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

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4/30/2022

Grant Period: 11/30/16 to 9/30/2022, Reporting Period: 10/1/21 to 3/31/22
Grant: 69A3551747132, Duns: 098377336, EIN: 88-6000024

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 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 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, 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-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 become engaged in the rail industry; and 3) providing short courses suitable for practicing engineers who wish to hone their skills further. 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. This project is developing a practical energy harvester tie (EHT) that can be used to provide trackside power in places where electricity is not readily available, which is most of the U.S. rail network in remote location. The availability of power will enable the adaptation of sensors and electronics that are essential for *in situ* monitoring of the track condition. It also enables integrating intelligence into the track concerning maintenance diagnostics and possibly prognostics. We have made excellent progress toward the critical tasks of this project. We have completed the detailed analysis of the prototype EHT that is available at the Railway Technologies Laboratory, as well as the design and fabricate of a full-sized energy harvester tie. The tie has been tested in the lab using a stationary means to test the system functionality. The system functionality has also been tested using a specially-designed platform and a pickup truck that can roll over the EHT to emulate a rolling railroad wheel on a track. We are currently awaiting receiving commitment from Norfolk Southern in order to potentially install and test the energy harvester on a revenue service track for field testing. We expect to complete the field installation and testing, as well as the data analysis of the field tests by the end of 2022.

VT-2: Application of Doppler LiDAR Sensors for Assessing Track Gage Widening in Curves and Locations with High-lateral Forces. This study, which will mark Year 3 under the DOT-UTC funding, is continuing the work that was done in the past at the Railway Technologies Laboratory for in situ assessment of weak (soft) tracks potentially causing gage widening and possibly derailment. Funding from the Association of American Railroads (AAR) contributes to this study, as was the case in 2022. The approach adopted for this project includes using four LIDAR measurement units that measure track lateral and vertical movement under the weight of a passing wheel. The LIDAR system and associated data acquisition unit are mounted onboard a moving railcar (preferably a track geometry measurement car) and collect in-situ measurement of the rail movement. The analysis of the LIDAR data provides an assessment of any excessive track movement that could be an early indication of a soft track.

We are continuing our data analysis for 2022. The lessons learned from the earlier analysis of the data is being used to improve the machine learning approach that has been adopted to identify the rear occasions of soft track in revenue service. The emphasis for this year's work is being place on the "learning" aspect of machine learning. We are exploring better means of processing the data such that the machine learning algorithms can provide more reliable and accurate information. Also, a larger portion of the extensive data that we have collected in 2022 on more than 3000 miles of revenue service track is being used for improving the learning process of the data. This project remains on schedule and we expect the remaining tasks to be completed by the end of the project in 2023.

VT-3: High-precision Evaluation of the Effect of 3rd Body Layers on Rail, Including Top of Rail Friction Modifiers. This project uses the high-precision Virginia Tech-Federal Railroad Administration (VT-FRA) roller rig at the Railway Technologies Laboratory (RTL). We are continuing our earlier studies on the effect of Top-of-Rail Friction Modifiers (TORFM) on the wheel-rail longitudinal and lateral traction. We have expanded the application of 3rd-body layers beyond TORFM to include materials such as water, oil, and grease. Oil, grease, and similar agents are contaminants that can accumulate on the rail. Similarly, water and other natural substances are present in the environment and can be present on the rail. Irrespective of how these elements amass on to the top of the rail, they significantly affect the necessary wheel-rail traction to move or stop a train.

The results obtained thus far indicate that all of the agents that we have tested (i.e., water, oil, and grease) significantly reduce the wheel-rail traction. For water, the reduction in traction is eliminated and the rail returns to dry friction as soon as the application of water is stopped and the rail reruns to its dry condition. For oil and grease, however, the effects differ drastically. Even a small amount of oil or grease causes a long-lasting traction reduction, even when no new material is added. Additionally, they reduce traction more than water even in their early presence. Of course, such a reduction can be detrimental to a train's ability to deliver motive power to move forward or apply braking power to stop.

VT-4: Automated Inspection of out-of-sight Under-train Equipment. This project aim to develop a remotely-controlled Track Crawler Robot (TCR) to fit in between the rails and travel the length of a standing train without any interference. The TCR will be fitted with cameras, thermal imaging systems, and other such sensors to record the conditions of the components in out-of-sight locations, which are not readily visible to the train inspector during walk-along inspections.

We have designed the TCR to have a robust structure that can sustain the rigor of the railroad environment. It includes two tank tracks that allow it to crawl over a rail and move along the length of the train (when it is stopped in a railyard and siding) on the ties and ballast. The profile of the TCR is such that it easily fits in between the tracks and become low enough to crawl under a train without any interference.

Beyond the design of the TCR, we have been working on the installation of cameras and imaging systems that can sustain the high-vibration environment and easily fit in the limited onboard space. This aspect of our research is ongoing, and we plan to provide additional updates in the next semiannual report.

UD-1: Development and Validation of a New Generation Rail Wear Model Using Emerging Big-Data Analytic Techniques. This project is ongoing and work continues on Phase II of the rail wear model. Amtrak has restated their interest in this rail wear model and will be providing additional data for the analysis activity. This includes transverse rail profile data that were collected for a more than 10-year period from annual inspections for approximately two miles of track. The data were used to develop two-dimensional wear rates, and we are now working on predicting the evolution of the profile based strictly on its past performance, after a delay due to the coronavirus (during which Amtrak was not able to provide data support). Work is now progressing on the prediction of the transverse rail profile, based on historic changes in the transverse profile using the 2DARIMA modeling approach developed previously under this activity. This approach treats the transverse Cartesian data as time series with adjoining weighting functions that constrain adjacent growth. Data is now being used to train an AI based analysis model.

UD-2: Load Transfer from Track to Bridge Structure on Curves. This activity has been concluded, and a paper was published in February 2021 in The Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit. The project began in September 2019, and it addresses the issue of the transfer of thermal longitudinal rail forces from the track to the structure of the bridge on a curved track. The design of a railway bridge is significantly different from the design of a conventional highway bridge because of the additional loading on the bridge due to the behavior of the track structure under vehicle and thermal loading. This difference is enhanced on curves, i.e., where the bridge supports a track that has a curvature. This research focuses 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 S. Timoshenko and by A. D. Kerr as well as a finite element model, and, there was excellent agreement when the results were compared. An UTC Report was submitted in January 2021, and a journal paper was published in 2021 by the Journal of Rail and Rapid Transit.

UD-3: Track Geometry Models Using the "Small Data" Algorithm. This project has been concluded, and a paper is scheduled to be presented at the annual meeting of the Transportation Research Board in 2022. The activity addressed the use of "small data" algorithms to model the geometry of railway tracks. The quality of the track geometry is correlated directly to the safety, reliability, and ride quality of the vehicles. Therefore, the performance of the track is affected considerably when its geometry deviates from the specified limits due to the weight of the loads it carries and continuous usage. The analysis of track geometry data allows for the prompt application of preventive and corrective maintenance measures, such as tamping, to increase the lifespan of the track and provide higher speeds for trains, thereby optimizing the performance of the track. The first section of this research focuses 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 non-parametric models (Gaussian Processes) to select the best model of track degradation. 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 the Life of Wood Crossties. This research activity is ongoing, and one paper was published in the May 2021 edition of the Journal of Transportation Infrastructure Geotechnology as well as an article on the research published in Railway Track & Structures in October 2021. A presentation was also made at the Big Data in Railroad Maintenance Planning conference of December 2021. This activity continues in order to study the effect of adjacent tie conditions on the life of a railroad cross-tie using automated crosstie inspection taken from the same track over multiple years. This approach takes into account the dynamic changing of the conditions of adjacent ties to more accurately predict the life of the rail and develop improved models of the life of ties. The project currently focuses on the interaction of the degradation rates over time, as well as the iterative process that can be described as how the change of the support condition impacts the middle tie and the adjacent ties. The development of a closed-form expression that describes the deterioration behavior of wood ties as a function of the degradation rates of adjacent ties is underway. Then, a data science approach will be used to develop the relationships identified in the closed form solution, to include the relationship between tie condition and load distribution, and the corresponding relationship between load distribution and degradation rate. Additional tie condition data has been obtained to now include data from approximately 100,000 crossties over the five-year period from 2016 to 2021. This activity aims to provide a method to predict and model the lives of ties based on dynamically changing support conditions as defined by the changing condition of adjacent cross-ties.

UD-5: <u>Risk Modeling of Grade Crossing Accidents</u>. 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: <u>Random Forest-Based Covariate Shift in Addressing Non-Stationarity of Railway Track Data</u>. 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, the supervised Machine Learning (ML) methods were used to detect the non-stationarity of the geometric data. 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 accuracies of 97% and 97.1%, respectively. Similarly, for validation, the Random Forest performed better than the other classifiers with 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.

UNLV-1: Mobile 3D Printing of Rail Track Surface for Rapid Repairment. In this reporting period, a segment of worn rail was welded and tests on the repaired rail have been conducted. At the same time, the rolling contact fatigue tester has been under construction, which is near completion. A journal and a conference paper were published and two presentations were given at different conference and seminar.

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

UNLV-3: Development of Acoustics Technology to Detect Transverse Defects in Rail at High-speed (220 mph). After field data collection at TTCI in July, 2021, the team worked on dataset preparation for defect classification. Accordingly, the team finished labeling the data collected from the HTL test (among the data sets from three tracks, RDTF, HTL, and RTT). For classification analysis, the team used a machine-learning (ML) approach to the labeled HTL data. Due to low accuracy from considerable noise in the dataset, the team is taking a progressive plan by including datasets that are relatively revealing and excluding datasets that could introduce confusion in ML classifications. This investigation was conducted with parameters studies (e.g., the cut-off frequency of the high-pass filters, data proportions, and ML parameter tunings) and led to accuracies ranging from 70% to 84% on the selected datasets for initial investigation. For further investigation for improvement and inclusion of more complex datasets, the team is investigating the relationships among defect types, defect locations, sensor installation location, and classification accuracy. The team is also studying the differences between defect types (e.g., shell and transverse) and ambient noises by analyzing data.

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 acquired a new signal acquisition device (Tektronix RSA 306) and a subsequent data collection and processing platform (Intel NUC). The team is studying the Tektronix API and has gathered raw signal data from the RSA 306 and saved it on a local machine. Since the API is compiled based on the x86_64 ISA and due to the significant data throughput requirement, an ARM-based system may not be compatible, and a high-end intel mini-PC platform with USB 3.0 and PCI-E data bus is acquired for the entire data acquisition and processing (DAQP) system. Due to the limitation of the scanning bandwidth (i.e., 40Mhz) for RSA 306, the team is now configuring the program with Tektronix API to enable the system to periodically scan the spectrum for signal acquisition. The team will be looking for the testing equipment or on-site test to validate the DAQP system in signal collection. Data analysis algorithms will be performed and studied at the same time.

UNLV-5: Non-Propriety Ultra-High-Performance Concrete (UHPC) for Ballast-Track High-speed Railroad Sleepers. For the second phase of this project, we have identified a number of UHPCs from Phase 1 as the potential for the selected mixture of Phase 2. We conducted short, medium, and accelerated long-term engineering properties for the selected mixture. We have prepared sufficient raw materials through the required gradation of the UHPC constituents. We are building the formwork for sleepers. We are fabricating a new testing facility for the large-scale static and fatigue testing. Meanwhile, we prepared formworks for five 7 feet long plain and fiber-reinforced sleepers. Both grade 60 and 100 reinforcing bars will be used to satisfy longitudinal and transverse flexural requirements.

UNLV-6: Development of UAV-Based Rail Track Irregularity Monitoring and Measuring Platform. The team has improved the post-processing and geometry measurement of rails after the ML-based segmentations. The measurement is visualized and can be applied to each annotated PCD frame. The team has also explored multiple IMU sensors, and has successfully collaborate one of them with the LiDAR, so that more accurate IMU data (e.g., acceleration, angle velocity, quaternion, etc.) can be fused to the PCD frames. The team did some tests in the lab (i.e., an indoor environment) and it validated the feasibility of recovering the rotated PCD frames to level. With that, the absolute level information of rails may be achieved, and the cross-level and warp can be modeled and calculated. The team has recently finished collecting another set of on-site data (i.e., PCD frames of rails and corresponding IMU data) in the rail museum, and is deploying the pre-trained ML models to segment the rails and background in the PCD frames. Further post-processing and geometry measurement (i.e., cross-level and warp) will be applied.

UNLV-7: Efficient Railway Analysis Using Video. Benchmarking of three different state-of-the-art semantic segmentation algorithms (FRRN-B, HRNet-OCR, and SFSegNets) has been completed on the RailSem19 public railroad dataset to characterize segmentation quality and processing time using GPU and CPU. Our current work addresses implementation of the networks on lower-powered devices or single-board computers (SBCs) such as the Raspberry Pi or Nvidia Jetson. Initial tests show the Raspberry Pi is not powerful enough for the segmentation networks and the Jetson needs to be used for GPU speedup. A locomotive camera system package is in development for unattended data collection with the Nevada Southern Railway Inc. in Boulder City of Nevada.

Initiating new research programs

At Virginia Tech, we are planning to undertake our current projects as planned until the end of 2023. UNLV will continue to work on the projects that are active now.

The University of Delaware is initiating one new research project as described below:

UD-7: Topological Data Analysis and Track Geometry Data. Topological data analysis (TDA) is a data-driven approach that involves studying high-dimensional data without any 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.

Upgraded education opportunities

The efforts continue to provide a distance learning graduate course, entitled "Rail System Dynamics," but the implementation is taking longer than anticipated. When this course is implemented, it will be made available online to graduate students at the University of Delaware and UNLV. The students at each university will receive credit toward their graduate degrees from their home institutions.

At the University of Delaware, four railroad courses were given; one in the Fall of 2021; CIEG 418/618 Railroad Engineering and three in the Spring; CIEG 317 Introduction to railroads, CIEG 414/614 Railroad Geotechnical Engineering and CIEG 417/617 Railroad Safety and Derailment Engineering. In addition, a new professional development course entitled "Continuous Welded Rail-Rail Neutral Temperature" was delivered to Metro North Railway in July 2021 via Zoom. At UNLV, two courses were offered in the Fall 2021 and Spring semesters in 2022, i.e. Introduction to Railroad Engineering and High Speed Rail. Each course was attended by more than 20 graduate and undergraduate students.

Opportunities for training and professional development

Virginia Tech is hosting the 2nd Symposium on Infrastructure Diagnosis and Prognosis in May 23-24, 2022 in Hotel Roanoke, a historic railroad hotel in Roanoke, Virginia. It will be made available free of charge to the participants from industry and academia. We will have 5 panel sessions, each including three panelists over the course of 1.5 days.

The University of Delaware's Professional Engineering Outreach provides professional courses for practicing railroad and transit professionals. These professional development courses include the new Continuous Welded Rail-Rail Neutral Temperature course noted above (July 2021), with other recent professional development courses, such as Application of Emerging Data Science Techniques for Railway Maintenance Planning, Rail Grinding and Rail Maintenance, and Rail Industry Growth for Increased Long-Term Profitability.

The Big Data in Railroad Maintenance Conference takes place in December each year at the University of Delaware, and the Conference is co-sponsored by the RailTEAM UTC. This Conference addresses the growing use of data analytics in the planning and management of railroad maintenance, and it usually has more than 200 attendees from railroads, transit systems, railway suppliers, data analytic companies, and academia. The 2021 live format conference was held on December 15-16, 2021 at the University of Delaware's Newark DE campus. It is one of the first in-person conferences held in 2021.

Results disseminated

We are currently preparing three reports on our past projects that we will share with the DOT through the lead university, UNLV. We made one presentation on some of the work on track stability at the 2021 Big Data at the University of Delaware on December 15-16, 2021. Additionally, we will make six presentations at the upcoming ASME Joint Rail Conference that will take place virtually on April 20-21, 2022. We have also had occasional Zoom and in-person meetings with researchers and engineers from FRA and with some of our industrial partners, such as Norfolk Southern and AAR's Transportation Technology Center, Inc. (TTCI).

The University of Delaware conducted two major activities to disseminate results to industry and academia. The next Big Data conference that occurred December 15-16, 2021 in live format, included presentations concerning the UTC projects that are being conducted at Virginia Tech and the University of Delaware. The University of Delaware maintains contact with industry partners and its own railway advisory board to present the results of the UTC project. In the UD Railway Advisory Board meeting in December 2021, the results of the UTC project were presented from several UTC sponsored projects.

In addition, Amtrak has rejoined the rail wear project, and is now again supporting that activity with rail wear data and is interested in utilizing the results in their rail maintenance management program. This Amtrak activity was suspended for almost two years due to Covid but has recently been reinstated.

UNLV held the first in-person gathering of the partnering consortium universities on campus where UNLV gave five presentations of their research projects. The gathering was well attended by about 40 students and faculty. In addition, our students including underrepresented graduate student gave presentations at ASME conference, AREMA student showcase and the Fall Transportation Conference in Las Vegas, Nevada. Two journal papers from our high speed rail pantograph strip project have been submitted to a highly rated journal.

Plan for the next reporting period

At Virginia Tech, we intend to continue the progress on the four research projects that we are currently undertaking throughout the rest of the year and in 2023. At the University of Delaware, we plan to continue research activities with our graduate students and research scientists. UNLV will continue the research projects and offer railroad classes in the Fall of 2022.

2. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

Organizations involved as partners

We continue a reasonable amount of interaction with Norfolk Southern. Our collaboration with MxV Rail (previously called the Transportation Technology Center, Inc.), the R&D arm of the Association of American Railroads (AAR), continues to be strong. TTCI is providing $154,300 of matching funds for Task 2. The information related to AAR/TTCI's matching funds is:

- Organization Name: MxV Rail or Association of American Railroads (AAR)
- Location of Organization: Pueblo, Colorado
- Partner’s contribution to the project (identify one or more): Financial Support for $154,300

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

Nevada Southern Railway Inc. has been continuing to provide support for our research projects at UNLV. In this reporting six months, they met with our researchers about collecting video data using their locomotive and their track. Tests on the acoustic sensors were also conducted using a rail car they own on their track. They identified the geometric data to be provided to our UAV project team.

Other collaborators or contacts involved

None to report during this reporting period.

3. OUTPUTS

Output performance measures

In this reporting period, 17 papers were produced from our research which is far above the semi-annual target of 3-4 papers. One invention disclosure was filed which is in the range of semi-annual target of 0-1 disclosure. We have one patent application filed in this period, which is also in the range of semi-annual target of 0-1 application.

Publications, conference papers, and presentations

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

Publications

1. Pan, Y., Zuo, L., and Ahmadian, M., A Half-wave Electromagnetic Energy-Harvesting Tie towards Safe and Intelligent Rail Transportation, Applied Energy, Accepted February 2022, in print. UTC support acknowledged (Virginia Tech)
2. Hosseini, S-M, Ahangarnejad, A.H, Radmehr, A., and Ahmadian, M., A Statistical Evaluation of Multiple Regression Models for Contact Dynamics in Rail Vehicles Using Roller Rig Data, International Journal of Rail Transportation, published online, January 4, 2022, https://doi.org/10.1080/23248378.2021.2021829. UTC support acknowledged (Virginia Tech)
3. Hosseini, S-M., Hosseinian, A., and Ahmadian, M., Unleashing the Power of Statistical Data-driven Models for Analyzing Complex Engineering Data, the 2021 Joint Rail Conference, Baltimore, MD, April 20-21, 2022. UTC support acknowledged. (Virginia Tech)

4. Radmehr, A., Pan, Y., Tajaddini, A., and Ahmadian, M., Wheel-Rail Contact Force and Wear Analysis Under Wet Surface Condition, the 2021 Joint Rail Conference, April 20-21, 2022. UTC support acknowledged. (Virginia Tech)
5. Molzon, M. and Ahmadian, M., Development of a Mobile Robot System for the Visual Inspection of Railcar Undercarriage Equipment, the 2021 Joint Rail Conference, April 20-21, 2022. UTC support acknowledged. (Virginia Tech)
6. Hosseini, S-M, Radmehr, A., and Ahmadian, M., Data Visualization using Google Earth Engine Coupled with Unsupervised Learning, A Practical Approach to Detecting Track Instability, the 2021 Joint Rail Conference, April 20-21, 2022. UTC support acknowledged. (Virginia Tech)
7. Radmehr, A., Pan, Y., Tajaddini, A., and Ahmadian, M., Experimental Evaluation of the Effect of Rail Cant Angle on the Wheel-Rail Contact Forces, Traction Coefficients, and Contact Patch Shapes, 2021 Joint Rail Conference, April 20-21, 2022. UTC support acknowledged. (Virginia Tech)
8. Mast, T., Radmehr, A., Hosseini, S-M, Hosseinian, A., Holton, C., and Ahmadian, M., Onboard Installation of LiDAR Doppler Systems for Track Instability Measurements, 2021 Joint Rail Conference, Baltimore, MD, April 20-21, 2022. UTC support acknowledged. (Virginia Tech)
9. Pan, Y. and Ahmadian, M., Design and Field Testing of an Energy Harvester Tie: Enabling Rail Safety and Connectivity, 2021 Joint Rail Conference, Baltimore, MD, April 20-21, 2022. UTC support acknowledged. (Virginia Tech)
10. Zarembski, A. M., Palese, J. W., Soufiane, K. and Grissom, G., How Do Failed Adjacent Ties Effect the Life of Wood Crossties, Railway Track & Structures, October 2021. UTC support acknowledged (University of Delaware)
11. Soufiane, K., Zarembski, A. M., and Palese, J. W., Effect of Adjacent Support Condition on Premature Wood Crosstie Failure" Journal of Transportation Infrastructure Geotechnology, May 2021. DOI doi.org/10.1007/s40515-021-00168-5. UTC support acknowledged (University of Delaware)
12. Balogin, I and Attoh-Okine, N., Hybrid Reduction Techniques with Covariate Shift Optimization in High-Dimensional Track Geometry, ASME Journal of Computing and Information Science in Engineering, Volume 22, February 2022. UTC support acknowledged (University of Delaware)
13. Balogin, I, Leadingham, M., Guillot, D, and Attoh-Okine, N., Deep Learning Approach Towards Squat Isolation 1n a Multi-Embedded Track Geometry Defects, 2021 IEEE International Conference on Big Data (Big Data), December 2021. UTC support acknowledged (University of Delaware)
14. Olubode, O. and Schill, R.A. Jr., Carbon Strip Degradation Monitoring I: Theory and Computer Simulation, under review by Transportation Research Part C, January 2022. UTC support acknowledged. (University of Nevada Las Vegas)
15. Olubode, Q. and Schill, R.A. Jr., Carbon Strip Degradation Monitoring II: Experiment, under review, Transportation Research Part C, January 2022. UTC support acknowledged. (University of Nevada Las Vegas)
16. Mortazavian, E., Wang, Z. and Teng, H., Finite Element Investigation of Residual Stresses during Laser Powder Deposition Process as an Innovative Technique to Repair Worn Rails,

accepted for publication in the Journal of Rail and Rapid Transit, March 2022. UTC support acknowledged. (University of Nevada Las Vegas)

17. Mortazavian E., Wang, Z. and Teng, H., Measurement of Residual Stresses in Laser 3D Printed Train Rail using X-Ray Diffraction Technique, Proceedings of the ASME 2021 International Mechanical Engineering Congress and Exposition, November 1-5, 2021. UTC support acknowledged. (University of Nevada Las Vegas)

Books or other non-periodical, one-time publications

None

Other publications, conference papers and presentations

1. Hosseini, S-M. Radmehr, A.H., Mast, T. Holton, C., and Ahmadian, M., Evaluating Track Stability using Unsupervised Machine Learning Models, Big Data in Railroad Maintenance Planning 2021, Newark, DE, December 15-16, 2021. UTC support acknowledged (Virginia Tech)
2. Zarembski, A. M., Using Data Science to Better Understand and Maintain Rolling Stock Performance, Railway Age, February 2021. UTC support acknowledged. (University of Delaware)
3. 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)
4. Soufiane, K, Zarembski, A. M., and Palese, J, Impact of Adjacent Support Condition on Premature Crosstie Failure, Railway Tie Association Annual Symposium and Technical Conference, November, 2021, UTC support acknowledged. (University of Delaware)
5. Soufiane, K and Zarembski A. M., The Effect of Adjacent Tie Condition on Wood Cross-tie Life, Big Data in Railroad Maintenance Planning Conference, Newark DE, December 2021. UTC support acknowledged. (University of Delaware)
6. Attoh-Okine, N, Advances in Data Analytics as Applied to Railroad Track Geometry Analysis, Big Data in Railroad Maintenance Planning Conference, Newark DE, December 2021. UTC support acknowledged. (University of Delaware)
7. Mortazavian E., Wang, Z. and Teng, H., Measurement of Residual Stresses in Laser 3D Printed Train Rail using X-Ray Diffraction Technique, Presentation at the ASME 2021 International Mechanical Engineering Congress and Exposition, November 1-5, 2021. UTC support acknowledged. (University of Nevada Las Vegas)
8. Mortazavian, E., Wang, Z. and Teng, H., Mobile 3D Printing of Rail Track Surface for Rapid Repairment, Presentation at the Railroad Seminar Sponsored by Railroad University Transportation Center at UNLV, November 2, 2021. UTC support acknowledged. (University of Nevada Las Vegas)
9. Jia, L., Park, J., Zhu, M., Jiang, Y., and Teng, H., Developing Acoustic Technology to Detect Transverse Defects in Rail at High Speed (220 mph), Presentation at the Railroad Seminar Sponsored by Railroad University Transportation Center at UNLV, November 2, 2021. UTC support acknowledged. (University of Nevada Las Vegas)

10. Qiu, L., Jiang, Y., Zhu, M., Teng, H., and Park, J., UAV Applications to Track Inspection of irregularity measurement. Presentation at the Railroad Seminar Sponsored by Railroad University Transportation Center at UNLV, November 2, 2021. UTC support acknowledged. (University of Nevada Las Vegas)
11. Hasnat, A. and Ghafoori, N, Non-Propriety Ultra High-Performance Concrete for Ballast-Track High Speed Railroad Sleepers. Presentation at the Railroad Seminar Sponsored by Railroad University Transportation Center at UNLV, November 2, 2021. UTC support acknowledged. (University of Nevada Las Vegas)
12. Olubode, O. and Schill, R.A., Transit Degradation Monitoring and Failure Prediction of Carbon Strip in Pantograph. Presentation at the Railroad Seminar Sponsored by Railroad University Transportation Center at UNLV, November 2, 2021. UTC support acknowledged. (University of Nevada Las Vegas)
13. Olubode, O. and Schill, R.A., Degradation Monitoring of Carbon Strip in Pantograph-Catenary System using Electromagnetic Dots, Fall Transportation Conference in Las Vegas, Nevada, November 4-5, 2021, UTC support acknowledged. (University of Nevada Las Vegas)
14. Olubode, O., and Schill, R.A., High Speed Rail – Static Degradation Monitoring of Carbon Strip in Pantograph, the AREMA 2021 Virtual Conference Student Showcase, September 26, 2021. UTC support acknowledged. (University of Nevada Las Vegas)

Policy Papers

None to report

Website

Virginia Tech has updated its 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 railway research and associated 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 only raised the industry's awareness but have also made them more comfortable with adopting LiDAR systems for their maintenance of way practices.

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 2019 Conference entitled Big Data in Railway Maintenance 2019 and at the recent UD Advisory Board Meeting (June 2021). 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 Journal 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 published in the Journal of Transportation Infrastructure Geotechnology in 2021.

UNLV has been developing a 3D printing technology to repair worn rail on site. Instead of replacing the worn rail, it can be repaired and can continue to provide service. This technology will save significant maintenance costs for the railroad industry. Another technology that UNLV is developing is the inspection of track irregularities such as gauge and curves using LiDAR and UAV technology. This technology can replace the labor extensive track inspection using the current inspection cart. UNLV has developed a technology to detect internal defect within rails using the acoustic technique. This acoustic technique is vibration based and is more sensitive to defects in rail and can detect the internal defects more accurately. The other technology is to monitor the photograph strip that receives electricity from overhead wires to high speed rail trains. This strip constantly touches the wire and wears out quickly. This monitoring technology can tell the extent the strip is worn out in real time, which provides information as to the time to replace the strip. We also found that PTV Vissim, a highway traffic simulation software, can simulate the operation of high-speed rails, which provides a way to evaluate them.

Inventions, patent applications, and/or licenses:

We have one patent file: Kinetic Energy-Harvesting Device for Powering and Charging Railway and other Applications, USPTO Application No. 17719971, filed on April 13, 2022.

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, a major maintenance cost area.

Increases in the body of knowledge

Many of the technologies that we are developing are expected to significantly increase the body of knowledge related to rail transportation, specifically as it pertains to track and rail vehicle maintenance diagnosis and prognosis. That is the main thrust of the RailTEAM consortium. For instance, the LiDAR sensors that we are developing in VT-2 promises to significantly advance inspection and detection of track stability. The same is true for the measurement and assessment of track contaminants in VT-3 and Track Crawler Robot in VT-4. The critical knowledge gained from these projects will advance rail inspection and safety methods significantly.

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 the development of new relationships between performance, component degradation, and safety. Current research activities already address this in the following areas, i.e., degradation of crossties (sleepers), wear of railway wheels, wear of railway rails, railway rail fatigue, track geometry degradation, and forecasting derailments.

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

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

The results from the VT-3 indicate the possibility of strong advances in improving rail friction management practices to better manage train traction and braking. The same is true of safety advances gained from VT-2 with better assessment of gage widening. Such improvements promise to bring hundreds of millions of dollars in cost savings in the form of reducing derailments and improving safety.

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.

Safety is the most important issue in railroad operation. Our project on applying acoustic technique to detect internal defects can improve safety on the railroad. In addition, our project on 3D printing technology can reduce maintenance cost significantly to the railroad industry.

Enlargement of the pool of trained transportation professionals

We remain highly active in our interaction with others outside of our immediate research team through participating in professional conferences and communicating our findings to our industrial partners, such as Norfolk Southern and MxV Rail. The conferences we attend include transportation professionals, many of whom are young engineers. We believe our efforts have been effective in enlarging the pool of trained transportation professionals.

The railroad program at the University of Delaware trains working professionals who earn UD's Graduate Certificate in Railroad Engineering, which includes professionals from Amtrak, SEPTA, the U.S. Navy, and numerous consulting groups and international railways. UNLV has been working with professionals in high speed rail agencies on education and research, which is a way to enlarge the pool of trained transportation professionals.

Adoption of new technologies, techniques, or practices

All of our projects use new technologies, techniques, and practices. We are in 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 can help the industry. Our projects have successfully bridged this gap.

The LIDAR project described in VT-2 is improving rail safety through in situ measurement of track movement under the weight of a passing wheel. This early sign of track instability promises to improve the detection of “soft” track structure and track instability in its early stages when costly repairs and potential derailments can be avoided.

Similarly, the track crawler robot that is being developed in VT-4 is showing promising result for detecting damaged or worn undercarriage elements on a train that are not visible during trackside inspection. It also promises to have a significant outcome for train inspection and detection of any malicious device that could cause harm.

We have built a working prototype of the energy harvester tie in the VT-1 plan to install it on the revenue service track with one of the Class I railroads (most likely, Norfolk Southern) for in-field assessment. The prototype systems that we have achieved in our projects, such as the Track Crawler Robot an energy harvester tie, are tangible engineering outcomes that have been advancing our research way beyond paper research.

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

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

Outcome performance measures

In this reporting period, we have 40 citations, which far exceeds our semi-annual target of 3-5 papers. We also have two news coverages which is also more than planned target of 1-2 in six months.

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 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 are related directly to improving track-maintenance practices. U.S. railroads collectively spend billions of dollars in maintenance on the tracks. Even small improvements in maintenance practices will have a major positive financial impact for the railroads. 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 resulted from the better understanding and management of friction, ability to detect failed components and malicious out-of-sight packages, etc.

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 this information how to incorporate it 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. So this work results in increased data accuracy from track geometry car measurements.

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

Impact on the adoption of new practices

The LiDAR system, the energy harvesting pre-production tie, and the Track Crawler Robot prototype that have been developed by Virginia Tech have significantly pushed our commercialization goals forward. These technologies will have significant impact on improving railroad engineering practices. For instance, the ability to measure the existence or lack of rail lubricant through LiDAR sensors will enable railroads to better manage wheel-rail friction on the top of rail or flange face, thereby reducing the fuel cost due to rolling resistance of the wheels and also reduce wheel/track wear (and even damage) due to unnecessarily high friction. In addition, LiDAR systems can be adopted for in-situ measurement of track gage widening onboard a locomotive or Hyrail truck. This would enable detecting and fixing "soft" spots on the track before they lead to costly derailments. Similarly, the commercialization of the energy harvester tie 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.

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 costs 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 contaminant 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, the LiDAR technology can assess roadway surface conditions. The Track Crawler Robot that has been developed in VT-4 can also be used for under-train inspection by the Department of Homeland Security.

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 railroad industry continuously seeks our graduate students and undergraduate students because of the skills they learn in our rail engineering program. In addition, we are promoting the rail industry among engineering students at Virginia Tech. In this regard, each year we host a railroad-specific career fair to introduce students to railroad companies. Over the years, this event has resulted in promoting the rail industry to our students and placing many of them with Class I railroads and suppliers.

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, which includes planning, designing and constructing high speed rails in the U.S. Some new employees at the current high speed rail projects have been seeking professional development related to their projects.

Impact performance measures

In this reporting period, we have three cases where stakeholders requested RailTEAM expertise in the application of research products which is more than one targeted request. We do not have any research results transferred to companies, adoption of new practices, or the initiation of new startups in this period, which also falls in the range of target of one result.

6. CHANGES/PROBLEMS

No changes in approach.

Actual and anticipated problems or delays

We have mostly recovered from the interruptions caused by the COVID-19 Pandemic, which mainly affect how we conduct our field tests. During the past few months, we have ramped up this aspect of our work and hope that we will be back to pre-pandemic levels by the end of 2022 (of course, barring any surge in infections in the U.S.)

The primary impact on our expenditures has been the delays in field testing. 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 location of the primary performance site from the original proposal.

The effects of the COVID-19 Pandemic remain, but they have lessened significantly since our last report. This is particularly true for both data collection and field tests that we had planned for this year. We hope that the lowering effect will continue in 2022, to the point of returning to “normal” or at least as normal as one can hope for in a pandemic era.

No changes have had any significant impacts 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 location of the primary performance site from the original proposal.

7. SPECIAL REPORTING REQUIREMENTS

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