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 goal of this program is to conduct research, promote education, and facilitate technology-transfer activities to improve the sustainability and durability of the 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 the railroad system. The future need for faster transfer of goods and people also will necessitate high-speed rail transportation, as has occurred in all developed and developing countries around the world. High-speed rail will place far higher demands on maintaining and sustaining the rail infrastructure, which only can be accommodated through advanced technologies, such as those detailed within the goals and objectives of this DOT-UTC.

The first objective of the program focuses on four areas of research that are critical to railroad system operations and safety, i.e.:

- 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- and GPS-based systems. The University of Delaware focuses on asset management and performance management using big data (data analytics) techniques, and application of new material, analytic models and technologies. The University of Nevada Las Vegas 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 to engineering students; 2) establishing certificate programs suitable for the new generation of engineering students and young professionals who wish to become engaged in the rail industry; and 3) providing short courses suitable for practicing engineers who wish to further hone their skills. Thus, all three partnering universities are 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. Also, we will write and submit articles for journal publication.

Goal accomplishments

Continuing active research projects

Our consortium universities have continued 16 research projects in this reporting period, i.e., four at Virginia Tech, five at the University of Delaware, and seven at UNLV. Significant advances have been made in each project. The progress of the projects is described below.

VT-1: Methods for Qualitative and Quantitative Measurement of Top of Rail (ToR) Friction Modifiers in Revenue Service. The primary objective of this study is to continue the efforts to evaluate, design, and build highly accurate devices for the qualitative and quantitative measurement of Top of Rail (ToR) friction modifiers in revenue service. Two new generations of LiDAR-based measurement techniques were designed, and they have undergone extensive evaluation both in the lab and on revenue-service track. The 2021 effort has emphasized mainly the application of LiDAR measurement units at high speeds in the field. Due to the Pandemic, however, we have not been able to perform any field tests with our project partner, Norfolk Southern (NS). Thus, we have limited our activities to extending our laboratory testing of the units and analyzing the data to a greater extent than was done in the past, and these efforts are ongoing at the present time. We hope that the recent national vaccination program will allow the travel and in-person meeting restrictions to be rescinded and that we will be able to test the units in the field with NS before the end of the year. The results of this project also are being assisted by another one of our current projects, i.e., VT-4, which will be described later. VT-4 uses the state-of-the-art VT-FRA roller rig to assess the short-term and long-term effects of ToR on the wheel-rail contact mechanics and dynamics. This study has resulted in three papers that will be presented at the 2021 ASME Joint Rail Conference (JRC) on April 20 – 21, 2021. The virtual presentations will be made by the graduate students and research scientist assisting with the project.

VT-2: Energy Harvester Tie for Serving the Needs of the Railroad Industry to Access Electric Power in Remote Locations. The primary objective of this research is to design and develop a practical energy harvester tie (EHT) that can be used for setting up remote electric power stations to satisfy the needs of the railroad industry. The objectives of the project are intended to be met through the following four tasks: (1) Detailed Analysis of EHT prototype available at the Railway Technologies Laboratory, (2) Design and Fabrication of a Full-Size Energy Harvester Tie, (3) Development of an Energy Storage System and Integration of the Wireless Charging Platform, and (4) Field Evaluation of the Full-Size Energy Harvester Tie.

To date, we have almost finished Task 1, and Task 2 is underway. A ½-tie energy harvester prototype has been fabricated and tested in the laboratory. The test results have been promising, indicating that a reasonably large amount of energy (in the range of 5 – 10 Watts) could be harvested if the tie were to be installed in the field. Our earlier plans for field testing the ½-tie harvester have been modified due to the Pandemic. Since we could not test the ½-tie in the field, we have directed our efforts to Task 2 to develop a full-size tie, the design of which currently is underway. We have managed to resolve most of the field-implementation challenges, and the CAD drawings for various components are being prepared. The parts list for acquiring or fabricating various components is nearly complete. We also have secured two plastic ties from our industrial partner, Norfolk Southern. We are optimistic that the current restrictions associated with the Covid Pandemic will be lifted by the time we finish the fabrication and assembly of the tie in the September to October 2021 time frame and that we will be able to complete the field installation before the end of 2021, as originally planned. We, however, remain flexible and will adjust the workflow if needed to meet the challenge posed by Covid.

VT-3: Application of Doppler LiDAR Sensors for Assessing Track Gage Widening in Curves and Locations with High-lateral Forces. Gage widening due to the softness of the track foundation or misalignment in curves can cause derailments. The primary objective of this study is to evaluate the application of Doppler LiDAR sensors for *in situ* assessment of track gage widening in curves and locations with high lateral forces. The proposed method uses track measurements by two low-elevation, slightly-tilted LiDAR sensors nominally pointed at the rail gage face on each track. Recently, the system was tested on board a Hyrail truck on revenue service tracks, and the results of those tests are being analyzed. The findings currently are inconclusive. This is partly due to our inability to verify through field measurements any excessive track movements that appeared in the data. In addition, we are observing a large amount of high-frequency measurements that may be due to the movement of the truck body (to which the LiDAR system is attached) against the axle/rail through the suspension. We are evaluating various data processing approaches that could help remove the high-frequency content from the measured data. However, this is proving to be a difficult task. We also are installing the system onboard a track geometry car and will be performing the tests over far longer distances. The installation of the track geometry car also will have the benefit of reducing the effect of the vehicle dynamics on the measurements.

VT-4: Quantitative Evaluation of the Effect of Top of Rail Friction Modifiers on Reducing the Wear on the Wheels and Rails. The primary goal of this project is to provide a quantitative evaluation of the influence of various amounts of Top of Rail Friction Modifiers (TORFM) on the wear of the wheels and the rail. During this report period, we have conducted a large series of experiments using the Virginia Tech-FRA (VT-FRA) roller rig. The tests were aimed at studying the effect of various volumes of Top-of-Rail Friction Modifiers (TORFM) on the energy efficiency of a wheel rolling on the rail. The ToR quantity is varied from a very small amount to a very large amount. For the tested cases, we analyzed the longitudinal traction, which provides a measure of the rolling resistance of the wheel on the rail. Also, the tests are used to evaluate the amount of wear of the wheel and rail. Currently, we are attempting to relate the wear data with the amount of ToR applied to the rail. The preliminary results showed that a nonlinear relationship exists between wear and the amount of ToR. In other words, more ToR does not necessarily mean less wear, and, conversely, less ToR does not mean more wear. We are continuing our efforts to analyze the tests that have been done to date, and we are conducting other tests with different ToR conditions than the tests that have been conducted to date. We anticipate that the results of the tests will help identify the best ToR practices for improved safety, cost efficiency, reduced wheel and rail wear, and better maintenance practices.

UD-1: Development and Validation of a New Generation Rail Wear Model Using Emerging Big-Data Analytic Techniques. Work continues on Phase II of the rail wear model. Transverse rail profile data were collected for a 10-year period from annual inspections for approximately two miles of track. The data were organized, and longitudinal alignment algorithms were used. For a set of 10 profiles at a particular location on the track, the profiles were aligned/overlaid to develop wear values transversely across the rail head, as opposed to two locations as is done traditionally, i.e., wear is calculated from measurement to measurement as opposed to the original reference. Then, these data are used to develop two-dimensional wear rates. The next step is to predict the evolution of the profile based strictly on the past performance of the profile. This activity has been delayed due to the coronavirus.

UD-2: Load Transfer from Track to Bridge Structure on Curves. This activity has been concluded. The project began in September 2019, and it addressed the issue of the transfer of thermal longitudinal rail forces from the track to the structure of the bridge on curved track. The design of a railway bridge is significantly different from the design of a conventional highway bridge because of the additional loading imposed onto the bridge due to the track structure behavior under vehicle and thermal loading. This difference is enhanced further on curves, i.e., where the bridge is supporting a track that has a curvature. The focus of this research is on the effect of thermal forces on welded rail in the curves of bridge structures. The presence of a curve results in this force having both lateral and longitudinal components. Both theoretical models were developed based on fundamental research by Timoshenko and by A. D. Kerr as well as a finite element model, and, when the results were compared, there was excellent agreement. A UTC Report was submitted in January 2021, and a journal paper was accepted by the Journal of Rail and Rapid Transit in February 2021.

UD-3: Track Geometry Models Using "Small Data" Algorithm. This project is ongoing, and it addresses the use of "small data" algorithms for modeling the geometry of railway tracks. The quality of the track geometry is linked directly to the safety, reliability, and ride quality of the vehicles. Therefore, the performance of the track is affected considerably when the geometry of the track deviates from the specified limits due to load weight and continuous usage. The analysis of track geometry data can allow for the prompt application of preventive and corrective maintenance measures, such as tamping, to increase the lifespan of the track and provide higher train speeds, thereby optimizing the performance of the track. The first section of this research focused on the implementation of Approximate Bayesian Computation (ABC), also known as the likelihood-free method, to estimate the parameters of track degradation models for track maintenance. The second part of this research compares the ABC models to Bayesian nonparametric models (Gaussian Processes) to select the best track degradation model. An UTC Report was submitted in February 2020, and a paper entitled "Approximate Bayesian Computation for Railway Track Geometry Parameter Estimation" has been accepted for publication by the Journal of Rail and Rapid Transit.

UD-4: Effect of Adjacent Poor Ties on Wood Crosstie Life. This research activity studies the effect of adjacent tie conditions on the life of a railroad cross-tie. Using automated crosstie inspection taken from the same track in multiple years, the goal is to develop improved tie life models, taking into account local conditions. Using these different tie conditions and the corresponding different periods in the lifespan of a tie, the project focus on determining the average tie life, by mathematical modeling techniques, such as piecewise reconstruction. The aim of this activity is to provide a method to predict and model the lives of ties based on support conditions as defined by the condition of adjacent cross-ties. The analysis approach uses Dijkstra's algorithm, Markov Chain analyses, and tie condition data from two different inspections performed within a span of three years.

UD-5: Copula-Based Models in Safety Analysis. This activity has been completed. Assessing and maintaining track geometry within acceptable limits are key components of railroad infrastructure maintenance operations. Track geometry conditions have a significant influence on the comfort and safety of riders. To maintain the quality of the ride and the safety of the track, maintenance activities are performed that pertain to track geometry, such as tamping. Tamping enhances the quality of the track geometry, but it fails to return the track geometry to an "as-good-as-new" condition. The majority of studies have evaluated tamping recovery using deterministic techniques that assume that tamping recovery depends on the quality of the track geometry prior to tamping. However, those studies failed to capture the uncertainty of the recovery values. Probabilistic approaches are being used increasingly to account for the uncertainty, but they fail to model the underlying dependence between the variables, which may exhibit nonlinear dependences, such as tail or asymmetric dependences. To accurately model the tamping recovery phenomenon, in this research we used the copula models in combining arbitrary marginal distributions to form a joint multivariate distribution with the underlying dependence. Copula models are used to estimate the tamping recovery of track geometry parameters, such as surface (longitudinal level), alignment, cross level, gage, and warp. Several journal papers have been written based on this work, and an UTC report has been submitted.

UNLV-1: Mobile 3D Printing of Rail Track Surface for Rapid Repairmen. During this reporting period, we repaired a worn rail using a welding technique. The quality of the welding seems significantly improved. Currently, we are conducting various tests on the repaired rail. At the same time, we developed a new design of a device for testing rolling contact fatigue, and it will be submitted to the Transportation Technology Center, Inc. (TTCI) for review. During this time period, four papers were written and submitted to journals for publication.

UNLV-2: High-speed Rail Access Charge for the XpressWest of Nevada. In the last six months, the research team has focused on 1) developing a framework for the analysis of train operations, including the impact of incidents on the operations, and 2) determining access charges for a shared HSR system using VISSIM traffic simulation software based case projects, i.e., California High-Speed Rail (CHSR) and XpressWest. During this period, we analyzed the train operations and the impact of incidents on the Palmdale - Los Angeles shared HSR corridor. The analysis of train operations showed that the XpressWest can operate together with the planned operations of the CHSR on the shared corridor without causing any significant additional congestion. The access charge pricing for the operation and maintenance of the Palmdale - Burbank corridor was calculated based on the framework that was developed and the VISSIM simulation model of the shared corridor. Since there was new information and major changes in the XpressWest ownership and its operation parameters, the research team identified the need for further investigation and refinement of the total cost of access. By the end of the summer, the research team will recalculate the access charge based on the updated information and submit the final report for the access charge with all of the cost elements.

UNLV-3: Development of Acoustics Technology to Detect Transverse Defects in Rail at High Speed (220 mph). The team has set up the data collection system successfully, and it includes NI DAQ devices, three sets of acoustic sensors and pre-amplifiers, one tachometer, one high-speed camera, and one GPS module. The system can collect acoustic data at 1 MSPS (Mega Samples Per Second), which is sufficient for recording acoustic signals in the frequency range of 0 to ~500 kHz. The research team has conducted two complete track tests at the Nevada State Railway to verify the performance and stability of the system. The results indicated that the system could collect acoustic data and geo-information as required for next level testing at TTCI. The team is currently communicating with TTCI to outline the work plan for the field tests.

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 been working to identify a solution to address the difficult challenge of collecting and dealing with high-speed data in the range of gigabytes per second using an FPGA/SoC system. Since traditional FPGAs/SoCs are limited by the on-board clock rate, high-speed data transmission interfaces, and storage units, the team has been conducting research to identify feasible platforms/solutions for this application, possibly a completely customized circuit board design with specific high-speed computation and data storage circuits. Due to the COVID-19 Pandemic, the team has been working from home to keep the project on track.

UNLV-5: Non-Propriety Ultra-High-Performance Concrete (UHPC) for Ballast-Track High-speed Railroad Sleepers. During the first phase of this study, we evaluated more than 130 different non-proprietary, ultra-high performance concrete (UHPC) mixtures before arriving at the selected optimized concrete for the second phase of the study. The results of phase 1 of the study were submitted to three peer-reviewed journals, and all have been accepted for publication, two of which are now under print. The second phase of this study deals with the selected 1/2 scale UHPC sleepers, which we intend to test for static and dynamic flexural loading. We are trying to identify an outside manufacturing company that can cast prestressed UHPC sleepers for us. The Covid 19 situation has resulted in our being behind schedule. However, we are working diligently to make up for the lost time.

UNLV-6: Development of an UAV-Based Rail Track Irregularity Monitoring and Measuring Platform. The team has achieved full access to the raw point cloud data in the Cartesian coordinate system for multiple LiDAR sensors, including Ouster OS1-128 and Livox Horizon, and the team has completed the on-board data collection through the Raspberry Pi and LiDAR sensors on the UAV. The gathered point cloud data of each LiDAR are accessible directly, and they can be manipulated through MATLAB and Python, and the rail tracks from the background based on each point cloud frame can be visualized by human eyes. The team also has made strides in machine-learning based 3D point cloud semantic segmentations to extract/distinguish rails from the background. The team is conducting research on various deep learning network architectures and fine-tuning the algorithms in each layer to improve the segmentation performances (for example, weighted/unweighted accuracy, IoU, and recall). After the segmentation performance reaches a satisfactory level, the team will move to design programs to automatically identify the edges of the rail as reflected in the point clouds and consequently measure the geometries of the rails for the purpose of detecting and monitoring irregularities.

UNLV-7: Transit Degradation Monitoring and Failure Prediction of Carbon Strip in Pantograph. The weakest link in powering high-speed rail locomotives is the carbon strip of a pantograph collector that makes physical contact between the overhead power line and the electrical supply wires of the locomotive. The aim of this project is to determine the degradation effects of the carbon strip by monitoring the current in the input power line of the locomotive. During this reporting period, we performed a wide range of experimental studies for measuring the resistance of the carbon strip for various train loads and various carbon strip grooves. Initially, the experimental results were encouraging, but when the theoretical (with associated numerical study), experimental, and computer-aided electrical design (CAED) modeling results were compared, they were very different. However, the theoretical results and the results of CAED modeling were comparable. It took between two and three months to realize that the liquid coaxial resistor was unstable. The liquid resistor would alter its resistance by well over 10 ohms when driving high currents through the element. Train loads as low as 1 ohm and carbon strip loads as low as 3 mohms to 28 mohms are to be monitored. An unstable, unpredictable error of well over 10 ohms is not tractable for the resistance values of interest. We are working with vendors to identify suitable alternatives for our test stand resistance modeling of the train load. A final report is being written detailing all aspects of our efforts. An early prototype sensor and a new version were built and studied in the carbon degradation test stand. These will be submitted to the program manager when the final report is submitted. An EM dot base on microstrip/stripline technology also will be provided to the program manager. It is anticipated that our research efforts and final report will be completed before the end of the next quarter.

Initiating new research programs

Currently, no new research programs are planned at Virginia Tech. Two of our four projects, i.e., VT-2 and VT-4, were started this year, and it is anticipated that they will continue for 1-2 years beyond 2021. No new project was started in this reporting period at UNLV.

In this reporting period, the University of Delaware initiated two new research projects:

UD-8. Risk Modeling of Grade Crossing Accidents. Utilizing the national grade crossing inventory database and other readily available demographic data, a Bayesian Network will be developed to predict optimal crossing protection and accident/collision risk. Data will be assembled and distilled and an exploratory data analysis performed to identify critical variables in grade crossing accident risk. A literature search will be performed and an exposure metric will be used based on train and highway traffic density. This metric, along with other variables, will be used to develop a Bayesian Network that defines the protection level required for an individual crossing based on historic performance of similar crossings and predicts the probability of train/road vehicle collisions.

UD-9: Random Forest-Based Covariate Shift in Addressing Non-Stationarity of Railway Track Data. The multi-modal transportation network in which the freight rail has an essential role continues to enhance the United States' contributions in the global market. For years, track geometry defect data often were gathered by visual inspections. However, now, automated track vehicles are deployed for the same purpose to save time and reduce costs. One of the limitations of an automated vehicle is 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. In this study, the supervised Machine Learning (ML) methods were used to detect the non-stationarity of the geometry data. The methods included Random Forest (RF), Logistic Regression (LR), and Support Vector Machine (SVM). The researchers varied the train-test and validation ratio in phases to ascertain each Machine Learning methods' accuracy and 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 gave better results than the other supervised learners, with accuracies of 97% and 97.1%, respectively. Similarly, for validation, the Random Forest performed better than the other classifiers; its accuracy was 98%. Conclusively, the application of the models that were developed indicated that the Random Forest model was a more effective approach for detecting the non-stationarity of track geometry data.

Upgraded education opportunities

Virginia Tech plans to offer a distance learning graduate course entitled "Rail System Dynamics." This course potentially could be broadcast to the University of Delaware and UNLV. In addition, VT plans to offer a one-day professional development seminar on Fundamentals of Rail System Dynamics in the fourth quarter of 2021 assuming that the current Pandemic is under control. The plans will be confirmed and finalized in the second quarter.

At the University of Delaware, a new professional development course entitled "Rail Grinding and Rail Maintenance" was scheduled for delivery to Amtrak in March 2021, but it has been delayed due to the coronavirus. UNLV offered a "High Speed Rail" course in the Fall semester of 2020 and a "Railroad Engineering" course in the Spring semester of 2021, which is a way to prepare the workforce for the high speed rail project planned to connect Las Vegas, Nevada with Los Angeles, California.

Opportunities for training and professional development

Virginia Tech made final plans to offer a professional development seminar in 2022. Originally, this training was planned for 2020, but it was postponed due to the Covid Pandemic.

The University of Delaware's Professional Engineering Outreach provides professional courses for practicing railroad and transit professionals. These professional development courses include Application of Emerging Data Science Techniques for Railway Maintenance Planning, which was given in December 2019; Rail Grinding and Rail Maintenance, which was scheduled in March 2020; and Rail Industry Growth for Increased Long-Term Profitability, which was scheduled in October 2020.

The Big Data in Railroad Maintenance Conference is held in December each year at the University of Delaware, and it 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 usually has more than 200 attendees from railroads, transit systems, railway suppliers, data analytic companies, and academia. The 2020 conference was conducted in virtual format on December 16, 2020, and it had more than 270 registrants. The conference was implemented successfully in the virtual format, and there were attendees from North America, South America, and Europe.

Results disseminated

At Virginia Tech, the current Pandemic has created significant challenges in disseminating our results. The plans for attending conferences and meetings with industrial partners were canceled due to the Pandemic shut down. As mentioned earlier, the coronavirus also has affected our initiative to organize a symposium and workshop in 2021. Currently, we are evaluating the best path forward for 2022. We presented the results of our projects at the ASME Joint Rail Conference in April 2021. Multiple papers from our research were scheduled for publication and were presented at the conference. In addition, we have had Zoom meetings on our test programs and the test results with some of our partners, such as Norfolk Southern, and with government agencies, such as FRA.

The University of Delaware conducted two major activities to disseminate results to industry and academia. The annual "Big Data" in Railroad Maintenance Planning was held on December 16, 2020 in a virtual format, and it was a highly successful with more than 270 international professionals from companies, universities, and government agencies attending the one-day event. The results of the RailTEAM project were presented by speakers from the University of Delaware and Virginia Tech. The next conference is scheduled for December 15-16, 2021 in live format. The 2020 conference featured UTC-related presentations by Mehdi Ahmadian of Virginia Tech and Nii-Attoh-Okine and Allan Zarembski of 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 recent UD Railway Advisory Board meeting in December 2020, the results of the UTC project were presented from the Adjacent Tie Condition Project, and there also was a presentation of the Small Data project.

At UNLV, the research results were published in journals and presented at conferences during this reporting period.

Plan for the next reporting period

At Virginia Tech, we intend to continue our current four projects for the remainder of 2021 in order to achieve the objectives of each program.

At the University of Delaware, we plan to continue research activities with our graduate students and research scientists. We estimate that we will publish two or three journal papers and make two to four presentations. UNLV will continue with seven research projects, some of which will be completed in the next reporting period. At least four research papers are under review or in preparation and may be published soon. A new research project will be started in the next reporting period.

2. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

Organizations involved as partners

Virginia Tech maintains some level of collaboration with Norfolk Southern (NS) and Amtrak, although both have been affected by the Pandemic. During this reporting period, we have forged a new relationship with the Transportation Technology Center, Inc. (TTCI), the R&D arm of the Association of American Railroads (AAR) that consist of Class I railroads. This relationship has resulted in $98,834 of matching funds. The information related to these matching funds is:

- Organization Name: Association of American Railroads (AAR)
- Location of Organization: Pueblo, Colorado
- Partner's contribution to the project (identify one or more): Financial Support for $98,834

At the University of Delaware, Phase II of the rail wear project will have data and technical support from Amtrak's Engineering Department (Philadelphia, PA) as well as ongoing support and data from CSX Transportation in Jacksonville, FL.

Nevada Southern Railroad, Inc. (NSRI) has provided equipment, space, and staff for conducting research supported by the UTC program. For the project developing acoustic sensor detecting rail internal defects, the NSRI allocated a segment of rail track that was renovated with rails of certain defects. They also dedicated a rail vehicle on which the developed sensor can be installed. Their staff assisted in renovating the track, e.g., cutting the rail and reinstalling the track. They also trained our students to operate the rail vehicle. NSRI provided space for storing rails for the research projects. Their staff assisted our students with getting rail samples for our 3D printing project. They allowed our students to fly a drone over their tracks, which enabled us to test our system for measuring irregularities in the track.

It is important to mention that UNLV received a $30,000 endowment for railroad-related education and research. The interest generated from this endowment will be used as a scholarship to support a student every year to receive education and conduct research on railroads, particularly high speed rail.

Other collaborators or contacts involved

None to report during this period.

3. OUTPUTS

Output performance measures

Our outputs in this half year are above the targets in most of the measures we set for our center. Fourteen peer-reviewed publications were produced, i.e., considerably more than the target of 3 - 4 publications, and one invention disclosure was filed, which was more than the target of 0.5 - 1, and there were no patent applications, which was lower than the 0.5 target.

Publications, conference papers, and presentations

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

Publications

1. Yu, P., Radmehr, A., Tajaddini, A., and Ahmadian, M., An Experimental Study of the Influence of the Amount of Top-of-Rail Friction Modifiers on Traction, Proceedings of the 2021 Joint Rail Conference, St. Louis, Mo, April 20 – 21, 2021. UTC support acknowledged. (Virginia Tech)
2. Yu, P., Mast, T., Holton, C., and Ahmadian, M., Performance Evaluation of a Novel Optical Sensing System for Detecting Rail Lubricity Conditions," Proceedings of the 2021 Joint Rail Conference, St. Louis, Mo, April 20 – 21, 2021. UTC support acknowledged. (Virginia Tech)
3. Yu, P., Mast, T., Holton, C., and Ahmadian, M., Intermediate Distance Testing of Optical Tor Lubricity Sensors on a Remote-controlled Rail Cart, Proceedings of the 2021 Joint Rail Conference, St. Louis, Mo, April 20 – 21, 2021. UTC support acknowledged. (Virginia Tech)
4. Hosseini, S-M, Hosseinian Ahangarnejad, A., Radmehr, A., Tajaddini, A., and Ahmadian, M., A Statistical Approach to Evaluating Wheel-Rail Contact Dynamics, Proceedings of the 2021 Joint Rail Conference, St. Louis, Mo, April 20 – 21, 2021. UTC support acknowledged. (Virginia Tech)
5. Alsahli, A., Zarembski, A.M., and Attoh-Okine, N., Predicting Track Geometry Defect Probability Based on Tie Conditions Using Pattern Recognition Techniques, Proceedings of the ASME International Mechanical Engineering Congress and Exposition (IMECE2020), Portland, OR, November 2020. UTC support acknowledged. (University of Delaware)
6. Musazay, J., Zarembski, A. M. and Palese, J. W., Determining Track-Induced Lateral Thermal Expansion Forces on a Curved Railway Track, Proceedings of IMechE Part F: Journal of Rail and Rapid Transit, February 2021. DOI 10.1177/0954409721995318. UTC support acknowledged. (University of Delaware).
7. Ashley, G., and Attoh-Okine, N., Approximate Bayesian computation for railway track geometry parameter estimation, Journal of Rail and Rapid Transit, November 2020. DOI 10.1177/09544097209777726. UTC support acknowledged. (University of Delaware).

8. Hasnat, A. & Ghafoori, N. (2021). Abrasion Resistance of Ultra-High Performance Concrete for Railway Sleepers. Journal of Urban Rail Transit. Springer, DOI: 10.1007/s40864-021-00145-8. UTC support acknowledged. (University of Nevada Las Vegas)
9. Hasnat, A. & Ghafoori, N. (2021). Freeze-Thaw Resistance of Non-Proprietary Ultra-High Performance Concrete. Journal of Cold Regions Engineering. ASCE, DOI: 10.1061/(ASCE)CR.1943-5495.0000255. UTC support acknowledged. (University of Nevada Las Vegas)
10. Hasnat, A. & Ghafoori, N. (2021). Properties of Ultra-High Performance Concrete using Traditional Aggregates. Construction and Building Materials, Elsevier (under Revision) UTC support acknowledged. (University of Nevada Las Vegas)
11. Mortazavian, E., Wang, Z., Teng, H., Finite Element Investigation of Thermal-kinetic-mechanical Evolutions during Laser Powder Deposition as an Innovative Technique for Rail Repair", under review in Journal of Manufacturing Processes, Manuscript no. SMEJMP-D-20-02177. (Initial submission date: Oct 21, 2020) UTC support acknowledged. (University of Nevada Las Vegas)
12. Mortazavian, E., Wang, Z., Teng, H., Effect of Heat Treatment on Microstructure and Hardness of a Worn Rail Repaired using Laser Powder Deposition, revised version under review in International Journal of Transportation Science and Technology, Manuscript no. IJTST-D-20-00223R1. (revised submission date: Apr 03, 2021) UTC support acknowledged. (University of Nevada Las Vegas)
13. Mortazavian, E., Wang, Z., Teng, H., Finite Element Investigation of Residual Stresses during Laser Powder Deposition Process as an Innovative Technique to Repair Worn Rails, submitted to International Journal of Transportation Science and Technology. (Initial submission date: Apr 18, 2021) UTC support acknowledged. (University of Nevada Las Vegas)
14. Mortazavian, E., Wang, Z., Teng, H., Measurement of Residual Stresses in Laser 3D Printed Train Rail using X-Ray Diffraction Technique, to be submitted to Proceedings of the ASME 2021 International Mechanical Engineering Congress & Exposition, Manuscript no. IMECE2021-69822. (Abstract accepted on Mar 17, 2021) UTC support acknowledged. (University of Nevada Las Vegas)

Other publications, conference papers and Presentations

1. Yu, P., Radmehr, A., Tajaddini, A., and Ahmadian, M., An Experimental Study of the Influence of the Amount of Top-of-Rail Friction Modifiers on Traction, 2021 Joint Rail Conference, St. Louis, Mo, April 20 – 21, 2021. UTC support acknowledged.（Virginia Tech)
2. Yu, P., Mast, T., Holton, C., and Ahmadian, M., Performance Evaluation of a Novel Optical Sensing System for Detecting Rail Lubricity Conditions, the 2021 Joint Rail Conference, St. Louis, Mo, April 20 – 21, 2021. UTC support acknowledged.（Virginia Tech)
3. Yu, P., Mast, T., Holton, C., and Ahmadian, M., Intermediate Distance Testing of Optical Tor Lubricity Sensors on a Remote-controlled Rail Cart, 2021 Joint Rail Conference, St. Louis, Mo, April 20 – 21, 2021. UTC support acknowledged.（Virginia Tech)
4. Hosseini, S-M, Hosseinian Ahangarnejad, A., Radmehr, A., Tajaddini, A., and Ahmadian, M., A Statistical Approach to Evaluating Wheel-Rail Contact Dynamics, 2021 Joint Rail Conference, St. Louis, Mo, April 20 – 21, 2021. UTC support acknowledged.（Virginia Tech)

5. Attoh-Okine, N., Shortcomings of Current Machine Learning Techniques in Railway Track Engineering, Big Data in Railroad Maintenance, virtual conference, December 2020. UTC support acknowledged. (University of Delaware)
6. Zarembski, A. M., Palese, J., Soufiane, K., and Grissom, G., How Do Failed Adjacent Ties Effect the Life of Wood Cross-ties, Railway Track and Structures, April 2021. UTC support acknowledged. (University of Delaware)
7. Zarembski, A. M., Using Data Science to Better Understand and Maintain Rolling Stock Performance, Railway Age, February 2021. UTC support acknowledged. (University of Delaware)
8. Zarembski, A. M., Using Data Science to Better Understand and Maintain Right of Way Performance, Railway Age, March 2021. UTC support acknowledged. (University of Delaware)

Policy Papers

None to report

Website

Virginia Tech has developed a new and improved website for publicizing its domain. Many of the DOT-UTC initiatives have been included at the Center for Vehicle Systems and Safety's new web site (http://www.cvess.me.vt.edu), The railway Technologies Laboratory (RTL) website (http://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/).

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

Our efforts at Virginia Tech have resulted in significant advances in the application of LiDAR technology for railroad applications. The advances made in the LiDAR technology have not raised the industry's awareness but also have made them more comfortable with adopting LiDAR systems for their maintenance of way practices.

The University of Delaware developed noteworthy maintenance models. One is the method/model for predicting wear life of railway rails that was presented at the Big Data in Railway Maintenance 2019 Conference, December 2019. This is being updated and will be published soon. A second model is new track quality index for maintenance planning, included in a paper presented at the IEEE Big Data 2019 Conference, Los Angeles, CA. A third model is for determination of lateral thermal forces on curves, which was published in the Journal of Rail and Rapid Transit in February 2021.

UNLV is the first institution to find that Vissim is a simulation software that can be used to simulate train movement over a high-speed rail network. The high-speed rail simulation model developed at UNLV provides an alternative to existing simulation models in the railroad industry that are either too expensive to use or over-simplify railroad operations.

Inventions, patent applications, and/or licenses:

An invention disclosure has been filed with the Virginia Tech Intellectual Property (VTIP), the Virginia Tech organization for IP: Railroad Energy-Harvesting Tie for Powering and Charging Railway Applications, VTIP 21-066, Date of Disclosure, December 15, 2020.

4. OUTCOMES

Passage of new policies, regulation, rulemaking, or legislation

The University of Delaware has delivered wear degradation and vehicle performance results to NYCT to help them modify and upgrade maintenance standards and policies. The University of Delaware is working with Amtrak to develop new tools for improved rail maintenance management.

Increases in the body of knowledge

The body of knowledge related to the application of LiDAR sensors for railroad/transportation applications (VT-1 and VT-2) has increased through our efforts at Virginia Tech. Our study has scientifically highlighted capabilities and limitations of the LiDAR technology for precise, non-contacting measurement of maintenance of the way health, beyond the conventional methods used by the railroads for decades. The technologies that we are engaged in are truly ushering in a new era of assessing the condition of the railway! They promise to proactively improve track condition in a cost-effective manner. They promise to provide the means for both diagnostics and prognostics of the maintenance of railways.

The research at the University of Delaware deals with new generation data analytic tools to increase the amount of railroad inspection and operations data and development of new relationships between performance, component degradation, and safety. Current research activities already address this in the following areas: wear of railway wheels, wear of railway rails, railway rail fatigue, track geometry degradation, and derailment forecasting.

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

Early results from the VT-1 and VT-2 projects indicate the possibly of strong advances in improving the rail lubrication practices, to better manage the rolling resistance of the wheel on the rail. Such an improvement promises to bring hundreds of millions of dollars in cost savings in the form of increased fuel efficiency and reduced wheel and rail wear.

Research by the University of Delaware provides new analytical tools to address key rail transportation issues. These include degradation/failure mechanisms for both track and vehicle components, specifically wheels, rails, track geometry, and CWR on bridges, which represent critical cost, maintenance, and safety areas.

Enlargement of the pool of trained transportation professionals

Close collaboration between Virginia Tech, NS, Amtrak, and the Association of American Railroads has led to further training for their engineers who are involved with projects related to LiDAR sensors and data processing. The Nevada Southern Railroad staff, assisting with the UNLV testing acoustic rail defect sensor, has a better understanding of how the rail is inspected manually by using different technologies. The railroad program at the University of Delaware trains working professionals who get UD's Graduate Certificate in Railroad Engineering, which includes professionals from Amtrak, SEPTA, the U.S. Navy, and numerous consulting groups and international railways.

A proposal to Brightline West, a high speed rail company, to build high speed rail from Las Vegas to Southern California, has been written to provide training and education to future employees at Brightline West. The proposed Brightline West will start operation in three years after its construction this year. It is needed from the time now to recruit employees to work for the high speed rail.

Adoption of new technologies, techniques or practices

The University of Delaware's rail wear forecasting methodology is shared with Amtrak, which currently is working with UD to apply this 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 rate of wheel wear as well as 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, we have 36 citations, considerably more than the target of 3-5 citations. Five news coverages were reported for our center during this half year, which is more than the target of 1-1.5.

5. IMPACTS

Impact on the effectiveness of the transportation system

In general, much of the research conducted under this UTC activity has resulted in a safer and more reliable railway infrastructure. As accidents in the railway industry draw public attention, improvements in approaches to safety may have a direct impact on society's perception of safety using new and emerging technologies. The impact of technologies under development at the RailTEAM UTC are related directly to improving track-maintenance practices. U.S. railroads collectively spend billions of dollars in track maintenance. Even small improvements in maintenance of way practices would have a major positive financial impact for the railroads. The technologies in which we are engaged at Virginia Tech (LiDAR, energy harvesting, and others) promise to bring about significant cost savings and improved safety to the railroads. The cost savings are because of improved fuel efficiency due to better understanding and management of the friction between rail and wheel. Better management of friction also will provide reduced wheel/rail wear, which results in additional cost savings and improved safety in the form of reduced wheel/rail failures.

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 is providing guidance on practical application of the methodology, as well as data limitations. As this model gets 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.

Also, 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 either perform maintenance to extend life (e.g., wheel truing) or replace. This information is being examined by NYCT to determine how it can be incorporated in the Company's maintenance and safety programs.

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

Also, a model has been developed for the determination of lateral thermal forces on curves, to include curves on bridges which allow for the accurate prediction of these forces that can affect the load on bridge structures due to constrained thermal expansion in continuously welded rail. This was recently published in the Journal of Rail and Rapid Transit (February 2021).

The 3D printing technique applied to repair worn rail would significantly improve railroad productivity, saving on maintenance costs for railroad operation. The UAV technology, being tested at UNLV, would allow more convenient railroad track inspection and save time in maintaining tracks. In addition, the technology would allow more tracks to be inspected. The Non-Propriety Ultra-High-Performance Concrete, which is not expensive, was tested in our lab and is exceptionally durable to make railroad ties. This inexpensive concrete can reduce significant construction costs for installing new ties and operation cost in replacing ties.

Impact on the adoption of new practices

Projects at Virginia Tech have not reached a point at which the technologies are ready for commercialization. The closest is the LiDAR technology that is being developed in VT-1 and VT-2. This technology could have a significant impact on improving safety and operational efficiency for the rail industry. For instance, the ability to measure the existence or lack of rail lubricant will enable railroad systems to better manage wheel-rail friction at the running surface, thereby reducing the cost for fuel due to rolling resistance at the wheel and also reduce wheel/track wear (and even damage) due to unnecessarily high friction. An additional impact of the technology is its ability to provide in-situ measurement of track gauge onboard a locomotive or Hy-rail vehicle. Gage widening under high-lateral loads often is the cause of derailment on curves. This technology will enable the railroads to detect and fix “soft” spots on the track before they lead to a costly derailment. Again, this will have significant operational safety and cost impacts.

The 3D printing technique applied to repair worn rail and the acoustic rail defect sensor are two products identified by the UNLV commercialization office to have high commercial value. If the 3D printing technique is applied successfully, rail maintenance practice techniques would change significantly. The acoustic sensor can detect internal defects in rail, the biggest threat to railroad safety. Our sensor allows the inspection at speeds up to 220 mph, making track inspection more efficient.

Impact on the body of scientific knowledge

Virginia Tech is developing a LiDAR system that promises significant highway applications for assessing roadway surface conditions, thereby paving the way for a critical technology that is necessary for semi-autonomous and autonomous vehicles. LiDAR system technology could potentially impact the transportation industry by improving driving safety. For instance, the same technology we use for lubricity detection potentially can assess road surface conditions by detecting black ice and other events not readily discernable by drivers. The FLIR cameras being evaluated as part of VT-2 also can detect the presence of trespassers at railroad crossings, beyond what is possible with surveillance cameras installed at some locations. Whereas optical cameras need light to see, FLIR cameras can detect the presence of a warm object, such as a trespasser under all conditions, day or night. In addition, Virginia Tech's efforts with energy harvesting technology have the potential to be expanded into other areas of transportation, such as roadways for powering LED traffic signs in remote places where there is not easy access to electrical power.

The University of Delaware has developed approaches and methodologies for the maintenance of the railroad infrastructure that are readily adaptable in the area of highway pavement and airport runway research and analysis.

Impact on the development of transportation workforce development

At Virginia Tech, we are continuing our efforts to educate undergraduate and graduate students for the rail industry. In the past six months, one of our graduate students was employed by Wabtec, the world's largest diesel electric locomotive manufacturer. Another one of our graduates currently is seeking employment as a data analyst. One of the recent PhD graduates is working as a research scientist at Virginia Tech with the intention of joining either the rail industry or becoming a rail educator at a U.S. university.

Impacts on the rail industry consist of more informed and educated engineers and scientists who can transmit their knowledge to employers. Another impact is in terms of technology transfer to the industry. Graduates are the conduit for transferring learned technologies, developed in the lab, to their employers. At the University of Delaware, opportunities for research range from data sciences application to railway degradation analysis and maintenance planning (State of Good Repair). Both undergraduate and graduate students are going into this area under the UTC program. Students are provided with specialized skill sets, such as data analytics as applied to infrastructure conditions.

The UTC program at UNLV continues to provide railroad education by offering courses and holding seminars. The high speed rail project connecting Las Vegas to Los Angeles, California, is planned for construction in 2021. A workforce is highly needed to plan, design, and construct high speed rail. UNLV continues to provide railroad courses and to offer senior design projects related to railroad and high speed rail.

Impact performance measures

During this half year, we had 4 cases in which stakeholders requested RailTEAM expertise in the application of research products, and this exceeded our target of 0.5. In addition, we have one case in which our research results were transferred to companies, and this exceeded our 0.5 target. At UNLV, a company in California inquired about the ultra-high performance concrete tie project that is being conducted for collaboration. It is our hope that a joint research project will be conducted for testing the developed ties at UNLV. Another inquiry was from a company in Mexico on testing the properties of concrete tie, which was related to our concrete tie project. The third inquiry was made by a transit company in Brazil, and the inquiry concerned the application of 3D printing technology in repairing worn rail. In this inquiry, interest was expressed in using 3D printing technology to repair a light rail system if our research is successful.

6. CHANGES/PROBLEMS

No changes in approach.

Actual and anticipated problems or delays

At Virginia Tech, COVID-19 significantly has disrupted our research, education, and information dissemination activities. The RailTEAM Railroad Infrastructure Symposium originally scheduled for 2021 has been postponed until 2022. Funding from our partnering railroad industry may not occur. The purchase of some hardware was delayed by several months, which is expected to delay some of the future deliverables for the program. Some lab work cannot be conducted due to the restrictions of the Pandemic. At the University of Delaware, the December 2020 Big Data in Railroad Maintenance Conference was switched from its normal in-person format to a virtual format. At UNLV, the progress of several research projects has been delayed due to COVID-19 due to the late delivery of devices and parts needed for product development at UNLV. Some international students from France cannot come to UNLV for a concrete tie project, which may influence the progress of the project significantly.

No changes have had any significant impact on expenditures. There have been no significant changes in the use or care of human subjects, vertebrate animals, and/or biohazards. In addition, there has been no change in the primary performance site location from what was proposed originally.

7. SPECIAL REPORTING REQUIREMENTS

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