UTC-Semi-Annual Progress Report

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

Rail TEAM

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

Submitted to

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UTC Semi-Annual Progress Report

1. ACCOMPLISHMENTS

Major goals and objectives of the program

The goals of this program are to conduct research, promote education, and facilitate technology-transfer activities to improve the sustainability and durability of 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-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. 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 publication in various journals.

Goal accomplishments

Continuing active research projects

Our consortium universities have continued 17 research projects in this reporting period, i.e., four at Virginia Tech, six 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: <u>Methods for Qualitative and Quantitative Measurement of Top of Rail (ToR) Friction Modifiers in Revenue Service.</u> The primary objective of this study is to continue evaluating, designing, and building high-accuracy, non-contacting sensors for qualitative and quantitative measurement of ToR friction modifiers in revenue service. Two new generations of LiDAR-based measurement techniques have been designed, and they have undergone extensive evaluation both in the lab and on revenue-service track. The 2021 effort mainly was intended to emphasize the field evaluation of LiDAR measurement units at speeds higher than those tested in the past. However, due to the Pandemic, we have not been able to perform any field testing with our project partner, Norfolk Southern (NS). Instead, we have directed our activities to extending our laboratory testing of a prototype unit and analyzing the data to a greater extent than had been done in the past. The revised plans for 2021 have been completed. We intend to end this project at the end of 2021 and replace it with another project that is aimed at the use of a mobile robot called Track Crawler Robot (TCR) to inspect the undercarriages of trains. The findings from this study have been documented in three papers, and these papers were presented at the 2021 ASME Joint Rail Conference (JRC) on April 20 and 21 in 2021. Also, the findings have been used in another one of our current projects, i.e., VT-4, which uses the state-of-the-art VT-FRA roller rig to assess the short-term and long-term effects of ToR on the mechanics and dynamics of the wheel-rail contact.

VT-2: <u>Energy Harvester Tie for Serving the Needs of the Railroad Industry to Access Electric Power in Remote Locations</u>. 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 condition of the track. It also enables integrating intelligence into the track concerning maintenance diagnostics and possibly prognostics. Four tasks will be conducted in this project. First, we will acquire a detailed analysis of the prototype EHT that is available at the Railway Technologies Laboratory. This task has been completed. Second, we will design and fabricate a full-sized energy harvester tie. This task is currently underway, and it is estimated to be about 60% complete. Third, an energy storage system will be developed and integrated with a wireless charging platform. Currently, about 20% of this task has been completed. Fourth, we will conduct a field evaluation of the full-size energy harvester tie. This task has not been started yet; it will be started when Task 2 has been completed. The project will be continued in 2022. In 2021, we anticipate that the remaining work for Task 2 will be completed as well as possibly another 20% of Task 3. The remainder of the work will be done next year.

VT-3: Application of Doppler LiDAR Sensors for Assessing Track Gage Widening in Curves and Locations with High-lateral Forces. This study includes the application of Doppler LiDAR sensors for the *in situ* assessment of track gage widening in curves and locations with high lateral forces. The prototype system that was tested earlier on a Hyrail truck on revenue service tracks was adapted to a track geometry railcar. The system was installed onboard the railcar successfully and tested on nearly 3000 miles of revenue service track with a Class I railroad. The analysis of the field data that currently is underway has been extremely helpful in validating the system's utility for the assessment of the stability of railroad tracks. The results have been very encouraging, although the ultimate utility will not be known until the identified soft spots have been identified independently by track stiffness inspections. More importantly, the data have been used for developing novel data analysis methods based on machine learning and statistical techniques to provide data processing automation. After further developed, these methods are expected to provide powerful tools for using test data to extract useful information about the condition of railway tracks for both the LiDAR system mentioned above as well as for other similar onboard sensors. Currently, this project is ongoing, and it will be continued at least until the end of 2022 and possibly longer. The Association of American Railroads (AAR) has contributed $98,834 of matching funds for this project.

VT-4: Quantitative Evaluation of the Effect of Top of Rail Friction Modifiers on Reducing the Wear on the Wheels and Rails. This project is intended to provide a quantitative evaluation of the influence of various amounts (and types) of Top of Rail (ToR) Friction Modifiers to reduce the wear of wheels and rails. We have conducted a series of highly precise and controlled experiments using the Virginia Tech-FRA (VT-FRA) roller rig. In the experiments, the ToR quantity and rate of application are controlled precisely through a scientific fluid dispensing system, and they vary from a very small amount to a very large amount. The longitudinal traction that controls the ability to generate motive (adhesion) and braking power at the rail is evaluated precisely for each amount of ToR. In addition, the amount of wheel wear for each test condition is evaluated by a high-precision laser surface profiler. The traction and wear data are related to the amount of applied ToR friction.

The results showed a highly nonlinear relationship between wear and the amount of ToR; they indicated that more ToR does not cause the same proportion of less wear. Hence, the best cost-to-benefit ratio or return on investment is achieved by applying small amounts of ToR over shorter distances at separate locations on the rail. This also would reduce the amount of excess ToR material that does not provide any substantial benefits and contributes to trackside pollution. The effect of ToR on wheel-rail traction is parallel to the wear findings. Less ToR volume applied more frequently (over shorter distances) would provide more favorable adhesion and braking than a large ToR volume applied farther apart. We intend to continue this effort through the remainder of 2021 and in 2022. Funding provided by the Federal Railroad Administration for VT-FRA roller rig studies is used to augment the UTC funding, but it is not counted as matching funds.

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. Transverse rail profile data were collected for a 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 working now on predicting the evolution of the profile based strictly on its past performance, however this activity had been delayed due to the coronavirus. Work has progressed on the prediction of the transverse rail profile, based on historic changes in transverse profile using a newly developed 2DARIMA modeling approach that treats the transverse Cartesian data as time series with adjoining weighting functions that constrain adjacent growth. The next step, which is being pursued actively, is to utilize the data in a mode that consists of 70% training and 30% evaluation to determine the accuracy of the approach.

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 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 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 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 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 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 the weight of the loads it carries 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 speeds for trains, 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 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. This activity is continuing 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 in multiple years. The goals of the next step are to account for 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. Using these different conditions of ties and the corresponding different periods in the lifespan of a tie, the project continues to focus on determining the average life of ties by mathematical modeling techniques, such as piecewise reconstruction. The initial analysis approach used Dijkstra's algorithm, Markov Chain analyses, and tie condition data from two different inspections performed within a span of three years. The current focus is 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 based on the tie inspection data from approximately 100,000 crossties over the four-year period from 2016 to 2020. The aim of this activity is 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. Risk Modeling of Grade Crossing Accidents. This project has been completed, and a follow-up activity is being considered. This activity utilized the national grade crossing inventory database and other readily available demographic data to develop a Bayesian Network to predict optimal crossing protection and accident/collision risk. An exposure metric was developed based on the densities of both train and highway traffic. This metric, along with other variables, was employed in the development of the Bayesian Network to define the protection level required for an individual crossing based on the historic performances of similar crossings, and it predicts the probability of collisions between trains and vehicles on the road.

UD-6: Random Forest-Based Covariate Shift in Addressing Non-Stationarity of Railway Track Data. This activity has been completed, and a paper was published in the ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering, 2021. This project addressed the issue of the accuracy of the data 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 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.

UNLV-1: Mobile 3D Printing of Rail Track Surface for Rapid Repairment. In this reporting time period, the submerged arc welding technique was being prepared to repair a worn rail. The welding will be conducted in the next six months. At the same time, a twin-disc rolling contact fatigue tester was being built, and it will be used to test the repaired rail. One conference paper and one journal paper have been written based on prior research work, and both papers are being reviewed now.

UNLV-2: High-speed Rail Access Charge for the XpressWest of Nevada. In the last reporting period, the Access charge for XpressWest for the Palmdale to Los Angeles section of California High-Speed Rail was estimated at $14.61 per train-mile. The cost elements included were the train operations and maintenance costs. Capital Cost (CC) and the Rehabilitation Cost (RC) for the construction and maintenance of the CHSR system were not considered. This access charge cost was considerably lower than the European access charge costs per train-mile where CC and RC costs were considered differently. In this reporting period, the CC and RC were considered and were estimated at $123.02 and $1.11 per train-mile, respectively. Along with the CC and RC, the total access charge cost is $138.74 per train-mile, which is extremely higher than the European access charge costs per train-mile. An initial investigation showed that the construction costs of the CHSR system were significantly higher than the construction costs for European HSR. This was due to the various types of terrains in California and the higher number of aerial and tunnel structures. The construction costs of many European High-Speed Rail systems include the cost of new construction and the cost required to upgrade the older infrastructure. This might have led to lower recovery of the capital cost in the European access charge costs.

UNLV-3: Development of Acoustics Technology to Detect Transverse Defects in Rail at High-speed (220 mph). The team solved a data saving issue of the NI DAQ system, and the system can record acoustic signals in a frequency range from 30 kHz to 500 kHz. With the use of a producer-consumer loop, the system simultaneously can save data in four channels continuously into a TDMS file. With the system's data collection and saving stability confirmed, the team completed field tests at the Transportation Technology Center, Inc. (TTCI) in mid-July, 2021. The tests that were conducted included tests with different speeds on three tracks. All of the tests were conducted at different speeds, and they were tested three times for each speed. The data that were collected included 1) three sets of acoustic data recording defect signals, general train vibrations, and other ambient noises, 2) two sets of videos recording rail geo-information with Gopro cameras (240 fps), and 3) speed information from a tachometer. Videos and acoustic recordings were synchronized for follow-up analysis. Currently, the team is analyzing the 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. Considering the obstacles involved in fully customizing an ultra-high frequency (UHF, i.e., 1 GHz and above) data acquisition (DAQ) module that can store an extensively huge amount of data or that allows a host computer to access the raw collected data with high bandwidth data transmission, the team has investigated the existing products in the market, and they found a potential DAQ module to fulfill the desired requirements. Currently, the module is in transit, and when it is delivered the team will study the data transmission specifications and develop a program to establish the transmission of data between the DAQ and the host computer. This will allow the host computer to access and analyze the raw data that are collected in the DAQ.

UNLV-5: Non-Propriety Ultra-High-Performance Concrete (UHPC) for Ballast-Track High-speed Railroad Sleepers. For the second phase of this project, we identified a number of UHPCs from Phase 1 as the potential for the selected mixture of Phase 2. Short, medium, and accelerated long-term engineering properties were determined for the selected mixture. We have prepared sufficient raw materials through the required gradation of the UHPC constituents, and we are building the formwork for sleepers. A new testing facility is being fabricated for the large-scale static and fatigue testing. Upon preparation of the formwork, we will be casting sleepers and have them ready for testing.

UNLV-6: Development of UAV-Based Rail Track Irregularity Monitoring and Measuring Platform. The team now has completed all of the major steps in measuring the geometry of the rail track, including collecting 3D point cloud data (PCD) in arbitrary perspectives by using a LiDAR-UAV-based airborne data acquisition platform, machine-learning based 3D point cloud semantic segmentations to extract/distinguish rails from the background, coordinate transformation and edge detection to finally measure the most aspects of the rail geometries, e.g., gauge, warp, profile, and others. The team is programming to visualize the measurement on each PCD frame. However, due to 1) the lack of absolute level information in each PCD frame, 2) the limitation of the UAV's instability during the flight, and 3) potential measurement error (up to2 cm) caused by the LiDAR itself, accurate measurement (accuracy ~1 mm) of the crosslevel/superelevation is still being researched. The team plans to introduce gyroscopic information during the collection of the PCD on UAV, 3D point cloud registration/stitching, and data fusion between 2D RGB images and 3D PCD to improve the accuracy of the measurements. Although this research is complicated, it may result in a breakthrough that can benefit any application that involves geometry measurements.

UNLV-7: Transit Degradation Monitoring and Failure Prediction of Carbon Strip in Pantograph. In this reporting period, a final report was developed.

Initiating new research programs

As stated earlier, Virginia Tech is retiring VT-1, the lubricity assessment project. In its place, we will undertake a new project on using a mobile robot, which we call the Track Crawler Robot (TCR), for unmanned inspection of the undercarriages of trains.

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 the study of high-dimensional data without any assumptions or feature selections. For many complex data sets, especially monitoring railway tracks, the number of possible hypotheses is very large, and the talk of generating useful hypotheses becomes extremely 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 generated the data initially. Compared with traditional principal component analysis (PCA), t-distributed stochastic neighbor embedding (t-SNE), and cluster analysis, TDA is more effective at detecting large and small patterns in data. Thus, the main objective of the project is to apply TDA to various track geometry data and attempt to develop a new approach, i.e., an invariant approach to traditional TQI, that can be more effective.

UNLV started a new project as follows:

UNLV-8 Efficient Railway Analysis Using Video. The project was initiated in August 2021 with the hire of an MS student who was studying Computer Science. From a video taken at the front of a train, the team has been evaluating different deep learning architectures for semantic segmentation of rail images. Benchmarking of performance has been performed using the public dataset entitled "RailSem19", which was provided by the Austrian Institute of Technology. The benchmark will compare state-of-the-art semantic segmentation network architectures (for on-road segmentation used for autonomous vehicles) for quality (intersection over union) and computation time. We have performed preliminary evaluations of PSPNet and HRNet-OCR with CityScapes' pre-trained networks. In our current work, we are examining the pre-training/fine-tuning processes, and we plan to perform initial training on the large Mapillary dataset, followed by Cityscapes, and finally fine-tuned for RailSem19 to match the literature. Plans during the next period include completion of the train/test framework on our benchmark algorithms and the initiation of a start of rail abnormality dataset (to detect vegetation overgrowth, pooled water, and distressed ballast).

Upgraded education opportunities

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

At the University of Delaware, 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 Spring and Fall semesters in 2021, i.e. Railroad Engineering and Introduction to Railroad Engineering. Each course was attended by more than 20 graduate and undergraduate students. Concurrently, with the support of our UTC program, UNLV has developed a course entitled "Introduction to Railway" that can be accessed worldwide.

Opportunities for training and professional development

In 2022, Virginia Tech made a final plan to offer a symposium on “Track Maintenance Diagnostics and Prognostics”. The symposium is scheduled for May 21 - 23, 2022 in Roanoke, Virginia. It will be made available free of charge to the participants from industry and academia.

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), together 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 is held 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 currently is scheduled for December 15-16, 2021 at the University of Delaware's Newark DE campus.

Results disseminated

After a pause in our efforts to disseminate our research results, we are delighted that we have resumed these efforts. We presented seven papers at the April 2021 ASME Joint Rail Conference, and we plan on further publishing as well as presenting our findings at the 2022 ASME Joint Rail Conference that will be held in Baltimore, Maryland in April 2022. In addition, we have submitted three papers to reputable journals in the area of transportation research, and currently we are waiting for the outcome of the review process for each paper. In addition, we have had occasional Zoom meetings with the 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 is scheduled for December 15-16, 2021 in live format, and it will include presentations concerning the UTC projects that are being conducted at Virginia Tech and the University of Delaware. The University of Delaware maintains contact with industry partners and its own railway advisory board to present the results of the UTC project. In the UD Railway Advisory Board meeting in June 2021, the results of the UTC project were presented from the Covariate Shift Problems in the Track Geometry Data Project, and there also was a presentation of the Rail Wear project.

UNLV will present its 3D printing work at the International Mechanical Engineering Congress and Exposition, IMECE202, on November 1-5, 2021. The UNLV representatives also will present their work on monitoring pantograph-catenary system at the 2021 Fall Transportation Conference in November at Las Vegas, Nevada. Their paper on ultra-high performance concrete tie was published in June 2021.

Plan for the next reporting period

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

At the University of Delaware, we plan to continue research activities with our graduate students and research scientists. The UNLV representatives will continue their seven research projects, one of which is expected to be completed. Two railroad courses will be provided to undergraduate and graduate students. At least one paper will be submitted for publication.

2. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

Organizations involved as partners

Our collaboration with Amtrak has been reduced significantly due to the Pandemic and the workforce reduction at Amtrak. We continue a healthy amount of interaction with Norfolk Southern, and the Company's representatives continue to assist us with our field-testing efforts. Our collaboration with the Transportation Technology Center, Inc. (TTCI), the R&D arm of the Association of American Railroads (AAR), continues to be strong. TTCI continues to provide matching funds ($98,834) and engineering input for Task 3. The information related to AAR/TTCI's 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. Results will be presented to Amtrak upon completion for incorporation in their maintenance management activities.

Nevada Southern Railway Inc. has continued to provide assistance to railroad research. They provided the track for testing an acoustic sensor to detect internal defects in rails. Our UAV equipped with LiDAR to measure geometric irregularities in tracks is allowed to fly over their track to collect experimental data. Our materials, such as rails, are stored in their yard. Their staff helped our researchers use various equipment, including the rail cutting saw and the track measuring lever.

Other collaborators or contacts involved

None to report during this period.

3. OUTPUTS

Output performance measures

In this reporting period, our UTC presented or published 12 papers in peer-reviewed conferences or journals, far exceeding our target of 3-4 in half a year. We did not file any invention disclosures in this half year, which is on the 0-1 target. We do not have any provisional or utility patent applications filed, and this also is on the 0-1 target.

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, in review. 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, in review. UTC support acknowledged. (Virginia Tech)
3. Pan, Y, 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)
4. Pan, Y., 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)
5. Pan, Y., 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)
6. Hosseini, S-M, Ahangarnejad, A.H., 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)
7. Cronin, J. J., Zarembski A. M., and Palese J. W., Prediction of Rail Defect Development using Parametric Bootstrapping Modified Weibull Equations, Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit, May 2021. doi.org/10.1177/09544097211020583, UTC support acknowledged. (University of Delaware)
8. Musazay, J., Zarembski, A. M. and Palese, J. W., Determining Track-Induced Lateral Thermal Expansion Forces on A Curved Railway Track, Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit, February 2021. DOI 10.1177/0954409721995318, UTC support acknowledged. (University of Delaware)
9. Balogun, I. and Attoh-Okine, N., Random Forest–Based Covariate Shift in Addressing Nonstationarity of Railway Track Data, ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering, 2021, 7(3): 04021028, 2021, UTC support acknowledged. (University of Delaware)
10. 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)

11. 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, submitted to proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit. (Resubmitted date: July 1, 2021). UTC support acknowledged. (University of Nevada Las Vegas)
12. Mortazavian, E., Wang, Z., and Teng, H., X-Ray Diffraction Measurement of Residual Stress in Laser Powder Deposition Process as a Potential Rail Repair Technique, Proceedings of the ASME 2021 International Mechanical Engineering Congress and Exposition, IMECE202, November 1-5, 2021, Virtual, Online. UTC support acknowledged. (University of Nevada Las Vegas)

Books or other non-periodical, one-time publications

1. Pan, Y. and Ahmadian, M. An Energy-Harvesting Railroad Tie for Improving Track Condition Monitoring and Safety, Quarterly Issue 4, U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology, October 2021. UTC support acknowledged. (Virginia Tech)
2. 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, Baltimore, MD, April 20 – 21, 2022. Abstract accepted, paper in preparation. UTC support acknowledged. (Virginia Tech)
3. Molzon, M. and Ahmadian, M., Development of a Mobile Robot System for the Visual Inspection of Railcar Undercarriage Equipment, the 2021 Joint Rail Conference, Baltimore, MD, April 20 – 21, 2022. Abstract accepted, paper in preparation. UTC support acknowledged. (Virginia Tech)
4. 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, Baltimore, MD, April 20 – 21, 2022. Abstract accepted, paper in preparation. UTC support acknowledged. (Virginia Tech)
5. 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, Baltimore, MD, April 20 – 21, 2022. Abstract accepted, paper in preparation. UTC support acknowledged. (Virginia Tech)
6. 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. Abstract accepted, presentation will be made at the conference. UTC support acknowledged. (Virginia Tech)
7. 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. Abstract accepted, presentation will be made at the conference. UTC support acknowledged. (Virginia Tech)
8. 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. Abstract accepted, presentation will be made at the conference. UTC support acknowledged. (Virginia Tech)

9. Olubode, O. and Schill R., Static Degradation Monitoring of Carbon Strip in Pantograph-Catenary System using Electromagnetic Dots, 2021 Fall Transportation Conference, Las Vegas, Nevada, November 4-5, 2021. Abstract accepted, presentation will be made at the conference. UTC support acknowledged. (University of Nevada Las Vegas)

Other publications, conference papers and Presentations

1. Ahmadian, M. Keynote Lecture: LiDAR System Applications for Improving Condition Monitoring and Asset Management of Railways, The Seventeenth International Conference on Condition Monitoring and Asset Management, Plenary Lecture, London, England, September 6 – 10, 2021. (Virtual). UTC support acknowledged. (Virginia Tech)
2. Ahmadian, M. Keynote Lecture: Achieving Improved Understanding of Wheel-Rail Interface Dynamics Through Roller Rig Testing, International Conference on Rail Transportation (ICRT2021), Chengdu, China, July 5 – 6, 2021. (Virtual). UTC support acknowledged. (Virginia Tech)
3. 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, April 202, UTC support acknowledged. (University of Delaware)
4. Ashley, G., Balogun, I., Prosper, A., and Attoh-Okine, N, Prediction of Track Geometry Defect Severity Using Machine Learning Techniques, accepted for presentation at 2022 Transportation Research Board, UTC support acknowledged. (University of Delaware)
5. 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)

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 also have 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 is determining 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.

Inventions, patent applications, and/or licenses:

None to report in this period

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 have developed (VT-1 and VT-3) significantly have advanced the understanding and effective application of optics sensors for rail applications. The same is true for the energy harvesting in VT-2 and Top of Rail (ToR) friction modifiers in VT-4. The critical knowledge gained in both will enable better means of track inspection and condition monitoring (VT-2), improve fuel efficiency, and reduce track/wheel wear.

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.

Our research at UNLV has indicated that internal defects can be detected using the vibration-based, acoustic emission technique which is a major contribution to understanding the behavior of an internal defect in a rail. In the future, this finding could provide a path for the development of technology for detecting internal defects. Our research also indicated that mounting a LiDAR sensor on UAVs allows the measurement of geometric irregularities in the track, which usually is not the case in the LiDAR application.

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

The results from the VT-1 and VT-4 projects indicate the possibility 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 wear of wheels and rails. Harvesting energy from the rail (VT-2) would enable broad integration of sensors and electronics in the track for better *in situ* condition monitoring and condition-based maintenance. VT-3 will significantly improve the application of data analytics and machine learning when a large volume of data exists, which has been a common trend in transportation engineering.

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. UNLV demonstrated that Vissim, a simulation software, is capable of simulating the operation of high speed rail in California and Nevada, which is a new way to evaluate the operation.

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 Amtrak, Norfolk Southern, and the Association of American Railroads. The conferences are attended by 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 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. UNLV provided high-speed rail course materials to professionals who started new positions on high-speed rail. In addition, we introduced new technologies to Nevada Southern Railroad, Incorporated.

Adoption of new technologies, techniques, or practices

All of our projects use new technologies, techniques, and practices. With many of them, we are in the leading edge of the application of these technologies in practice. Although interesting technologies are studied often in the laboratory, they fall significantly short of practical solutions that can help the industry. Our projects intend to bridge this gap.

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

Outcome performance measures

In this reporting time period, we have 72 citations, which far exceeds the 3-5 target. Our research work was presented in the coverage provided by six news media outlets, which is far more than the 1-2 target. Dr. Allan Zarembski at the University of Delaware was quoted in the news media, i.e., the New York Times, NPR, and the Associated Press concerning the Amtrak derailment in October 2021. His UTC research helped in identifying the potential causes that resulted in the derailment.

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 maintenance on the tracks. Even small improvements in maintenance 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 due to the improved fuel efficiency that resulted from the better understanding and management of the friction between rails and wheels. 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.

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 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, including curves on bridges, and this will 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).

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 accuracy of the data from track geometry car measurements.

The access charge project conducted by UNLV would directly impact the construction decision of XpressWest, which is considering building a high speed rail from Las Vegas to Los Angeles. This access charge was not considered by XpressWest when they initiated their project.

Impact on the adoption of new practices

The LiDAR system and the energy harvesting tie that have been developed by Virginia Tech are expected to be ready for commercialization within the next 6 – 12 months. Both of 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 would enable railroads to better manage wheel-rail friction at the running surface, thereby reducing the cost for fuel 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 gauge onboard a locomotive or Hyrail vehicle. This would enable detecting and fixing "soft" spots on the track before they lead to a costly derailment. Similarly, the commercialization of the energy harvester tie will enable seamless and practical means of having access to power in places where such power currently is not available. This will be a critical and enabling technology for integrating sensors and smart devices in the track, which will have several significant advantages.

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

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 the safety of driving. 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 the surveillance cameras that have been installed at some locations. Whereas optical cameras must be used in a lighted environment, 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, where the technology can be used to power 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

Both our graduate students and undergraduate students continue to be sought by the railroad industry 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, we are hosting a railroad-specific recruiting event in November to allow a select number of U.S. companies to promote their openings to a group of students selected by the student section of the American Railroad Engineering and Maintenance of Way Association (AREMA).

UNLV has been offering courses and seminars on high speed rail to undergraduate and graduate students. These students can join the force in the planning, design, and construction of high speed rail in the U.S. now and in the future.

Impact performance measures

In this reporting period, we have four stakeholders requesting RailTEAM expertise in the application of research products, which is far more than 1 one-year target. We also have transferred our research results to a company, which is on the one-year target.

6. CHANGES/PROBLEMS

No changes in approach.

Actual and anticipated problems or delays

The effects of interruptions caused by the COVID-19 Pandemic remain, but they have lessened significantly since our last report. This is particularly true for the field tests that we had planned for this year. We are hoping 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.