie: A Study Leveraging Unsupervised and Interpretable Machine Learning Techniques".

University of Delaware has issued one new UTC final report "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. A Big Data conference took place December 13-14, 2023 in live format, and included presentations concerning the UTC projects that are being conducted at the University of Delaware. The next Big Data conference will take place December 11-12, 2024. 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 January 2024, the results of the UTC project were presented from several UTC sponsored projects.

Our railroad UTC jointly hosted a conference with the Region 9 UTC from March 11 to 12, 2024 in Las Vegas, Nevada. Nine research projects (4 from Virginia Tech, 1 from UD and 4 from UNLV) were presented at the conference. A paper was submitted to and accepted by an ASCE conference in June 2024 at Atlanta, GA. Two papers were submitted to two journals that were under review.

Plan for the next reporting period

Virginia Tech intends to successfully complete the four projects that it is currently undertaking by the end of the RAILTeam's term in September 2024. 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 2024.

2. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

Organizations involved as partners

Norfolk Southern (NS) and MxV Rail continue to work closely with the VT RTL team in support of the rail research projects we are pursuing. During this reporting period, NS supported several of our field tests to further evaluate the technologies and systems we have developed in revenue service environment. The field testing on the NS has been in direct support of the energy harvesting project (VT-1), gage widening and track stability project (VT-2), and train inspection system (VT-4).

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.

Nevada Railroad Museum has continued their cooperation with UNLV, allowing conducting research projects using their facilities and personnel.

Other collaborators or contacts involved

None to report during this reporting period.

3. OUTPUTS

Output performance measures

In this reporting period, 12 publications were produced which exceeds our target, 3-4 semi-annually. We did not file any invention disclosures which is lower than expected 0-1 semi-annually. We did have a patent application in review which is consistent with our expectation.

Publications, conference papers, and presentations

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

Publications

1. Shaju, A., Southward, S. C., and Ahmadian, M., Enhancing Autonomous Vehicle Navigation with a Clothoid-Based Lateral Controller, Applied Sciences, Volume 14, Issue 5, February 2024. (https://doi.org/10.3390/app14051817). UTC support acknowledged (Virginia Tech)
2. Chen, Y., S. M. H. Mirzaei, Holton, C., Ahmadian, M., Development of An Optical Sensing System for the Detection of Lubricity Conditions on the Rail Gage Face, International Journal

of Rail Transportation, February 2024. (https://doi.org/10.1080/23248378.2024.2309618). UTC support acknowledged (Virginia Tech)

3. Chen, Y., Neighborgall, C., Zheng, X., and Ahmadian, M., Field Testing and Performance Evaluation of Roll Stability Control System of Double-trailer Trucks, Vehicle System Dynamics, accepted for publication, January 2024, pp. 1 – 20. (https://doi.org/10.1080/00423114.2024.2304052). UTC support acknowledged (Virginia Tech)
4. Ahmadian, M., Chen, Y., Zhang, Z., Emergency collision avoidance maneuvers of multi-trailer articulated heavy vehicles, Vehicle System Dynamics, January 2024. (https://doi.org/10.1080/00423114.2024.2305292). UTC support acknowledged (Virginia Tech)
5. Neighborgall, C., Chen, Y., and Ahmadian, M., Tyre lateral slip effect on off-tracking of a long combination vehicle, Vehicle System Dynamics, January 2024. (https://doi.org/10.1080/00423114.2024.2304052). UTC support acknowledged (Virginia Tech)
6. Shaju, A., Southward, S. C., and Ahmadian, M., PID-Based Longitudinal Control of Platooning Trucks, Machines, Vol. 11, Issue 12, December 2023. (https://doi.org/10.3390/machines11121069). UTC support acknowledged (Virginia Tech)
7. Zheng, X., Chen, Y., and Ahmadian, M., Interconnected Roll Stability Control System for Semitrucks with Double Trailers, SAE Technical Paper No. 2023-01-0906, 2023. (https://doi.org/10.4271/2023-01-0906). UTC support acknowledged (Virginia Tech)
8. Soufiane, K, Zarembski, A. M. and Palese, J. W., Assessing the Impact of Deteriorating Adjacent Crossties on the Future Condition of a Central Crosstie: A Study Leveraging Unsupervised and Interpretable Machine LearningTechniques, submitted to Journal of Infrastructure Systems, November 2023. UTC support acknowledged (University of Delaware)
9. Wang, Z., Zeng, Z., and Teng, H., Corrosion Test of the Steel Plate in a WJ-8 Fastener for High Speed Rail, Journal of Transportation Technologies, Vol.14, Issue, 01, pp. 16-30, 2024. UTC support acknowledged (UNLV)
10. Teng, H. and Kutela, B., Technical Feasibility Study of Passenger Rail Service along the West Route between Las Vegas and Los Angeles, Journal of Transportation Technologies, Vol. 13, Issue 4, pp. 746-755, 2023. UTC support acknowledged (UNLV)
11. Mohammadi, A. Wang, Z., and Teng, H., Mechanical and Metallurgical Assessment of a Submerged Arc Surfaced Rail, submitted to the Journal of Rail and Rapid Transit, October, 2023. UTC support acknowledged (UNLV)
12. Mohammadi, A., Wang, Z., and Teng, H., Finite Element Analysis and Validation of Submerged Arc Welding for Repairing 136RE Heavy Rails, International Journal of Transportation Science and Technology, October 2023. UTC support acknowledged (UNLV)

Books or other non-periodical, one-time publications

None

Other publications, conference papers and presentations

1. Chen, Y., Mirzaei, S. M. H., Holton, C., Ahmadian, M., Non-contact Detection and Evaluation of Rail Gage-face Lubricant using Optical Sensing Methods, the TTC Annual Conference, Pueblo, CO, November 7 – 8, 2023. UTC support acknowledged (Virginia Tech)
2. Radmehr, A., Kumar, N., Ahmadian, M., Experimental Evaluation of Wheel/Rail Contact, Third Body Layer, and Surface Finish on Risk of Derailment," the TTC Annual Conference, Pueblo, CO, November 7 – 8, 2023. UTC support acknowledged (Virginia Tech)
3. Ahmadian, M., Safety Evaluation of Interconnected Roll Stability Control Systems for Articulated Commercial Vehicles, The 16th IFToMM World Congress, Tokyo, Japan, November 5 – 11, 2023. UTC support acknowledged (Virginia Tech)
4. Kumar, N., Ahmad Radmehr, A. Ahmadian, M., Experimental Evaluation of Effect of Leaves on Railroad Tracks in Loss of Braking, The University Transportation Center's 2024 PSR Annual Congress, Moving Forward: Improving Transportation in Region 9, Las Vegas, Nevada, March 12, 2024. UTC support acknowledged (Virginia Tech)
5. Chen, Y., Morteza S. Mirzaei, H., Holton, C., and Ahmadian, M., Application of Laser-induced Fluorescence Technique for Measuring Lubricity Conditions on Rail Gage Face, Presentation at the University Transportation Center's 2024 PSR Annual Congress, Moving Forward: Improving Transportation in Region 9, Las Vegas, Nevada, March 12, 2024. UTC support acknowledged (Virginia Tech)
6. Kumar, N. Mantovani, G., and Ahmadian, M., Virginia Tech-Federal Railroad Administration Roller Rig Measurement Capabilities and Efforts to Improve its Capabilities, Presentation at the University Transportation Center's 2024 PSR Annual Congress, Moving Forward: Improving Transportation in Region 9, Las Vegas, Nevada, March 12, 2024. UTC support acknowledged (Virginia Tech)
7. Morteza, S., Mirzaei, H., Radmehr, A. Holton, C., and Ahmadian, M., Leveraging Non-contact Doppler LiDAR Sensors and Unsupervised Algorithms for In-motion Assessment of Railroad Track Stability, Presentation at the University Transportation Center's 2024 PSR Annual Congress, Moving Forward: Improving Transportation in Region 9, Las Vegas, Nevada, March 12, 2024. UTC support acknowledged (Virginia Tech)
8. Ahmed, M. and Palese, J., Predicting Track Geometry Using Machine-Learning Methods, Presentations at Big Data in Railroad Maintenance Planning 2023, December 13-14, 2023, Newark Delaware. UTC support acknowledged (University of Delaware)
9. Mohammed, O. and Palese, J., Development of a 3D Track Quality Index Incorporating Machine Learning Techniques and a Multivariable Normal Distribution. Presentations at Big Data in Railroad Maintenance Planning 2023, December 13-14, 2023, Newark Delaware. UTC support acknowledged (University of Delaware)
10. Soufiane, K., The Effect of Adjacent Tie Condition on Wood Cross-tie Life, Presentations at Big Data in Railroad Maintenance Planning 2023, December 13-14, 2023, Newark Delaware. UTC support acknowledged (University of Delaware)
11. Palese, J., Using Long Short-Term-Memory Networks and Mixture Density Modeling to Predict and Classify Track Geometry. Presentation at Cyber and Digitalinformation in Railway Engineering and Operations, University of Maryland, College Park, MD, March 7-8, 2024. UTC support acknowledged (University of Delaware)
12. Soufiane, K., Zarembski, A.M., and Palese, J.W., Effect of Adjacent Poor Ties on the Life of Wood Crossties, The University Transportation Center's 2024 PSR Annual Congress, Moving

Forward: Improving Transportation in Region 9, Las Vegas, Nevada, March 12, 2024. UTC support acknowledged (University of Delaware)

13. Jia, J., Park, J.W., Zhu, M., Jiang, Y. and Teng, H., Acoustic Emission Technology Based Method Proposed for Real-time Rail Monitoring, The University Transportation Center's 2024 PSR Annual Congress, Moving Forward: Improving Transportation in Region 9, Las Vegas, Nevada, March 12, 2024. UTC support acknowledged (UNLV)
14. Qiu, L., Zhu, M., Jiang, Y., and Teng, H., Development of Multi-Rotor-UAV-based Rail Track Irregularity Monitoring and Measuring Platform with Image and LIDAR Sensors, The University Transportation Center's 2024 PSR Annual Congress, Moving Forward: Improving Transportation in Region 9, Las Vegas, Nevada, March 12, 2024. UTC support acknowledged (UNLV)
15. Zhu, M. and Jiang, Y., 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 University Transportation Center's 2024 PSR Annual Congress, Moving Forward: Improving Transportation in Region 9, Las Vegas, Nevada, March 11-12, 2024. UTC support acknowledged (UNLV)
16. Mohammadia, A., Wang, Z., and Teng, H., 3D Printing to Repair Worn Rail, The University Transportation Center's 2024 PSR Annual Congress, Moving Forward: Improving Transportation in Region 9, Las Vegas, Nevada, March 12, 2024. UTC support acknowledged (UNLV)
17. Mohammadia, A., Wang, Z., and Teng, H., Finite Element Analysis of Submerged Arc Welding Process for Surface Repair of Heavy Rails, accepted for presentation and publication by the 19th International Conference on Automated People Movers and Automated Transit Systems, Atlanta, June 2024. UTC support acknowledged (UNLV)

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 journal paper is currently being prepared based on the latest UTC sponsored research. 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 Journal of Infrastructure Systems, November 2023.

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. The other technology monitors the pantograph strip that receives electricity from overhead wires to high speed rail trains. This strip constantly touches the wire and wears out quickly. This monitoring technology can tell the extent the strip is worn out in real time, which provides information as to the time to replace the strip.

Inventions, patent applications, and/or licenses:

Virginia Tech's patent application for the energy harvesting tie is in the final process of being granted by the USPTO. 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. Virginia Tech and Norfolk Southern are field testing the VT's Energy Harvesting Tie (EHT) to collect revenue-track data toward ruggedizing the technology and making it suitable for commercial production.

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.

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

In this reporting period, we received 41 citations for the technical publications produced from our research projects, which far exceeds the target 3-5 semi-annually. Dr. Hualiang Teng was interviewed by Las Vegas Weekly about the Brightline West high speed rail project. This news media is consistent with our performance target.

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 tie failure and the effect of adjacent failed ties is being applied by a major railway supplier Loram Technologies in its application of tie testing and replacement forecasting on several US Class 1 railroads.

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

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

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

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

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

Impact on the adoption of new practices

Virginia Tech's 's revenue-service-track and test-track and field testing of the LiDAR system, the energy harvesting pre-production tie, and the Track Crawler Robot prototype have all contributed to increasing the confidence in the commercial success of these technologies, beyond the immediate research by the RailTEAM UTC. If successfully deployed, these technologies will have a significant impact on improving railroad engineering practices. For instance, the LiDAR system in VT-2 can be adopted for in-situ measurement of track gage widening onboard a locomotive or Hyrail truck. This would enable detecting and fixing sections of the track with low

lateral strength before they lead to costly derailments. Similarly, the commercialization of the energy harvester tie in VT-1 will enable a seamless and practical means of accessing power in places where such power is currently unavailable. This will be a critical and enabling technology for integrating sensors and smart devices on the track, which will have several significant advantages. The track Crawler Robot in VT-4 would yield means of train inspection that is currently only available through highly sophisticated and costly systems.

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

Impact on the body of scientific knowledge

The knowledge gained in VT-3 regarding the effect of contaminants on traction has had measurable improvements in the basic science of how a railroad wheel interacts with the rail. The scientific knowledge gained in this regard has been significant enough that leading peer-reviewed journals have accepted our publications. Some of the technologies we are working on have scientific and practical applications beyond rail transportation. For instance, LiDAR technology can assess roadway surface conditions. The Track Crawler Robot can also be used for under-train inspection by the Department of Homeland Security and the U.S. Army. The learnings from the energy harvesting tie in VT-1 are directly applicable to units that can be used for road and highway applications; for example, an “energy harvesting road bumps” for powering a mobile LED sign and gently alerting drivers to slow down in road construction zones.

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

Impact on the development of transportation workforce development

The RailTEAM projects 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. In February, 2024, UPRR gave a seminar at UNLV introducing their railroad company to the students. In April, 2024, the Regional Transportation Commission of Southern Nevada gave two seminars on their public transportation system where

light rail was considered. All these seminars draw a great audience who are interested in railroad engineering. In addition, a senior design team chose to work on a high speed rail project designing the passing sidings of the single-track high speed rail line from Las Vegas, NV to the Southern California. These students would be hired by the Brightline West potentially.

Impact performance measures

In this reporting period, we have three requests on our research projects, which exceeds our target one (1) annually. UPRR inquired the 3D printing project and expressed the willingness to work together on this technology. In this half year, we do not have results transferred to companies, adoption of new practices, or the initiation of new startups targeted at one per year, which is lower than our expectation one (1) annually.

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.