UTC-Semi-Annual Progress Report

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

Rail TEAM

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

Submitted to

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UTC Semi-Annual Progress Report

1. ACCOMPLISHMENTS

Major goals and objectives of the program

The goal of this program is to conduct research, promote education, and facilitate technology-transfer activities to improve the sustainability and durability of the railroad infrastructure in the United States. Forecasts call for the U.S. economy to continue to grow, freight travel to remain steady or increase slightly. Railroads will play a larger role than ever in carrying this demand. Such increased use, in turn, will expedite deterioration of the railroad system. The future need for faster transfer of goods and people will also 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 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 the program focuses on four areas of research critical to railroad system operations and safety:

- Asset management and performance assessment
- Condition monitoring, remote sensing, and use of GPS
- Application of new materials and technologies
- High-speed rail (HSR) construction methodologies and management

Virginia Polytechnic Institute and State University (Virginia Tech) focuses on condition monitoring, remote sensing, and the use of laser- and GPS-based systems. The University of Delaware focuses on asset management and performance management using big data (data analytics) techniques, and application of new material, analytic models and technologies. The University of Nevada Las Vegas is engaged in technologies and construction methodologies to better enable further development and implementation of HSR in the U.S.

The second objective of the program is to improve workforce development and rail education in the U.S. through: 1) offering undergraduate and graduate courses to engineering students; 2) establishing certificate programs suitable for the new generation of engineering students and young professionals who wish to get engaged in the rail industry; and 3) providing short courses suitable for practicing engineers who wish to further hone their skills. Toward this end, all three partnering universities are engaged in complementary activities ranging from STEM activities to 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 results from 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 journal publication.

Goal accomplishments

Continuing active research projects

Our consortium universities have continued 16 research projects in this reporting period, four (4) at Virginia Tech, five (5) at the University of Delaware, and seven (7) at UNLV. Significant advances were made in each project. The project progress is described below.

VT-1: Methods for Qualitative and Quantitative Measurement of Top of Rail (ToR) Friction Modifiers in Revenue Service. The primary objective of this study is to continue the efforts toward evaluating, designing, and building highly accurate devices for qualitative and quantitative measurement of Top of Rail (ToR) friction modifiers in Revenue Service. This project involves research of optical scattering signatures of clean and lubricated rail in both a laboratory and field setting. To do this, custom optical instruments were developed to take lubricity measurements. Measurements of component scattered and reflected light intensities are evaluated to provide lubricity assessments. Two new generations of LIDAR-based measurement units were designed and extensively evaluated both in the lab and on revenue-service track. Further testing of one of the units (the most promise for eventual commercialization) on revenue service track was excellent during this reporting period. We were able to conduct tests with a new mobile unit that can be operated at far higher speeds than previously, using a remotely controlled, motorized rail cart operated from a Hy-rail truck. Beyond increasing the speed, the revenue service tests proved that laser-based measurements can be performed at speeds that are practical for commercial application of the device. One paper was prepared and accepted for presentation and publication at the 2021 ASME Joint Rail Conference (JRC) in Saint Louis, MO, originally scheduled for 2020 but delayed to next year due to COVID-19 social and travel restrictions.

VT-2: Monitoring and Detecting Fouled Ballast using Forward Looking Infrared Radiometer (FLIR) Aerial Technology. The primary objective of this research is to explore application of FLIR for assessing fouled ballast on tracks. Using off-the-shelf FLIR technology, the proposed method takes advantage of temperature differences measured by the FLIR camera between the top surface of clean and partially fouled ballast samples as an indicator of fouling. Ballast fouling is a common maintenance issue, occurring as a result of aggregate pulverization clogging up the ballast and preventing water drainage. Laboratory tests were carried out to study the thermal behavior and characteristics of clean, and partially- and fully-fouled ballast using a FLIR camera during earlier phases of the study. Results indicate that the cooling and heating rate at the top surface for clean, partially fouled, and fouled ballast are different during the daily heat-up cycle. It was determined that although the FLIR camera can measure some changes in the ballast temperature, the differences may be within the range of variations that could occur in field conditions. The study highlighted the range of measured temperature by the FLIR camera and pros and cons of using this approach in practice, as documented in two papers that were accepted for publication and presentation at the 2021 ASME Joint Rail Conference (JRC) (originally scheduled for 2020). Additional field testing is needed to validate or dispute the initial findings of the study. Such field testing, however, is not planned since we have not been able to receive the necessary commitment from the railroad industry. With the current COVID-19 situation, we do not anticipate any field testing is possible in 2020.

VT-3: Application of Doppler LIDAR Sensors for Assessing Track Gauge Widening in Curves and Locations with High-lateral Forces. The primary objective of this study is to evaluate the application of Doppler LIDAR sensors for in situ assessment of track gage widening in curves and locations with high-lateral forces. The proposed method uses track measurements by two low-elevation, slightly tilted LIDAR sensors nominally pointed at the rail gage face on each track. The LIDAR lenses are installed with a slight forward angle to measure track speed in both longitudinal and lateral directions. The lateral speed measurements are processed for assessing the track gauge and alignment variations, using a method based on the frequency bandwidth dissimilarities between the vehicle speed and track geometry irregularity. The research heavily relies on field testing onboard a Hy-rail vehicle. The analysis of the data will be closely tied to maintenance of the way practices. During this reporting period, we revitalized two LIDAR measurements that were used several years ago for field testing with Norfolk Southern. The units have been made for testing onboard Hy-rail trucks. Such tests have been delayed due to the social and traveling restrictions implemented by COVID-19, as well as office and lab closings at Virginia Tech. We hope to start testing when the current restrictions are lifted nationally.

VT-4: Application of Machine Learning Techniques Toward Time-based Changes in Track Condition Using an Onboard Sensor in Revenue-Service Rolling Stock. The primary objective of this study is to evaluate the application of machine learning techniques toward time-based changes in track condition using an onboard sensor in revenue-service rolling stock. Despite regular data collection for condition monitoring on different parameters, such as vehicle acceleration and track geometry, data processing is commonly performed without knowledge discovery of track condition. Motivated by the wealth of historical track data in practice, this study investigated the feasibility of using onboard data repeatedly collected over a period of time on a segment of the track to potentially identify its changes. To account for the stochastic nature of collected data, associated with the temporal mismatch between shifted time-series across different inspection runs, we worked on adopting the Matrix Profile concept without relying on time series synchronization. The preliminary findings of the study thus far indicate, among a total of 84 identified defects, 67 of them were successfully detected by the method, corresponding to a rate of 80%. Although this is an excellent rate of defect detection, far more field data is needed to further validate the early findings. We are currently in discussions with Amtrak to potentially use some data they collect in the Eastern Corridor for the purposes of this study. The challenges posed by COVID-19 has halted our discussions with Amtrak. We intend to resume our discussions when possible.

UD-1: Development and Validation of a New Generation Rail Wear Model Using Emerging Big-Data Analytic Techniques. Phase I of the model is complete and Phase II began last quarter. The results of Phase I included development of a new methodology for alignment of continuous track inspection data to overcome issues associated with variation in location data, missing data, and non-uniform data set length. It also included development of a new generation rail wear forecasting algorithm using the Auto Regressive Integrated Moving Average (ARIMA) approach to forecast life throughout the full curve. This forecasting model allows for long-term prediction of wear rate that was validated using actual wear data from a major US Class 1 railroad. The model also addresses the issue of when to replace the rail, based on a defined rail wear limit or standard.

Phase II extends development of the wear forecasting model to account for differences in wear rates at different locations in the same curve and to develop a forecasting algorithm for use by railroad companies to more accurately predict rail replacement. UD is working with Amtrak to develop and implement this new model using rail wear data from Amtrak's high-speed Northeast Corridor. The objective is to introduce this new rail wear forecasting model into Amtrak's rail maintenance planning and budgeting activity. A UTC report on this work "The Laplace Distribution in Railway Track Degradation - A Case Study for Rail Wear" was submitted in September 2019. A second UTC report "A Stochastic Rail Wear Forecast Using Mixture Density Networks and the Laplace Distribution" was submitted in November 2019.

UD-2: <u>Rail Fatigue Life Forecasting Using Big Data Analysis Techniques</u>. This activity is nearing conclusion with its focus on developing an alternate probabilistic approach to the traditional Weibull analysis of rail defect data using Parametric Bootstrapping for the Weibull analyses and prediction of rail defect development. One of the biggest differences between the normal Weibull method and the Bootstrapped method is that the bootstrapped method provides reasonable estimates of the defect rate for track segments without any prior defect data. This by itself allows far more data analysis, and accounting for in-maintenance planning efforts. In addition, there are a range of values to use in prediction, instead of a single value; it now becomes possible to estimate a "best case" and "worst case" scenario. This approach results in an ability to forecast the probability of rail defect occurrence as a function of cumulative tonnage experienced by the rail as well as other key track and traffic parameters that affect development of fatigue defects. This activity is finalizing the approach for direct application of fatigue defect forecasting and associated rail life prediction.

UD-3. <u>Principal Components and Development of a Combined Track Quality Index (TQI)</u>. This activity looks at traditional TQIs expressed in terms of individual track parameters like gage, cross level, etc. and developing combined or consolidated TQI. However, these traditional TQIs take a narrow view of track assessment by focusing on quality without considering safety. This research looks at how to create a hybrid index that combines both element of safety and geometry quality to predict only one maintenance regime based on track condition. It is an initial step towards creating indices that will be iterated based on defect probability thresholds. This study employs a linear and nonlinear dimension reduction technique that expresses the probability distribution of observations based on the similarity or dissimilarity in their embedded space whilst also maximizing the variance in data. This study found application in principal component analysis (PCA) and T-Stochastic neighbor embedding (TSNE) for separating geometry defects from higher dimensional space to lower dimensions. Results show that while both techniques effectively reduce track geometry data, PCA yields a potential defect probability threshold in spite of TSNE being a better geometry defect predictor. Ongoing research will continue to look at how to best combine track geometry parameters into one (or low) dimensional consolidated TQI that simplifies the track properties without losing much variability in the data using Principal Components. A UTC Report "Non-Linear Dimension Reduction for Hybrid Track Quality" was submitted in October 2019.

UD-4: Load Transfer from Track to Bridge Structure on Curves. This project began in September 2019, and addresses the issue of load transfer from track to bridge structure on curved track. The design of a railway bridge is significantly different from that of a conventional highway bridge because of the additional loading imposed onto the bridge due to the track structure behavior under vehicle and thermal loading. This difference is further enhanced on curves, where the bridge is supporting a track with curvature. The initial phase of this research focused on the effect of thermal forces on welded rail in bridge structure curves. The presence of a curve results in this force having a lateral as well as a longitudinal component. To date both theoretical models based on fundamental research by Timoshenko and also by A. D. Kerr have developed as well as a finite element model and the results are currently being compared. After completion of the thermal model, we will examine a second set of analyses that look at the dynamics of a railway vehicle going around a curve and the associated wheel/rail forces. This goal of this activity is to develop a load transfer model from the track to the bridge structure. Then we will identify the vertical, lateral and longitudinal forces transmitted from the track structure to the bridge structure to aid bridge design of the railway. Note that SEPTA is partnering with the University of Delaware and will provide engineering and technical support.

UD-5: Track Geometry Models using "Small Data" Algorithm. This project addresses the use of "small data" algorithms for track geometry modeling. Track geometry quality is directly linked to vehicle safety, reliability and ride quality. Track performance is therefore considerably affected when track geometry deviates from the specified limits due to load weight and continuous usage. Analysis of track geometry data can allow for the prompt application of preventive and corrective maintenance measures, like tamping, to increase track lifespan and provide higher train speeds, thus optimizing track performance. Recently, Bayesian statistical methods have been applied in track degradation models. However, most models rely heavily on likelihood functions which are intractable. The aim of this research is to apply Approximate Bayesian Computation (ABC), also known as the likelihood-free method, in estimating Track Quality Indices (TQIs) which are essential for track degradation modeling. ABC is applied using methods like the rejection algorithm and Markov Chain Monte Carlo (MCMC). In ABC, it is essential that summary statistics are computed from the observed data followed by simulation of summary statistics for different parameter values. Two ABC-MCMC algorithms were used for parameter estimation in this report. Although ABC is computationally expensive, it was successfully applied in TQI estimation. This approach will provide a framework for working with small data sets to generate an efficient geometry model. A UTC Report, "Approximate Bayesian Computation for Railway Track Geometry Parameter Estimation" was submitted in February 2020.

UNLV-1: Mobile 3D Printing of Rail Track Surface for Rapid Repairmen. In this reporting time period, we prepared a different 3D printing technique: identifying lab space and gathering materials for the melding. During the same time period, we wrote a paper based on the submerge arc welding (SAW) technique coupled with the quenching post processing method. The paper was accepted for publication in the International Journal of Advanced Manufacturing Technology. The student hired for this project recently quit due to COVID-19.

UNLV-2: High-speed Rail Access Charge for the XpressWest of Nevada. A VISSIM-based simulation model was developed for the Palmdale - Los Angeles section of the California High Speed Rail (CA-

HSR) Network where joint train operations between the CAHSR trains and XpressWest (XW) trains are proposed. The study objective focuses on evaluating the impact of XW trains operations on CAHSR train operations during peak hour periods and various incident scenarios. The simulation model will measure delays on CAHSR operations due to interaction with XW trains and is calibrated using the draft CAHSR timetable operation information provided by CAHSR Authority. Considering the CAHSR Authority and XW desired operations, we are analyzing a timetable that factors in minimal delay interactions between CA-HSR trains and XpressWest trains. Using Component Object Module (COM) of VISSIM, we are developing a Python-based program to create various incident scenarios during simulations and analyzing the simulation data. Along with delay interactions, different types of incident handling operations are being analyzed to improve handling operation methods to minimize delay of CAHSR trains and also minimize network delay. Results of this study will be used to obtain more accurate access charge fee estimates XW may have to pay to operate on the CAHSR network.

UNLV-3: Development of Acoustics Technology to Detect Transverse Defects in Rail at High-speed (220 mph). The research team has made significant progress on rail track preparation for testing. Through coordination with a participating agency, Nevada Southern Railway, Inc., the research team completed preparation of rails for follow-up tests on the investigated sensor systems. The research team conducted various analyses on the original sensor system. Due to incompatibility of the original system to capture acoustic signals at a designed rate, over 30 KHz, the research team switched to two alternative plans (Plans B and C) where the team made considerable progress. Plans B and C employ different types of acoustic sensors in different combinations. Plan B uses two identical air-borne acoustic sensors at a rate of up to 190 kHz. After individual and cross examination followed by various mathematic and digital signal processing approaches, the team preliminarily concluded that the system can generate data indicating railway defects. Currently, more delicate data processing is en route for Plan B. Significant progress has been made toward data management at the system level. After a test at the Nevada Southern Railway, the team recommends an additional pre-amplifier and power supply for Plan C to feed the data acquisition system for reliable reading. Securing these additional resources together with sensor and system calibration is in progress, and will be delayed for at least two months due to coronavirus pandemic. Rigorous sensor testing on the prepared track will be completed during Summer 2020, after which tests at TTCI will be conducted.

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 is still working on capturing signals over 20MHz. In addition, high-speed data recording (estimated 20MB/s or higher) posed another challenge, that is, it is difficult for a regular embedded system to reach such data throughput. The team is investigating the possibility of a full field-programmable-gate-array (FPGA) design with proper high-speed analog-digital converter (ADC of over 1G samples per second). Due to the COVID-19 pandemic, on-campus research is put on hold. The team is working from home.

UNLV-5: Non-Propriety Ultra-High-Performance Concrete (UHPC) for Ballast-Track High-speed Railroad Sleepers. The primary objectives of this study is to (1) evaluate non-propriety UHPC for high-speed railway sleepers to replace the currently-used prestressed concrete sleepers and (2) optimize mixture proportions of non-propriety UHPC to achieve suitable fresh properties, sufficient strength and dimensional stability, proper toughness and ductility, and adequate transport properties and durability for proper performance during service life. To this end, 118 non-proprietary UHPCs consisting of multiple combinations of cementitious materials, fiber content, and fiber type were examined for their mechanical properties, dimensional stability, and durability characteristics. Test results revealed that compressive strength, indirect tensile strength, and stiffness of the studied UHPCs surpassed those of prestressed concrete by several folds. Despite the high-cementitious material content of UHPCs, their dimensional stability, expressed in terms of drying shrinkage, remained manageable. The resistance to wear, freezing and thawing of the studied UHPCs were exceedingly superior to prestressed concrete typically used for railway ties. These encouraging results have prompted further evaluation of non-proprietary UHPCs in a bench scale study.

UNLV-6: <u>Development of UAV-Based Rail Track Irregularity Monitoring and Measuring Platform</u>. The UAV can now take the payload (mostly the data collection platform) and fly over the target rail tracks. The system includes a LIDAR for 3D cloud point modelling of surrounding objects, controlled by an on-vehicle Raspberry Pi and a remote laptop terminal, and a full high-definition (FHD, 19201080 resolution), high-speed (60 or 120 frames per second, fps) camera for 2D image collection. The LIDAR and the camera are mounted side-by-side to ensure they have nearly identical field of view, and the scanning angle is adjustable (between 0 for scanning forward and 90 for straight downward). The entire UAV system is operated through a remote controller, with a first-person-view (FPV) camera to assist flying. The data collection system works perfectly. However, a challenge occurs with system integration and data synchronization, as currently the LIDAR and the camera operates using their own controllers, which causes limited flight/data collection distance to 40m due to the wireless covering range. A baseline program for 2D image segmentation with deep learning architectures and convolutional neural network were developed and worked well in the current railway image dataset collected at Nevada Southern Railway Inc. in Boulder City, NV. More image processing algorithms will be investigated to improve segmentation accuracies and the following pixel-wise geometry measurement.

UNLV-7: <u>Transit Degradation Monitoring and Failure Prediction of Carbon Strip in Pantograph</u>. The weakest link in powering high-speed rail locomotives is the carbon strip of a pantograph collector which makes physical contact between the overhead power line and the electrical supply wires of the locomotive. This project aims to determine the degradation effects of the carbon strip by monitoring the locomotive’s input current line. During this reporting period, we purchased supplies, machined, built, and tested both single-pulsed and multi-pulsed power carbon degradation test stands. Independent voltage and current monitors dedicated to the test stand were designed, built, and tested. These monitors verify the accuracy of the electromagnetic dot sensors. We acquired a typical commercialized carbon strip from a vendor (compliments of Schunk). Sections of the carbon strip were altered to exhibit various configurations that suggest normal and abnormal wear and tear patterns on a macroscopic level. The electromagnetic dots are based on a coaxial configuration used to monitor the line current during evaluation of the test stand. Visually, the magnetic field signature generated by arcing is distinguishable from the discharge noise generated by the tube switch. At this time, data has not yet been recorded or evaluated. Prototype electromagnetic dots based on strip line/microstrip configurations have been designed and sent to third party printed circuit board (PCB) vendors for building. We are currently trying to develop a work around for violating PCB manufacturing protocols necessary to realize the sensor end of the dots. In October 2019, we presented our initial research efforts to the 29th Annual Fall Transportation Conference held in Las Vegas, Nevada.

Initiating new research programs

In this reporting period, no new research projects were initiated by Virginia Tech, the University of Delaware, or the University of Nevada Las Vegas. Rather the focus was on finishing existing projects and insuring all research is complete within the five-year UTC funding timeline.

Upgraded education opportunities

Virginia Tech plans to offer a distance learning graduate course on "Rail System Dynamics". This course could potentially be broadcast to the University of Delaware and UNLV. Additionally, VT plans to offer a one-day professional development seminar on Fundamentals of Rail System Dynamics on May 18, 2020, as part of the planned second RailTEAM Symposium on Track Maintenance Diagnostics and Prognostics on May 19-20, 2020 in Roanoke, Virginia. Both the seminar and symposium were cancelled due to COVID-19 travel restrictions. VT will evaluate the possibility of offering both at a later date in 2020 or 2021, when the current uncertainties pass.

At the University of Delaware, a new professional development course "Rail Grinding and Rail Maintenance" is scheduled for delivery to Amtrak in early 2020. A national webinar on "How to Use Railway Inspection Data for Maintenance of Way Decisions" was given by UD on October 24, 2019 in conjunction with Progressive Railroading magazine.

UNLV offered "Railroad Engineering" in the Spring of 2020. Starting from Spring 2020, a group of senior design students developed a project that designed an interchange at Blue Diamond Road crossing at the Union Pacific Railroad in Las Vegas, Nevada.

Opportunities for training and professional development

As mentioned earlier, the VT team was in ongoing efforts to offer a professional development seminar on May 18, 2020 in Roanoke, Virginia, in conjunction with the second RailTEAM Symposium on Track Maintenance Diagnostics and Prognostics until forced cancelation. The symposium was intended to provide ample training and professional development for rail engineers, researchers, and scientists in the area of improving track maintenance practices.

The University of Delaware's Professional Engineering Outreach provides professional courses for practicing railroad and transit professionals. These professional development courses include Application of Emerging Data Science Techniques for Railway Maintenance Planning, given in December 2019 as well as Rail Grinding and Rail Maintenance scheduled in March 2020.

The Big Data in Railroad Maintenance Conference is held annually at the University of Delaware and co-sponsored by the RailTEAM UTC in December each year. This conference addresses the growing use of data analytics in railroad maintenance planning and management and draws over 200 attendees from railroads, transit systems, railway suppliers, data analytic companies and academia. The last conference, December 11-12, 2019, featured a keynote speech by Mr. Jeffrey Knueppel, General Manager of Southeastern Pennsylvania Transit Authority (SEPTA) and over

30 technical presentations. The upcoming 2020 conference is currently scheduled for December 16-17, 2020 at the University of Delaware.

Results disseminated

At Virginia Tech, beyond the ongoing meetings with our industrial partners (Norfolk Southern and Amtrak), we attended conferences, such as the Big Data Conference at the University of Delaware in December 2019. We presented some of our research related to machine learning and data analytics (VT-4, described earlier) at this conference. Our contacts with potential industrial partners, such as Wabtec-GE, Plasser American, Alstom, and Ensco are currently on hold. The current economic downturn is anticipated to cease continuation of such discussions, although we do intend to continue pursuing the railroad industry for collaboration and funding.

The University of Delaware conducted two major activities to disseminate results to industry and academia. The annual "Big Data" in Railroad Maintenance Planning was held on December 11-12, 2019 and was once again a resounding success, with more than 200 professionals from a spectrum of companies, universities, and government agencies attending the one and one-half day event. RailTEAM project results were presented by speakers from both the University of Delaware and Virginia Tech. The next conference is scheduled for December 16-17, 2020 at the University of Delaware in Newark, DE. During the 2019 conference, presentations by Joe Palese of the University of Delaware and Mehdi Ahmadian and Milan Afzalan of Virginia Tech dealt directly with UTC projects in addition to presentations by Nii-Attoh-Okine and Allan Zarembski of the University of Delaware.

As noted above, a national webinar on "How to Use Railway Inspection Data for Maintenance of Way Decisions" was given by UD on October 24, 2019 in conjunction with Progressive Railroading magazine. This webinar, presented by Joe Palese of UD, included results from the UTC-sponsored Rail Wear Forecasting project, and was attended by over 200 participants.

Likewise, the University of Delaware maintains contact with industry partners and its own railway advisory board to present UTC project results. In particular, the recently completed wheel wear project as well as the ongoing rail wear project was presented to UD Railway Advisory Board in December 2019, as well as a presentation of results to the ASME Joint Rail Conference as reported previously.

UNLV presented three of their UTC projects at the Fall Transportation Conference on October 31, 2019 in Las Vegas, Nevada. As one of the few UTCs selected by the USDOT, UNLV also presented their research on 3D-printing application in repairing worn rail at the Consumer Electronics Show (CES 2020) on January 10, 2020 in Las Vegas, Nevada. News agencies followed up on our research for their reporting.

Plan for the next reporting period

The research proposed in all four Virginia Tech projects (VT-1 to VT-4), described earlier, intends to continue during the upcoming reporting cycle. Additionally, we are evaluating additional promising projects for pursuit in the future, 2021 and beyond.

At the University of Delaware, we plan to continue research activities with our graduate students and research scientists. We estimate publishing two to three journal papers and making two to four presentations.

In the upcoming half year, UNLV will test the new 3D printing technique for repairing worn rail. The access charge project will be completed with a final written report. The acoustic rail defect detection device will be tested in the lab in Las Vegas, Nevada, and in the field at TTCI in Colorado. A prototype UAV to measure track geometry will be developed with improvements to be made in the future. The second phase of ultra-high performance concrete for the high speed rail tie will be started in this period. Lab testing of the pantograph defect detection system will be completed in the next six months.

2. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

Organizations involved as partners

Virginia Tech continues its close collaboration with Norfolk Southern (NS) and Amtrak. This in-kind collaboration has been quite valuable to us, in terms of bringing engineering input into projects, providing access to revenue service track for field testing our systems, and providing us field data to evaluate the effectiveness of data analysis methods developed for most of our projects. Although these efforts have been greatly challenged by the COVID-19 situation, we are optimistic we will have the opportunity to resume collaboration with our past industrial partners when time permits.

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. CSX is also providing rail data for the rail fatigue project. In addition, the track-bridge interaction project is getting technical support from SEPTA (Southeastern Pennsylvania Transportation Authority) with headquarters in Philadelphia PA. In-kind support with SEPTA engineering personnel will provide technical information, support and guidance, including engineering details on track and bridge interaction design on SEPTA's elevated structures.

Nevada Southern Railway, Inc. has dedicated railroad track for our testing acoustic rail defect sensors and making field available to test the UAV getting LIDAR and camera data. Their staff runs the railroad car equipped with our track sensor on their track with defect embedded rail.

Other collaborators or contacts involved

None to report during this period.

3. OUTPUTS

In this reporting period, we published 11 technical papers in peer-reviewed conferences or journals, which far exceeds our target: three or four papers in six months. We do not have any invention disclosures and provisional or utility patent applications filed, which is lower than our target (one or two), each year, respectively. Hopefully, we will have invention and patent applications in the next six months.

Publications, conference papers, and presentations

The presentations and publications developed by our UTC team are listed below.

Publications

1. Mast, T., Neighborgall, C., Peterson, A., Holton, C., and Ahmadian, M., Sensor Selection Consideration for Top-of-Rail (TOR) Lubrication Detection, Proceedings of the 2020 Joint Rail Conference, St. Louis, MO, April 20-21, 2020. The conference was postponed to 2021 due to COVID-19 social and travel restrictions. UTC support acknowledged. (Virginia Tech)
2. Radmehr, A., Ahangarnejad, A.H., Tajaddini, A., and Ahmadian, M., Surface Profile and Third-body Layer Accumulation Measurement Using a 3D Laser profiler, Proceedings of the 2020 Joint Rail Conference, St. Louis, MO, April 20-21, 2020. The conference was postponed to 2021 due to COVID-19 social and travel restrictions. UTC support acknowledged. (Virginia Tech)
3. Afzalan, M., Jazizadeh, F. K., and Ahmadian, M., Towards Railway Automated Defect Detection from Onboard Data using Deep Learning, Proceedings of the 2020 Joint Rail Conference, St. Louis, Mo, April 20-21, 2020. The conference was postponed to 2021 due to COVID-19 social and travel restrictions. UTC support acknowledged. (Virginia Tech)
4. Radmehr, A., Ahangarnejad, A.H., Tajaddini, A., and Ahmadian, M., Influence of Angle of Attack on Wheel-rail Interface (WRI) Dynamics Under Various Friction Conditions, Proceedings of the 2020 Joint Rail Conference, St. Louis, MO, April 20-21, 2020. The conference was postponed to 2021 due to COVID-19 social and travel restrictions. UTC support acknowledged. (Virginia Tech)
5. Tan, Y., Hosseini, S-M, Chen, Y., and Ahmadian, M., Simulation Evaluation of Fouled Ballast Thermal Characteristics, Proceedings of the 2020 Joint Rail Conference, St. Louis, MO, April 20-21, 2020. The conference was postponed to 2021 due to COVID-19 social and travel restrictions. UTC support acknowledged. (Virginia Tech)
6. Dama, N. and Ahmadian, M., Discrete Element Modeling of Railway Ballast for Studying Railroad Tamping Operation," Proceedings of the 2020 Joint Rail Conference, St. Louis, MO, April 20-21, 2020. The conference was postponed to 2021 due to COVID-19 social and travel restrictions. UTC support acknowledged. (Virginia Tech)

7. Hosseini, S-M, Tan, Y., and Ahmadian, M., Forward-Looking Infrared Radiometry (FLIR) Application for Detecting Ballast Fouling," Proceedings of the 2020 Joint Rail Conference, St. Louis, MO, April 20-21, 2020. The conference was postponed to 2021 due to COVID-19 social and travel restrictions. UTC support acknowledged. (Virginia Tech)
8. Radmehr, A., Ahangarnejad, A.H., Pan, Y., Tajaddini, A., and Ahmadian, M., Wheel-Rail Contact Patch Geometry Measurement and Shape Analysis Under Various Loading Conditions, Proceedings of the 2020 Joint Rail Conference, St. Louis, MO, April 20-21, 2020. The conference was postponed to 2021 due to COVID-19 social and travel restrictions. UTC support acknowledged. (Virginia Tech)
9. Lasisi, A, Merheb, A, Zarembski, A.M., and Attoh-Okine, N., Rail Track Quality and T-Stochastic Neighbor Embedding for Hybrid Track Index, Proceedings of IEEE Big Data 2019 Conference, Los Angeles, CA, December 2019. UTC support acknowledged. (University of Delaware)
10. Alsahli, A, Zarembski, A.M., Palese, J. and Euston W., Investigation of the Correlation between Track Geometry Defect Occurrence and Wood Tie Condition, Journal of Transportation Infrastructure Geotechnology, pp. 226-244 Vol. 6, Issue 3, September 2019. UTC support acknowledged. (UNLV)
11. Mortazavian, E., Wang, Z. and Teng, H., Repair of light rail track through restoration of the worn part of the railhead using submerged arc welding process. Accepted for publication in the International Journal of Advanced Manufacturing Technology, March 2020. UTC support acknowledged. (UNLV)

Presentations

1. Attoh-Okine, N., Application of Data Analytcis to Railway Maintenance, Conference of Big Data in Railway Maintenance 2019, December 11-12, 2019. UTC support acknowledged. (University of Delaware)
2. Palese, J., Application of Data Analytics to Rail Wear Forecasting, Conference of Big Data in Railway Maintenance 2019, December 11-12, 2019. UTC support acknowledged. (University of Delaware)
3. Zarembski, A.M., Probabilistic Relationship for Development of a Severe Track Geometry Defect based on Ballast Condition as Measured by GPR, Conference of Big Data in Railway Maintenance 2019, December 11-12, 2020. UTC support acknowledged. (University of Delaware)
4. Lasisi, A, Merheb, A, Zarembski, A.M. and Attoh-Okine, N., Rail Track Quality and T-Stochastic Neighbor Embedding for Hybrid Track Index" IEEE Big Data 2019 Conference, Los Angeles, CA, December 2019. UTC support acknowledged. (University of Delaware)
5. Ashley, G. and Attoh-Okine, N.O. Approximate Bayesian Computation for Railway Geometry Modeling, Transportation Research Board Annual Meeting, Washington D.C., 2020. UTC support acknowledged. (University of Delaware).
6. Zarembski, A.M., Yurlov, D, Palese, J. W. and Attoh-Okine, N., Determination of Probability of a Track Geometry Defect based on GPR Measured Subsurface Conditions Using Data Analytics, 2019 World Congress of Railway Research, Tokyo, Japan, .October 28- November 1, 2019. UTC support acknowledged. (University of Delaware)

7. Dai, A., Zhu, M., Jiang, Y., and Teng, H., Development of UAV-based Rail Track Irregularity Monitoring and Measuring Platform, Fall Transportation Conference, Las Vegas, Nevada, October 31, 2019. UTC support acknowledged. (UNLV)
8. Ghafoori, N. and Hasnat A., Non-Proprietary Ultra High-Performance Concrete for Ballast-Track High Speed Railroad Sleepers, Fall Transportation Conference, Las Vegas, Nevada, October 31, 2019. UTC support acknowledged. (UNLV)
9. Schill, R., Transit Degradation Monitoring and Failure Prediction of Carbon Insert (Strip) in Pantograph Shoe, Fall Transportation Conference, Las Vegas, Nevada, October 31, 2019. UTC support acknowledged. (UNLV)

Magazine articles

1. Zarembski, A. M., Big Data in Railroad Maintenance Management: The Railroad Industry Continues to Make Use of Big Data, Railway Age, March 2020. (University of Delaware)

Policy Papers

None to report

Website

Virginia Tech's efforts are highlighted on the webpage for the Center for Vehicle Systems and Safety (http://www.me.vt.edu/research/centers/cvess/), as well as RailTEAM's webpage (https://www.unlv.edu/railteam). The University of Delaware has highlighted the railway research and educational activities in their Railroad Engineering and Safety Program website (railroadengineering.engr.udel.edu/). UNLV routinely updates the RailTEAM website with information from partnering universities.

Technologies or techniques

The body of knowledge related to application of FLIR technology for railroad/transportation applications (VT-2) has increased through our efforts at Virginia Tech. Our study has scientifically highlighted capabilities and limitations of the FLIR technology for early assessment of ballast fouling, beyond its conventional use for military and limited number of civilian applications. Additionally, the use of LIDAR systems in VT-1 and VT-3 for track applications has significantly improved the knowledge base on how optics sensors can be used for high-fidelity and precise measurements in railroad environment.

The University of Delaware developed noteworthy maintenance models. One is the method/model for predicting wear life of railway rails that was presented at Big Data in Railway Maintenance 2019 conference, December 2019. The other model is new track quality index for maintenance planning, included in a paper presented at the IEEE Big Data 2019 Conference, Los Angeles, CA.

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

Inventions, patent applications, and/or licenses:

None to report.

4. OUTCOMES

Passage of new policies, regulation, rulemaking, or legislation

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

Increases in the body of knowledge

The body of knowledge related to the application of FLIR technology for railroad/transportation applications (VT-2) has increased through our efforts at Virginia Tech. Our study has scientifically highlighted the capabilities and limitations of FLIR technology for early assessment of ballast fouling, beyond its conventional use for military and limited number of civilian applications. Additionally, the use of LIDAR systems in VT-1 and VT-3 for track applications has significantly improved the knowledge base on how optics sensors can be used for high-fidelity and precise measurements in railroad environment.

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

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

Early results from the VT-1 project indicates strong potential to improve track lubrication processes in terms of the amount ToR friction modifiers are applied to the rail. Better understanding of how far ToR migrates on the track from its application location will also assist with better placement of applicators on track relative to curves, etc.

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

Enlargement of the pool of trained transportation professionals

Close collaboration between Virginia Tech, NS and Amtrak has led to further training for their engineers who are involved with projects in the area of optics sensors and machine learning techniques. The Nevada Southern Railroad staff, assisting with the UNLV testing acoustic rail defect sensor, has a better understanding how the rail is inspected manually by using different technologies.

At the University of Delaware, graduate students working on research projects move into the rail and transit industry. One graduate student who worked on the wheel wear project has graduated and taken a position with SEPTA (Southeastern Pennsylvania Transportation Authority). Another PhD student took an extended internship with the US Federal Railroad Administration. Another senior, who works as an undergraduate research assistant, is doing his second summer internship with Amtrak this summer, and expects a job offer from Amtrak which he will accept.

The University of Delaware's undergraduate and graduate courses, including its Graduate Certificate in Railroad Engineering trains both undergraduate and graduate students for a railway or transit career. Graduates of the UD program have gone on to work at Amtrak, SEPTA, BNSF, international railways (Brazil, Israel), and several major railway consulting companies (such as WSP, HNTB. Jacobs, AECOM, etc.). The program also trains working professionals who get UD's Graduate Certificate in Railroad Engineering, which includes professionals from Amtrak, SEPTA, US Navy, and numerous consulting groups and international railways.

One UNLV student, who took a railroad engineering class in Spring 2020, accepted a position at a geotechnical engineering firm preparing to build the high speed rail from Southern California to Las Vegas, Nevada. Three undergraduates taking a senior design class chose to design an interchange at Blue Diamond Road Crossing for Union Pacific Railroad.

Adoption of new technologies, techniques or practices

University of Delaware's rail wear forecasting methodology is shared with Amtrak who currently work with UD to apply this to their current rail wear analysis and rail replacement planning tools as part of their maintenance planning programs.

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

In this reporting period, we have 13 citations for the research work we published which is five more than the citations we expected. University of Delaware's research activities are regularly reported in the major US railway news magazines. In this past six months we have seen articles in both Railway Age and Progressive Railroading about our research activities. The 3D printing work repairing worn rail demonstrated at the CES in Las Vegas in January 2020 was covered in the ASCE magazine. The total number of news stories, three this period, is more than the two we expected.

5. IMPACTS

Impact on the effectiveness of the transportation system

In general, much of the research conducted under this UTC activity lends itself to 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 technology. The impact of technologies under development at the RailTEAM UTC are directly related to improving track maintenance practices. U.S. railroads collectively spend billions of dollars in track maintenance. Even small improvements in maintenance of way practices would have a major positive financial impact for the railroads. Technologies that are part of Virginia Tech's studies are those identified by the U.S. railroads as having a significant impact on their revenue service operation. The eventual deployment of both the LIDAR and machine learning technologies are anticipated to have a positive and measurable impact in transportation safety and efficiency. At Virginia Tech, both FLIR and LIDAR technologies, that we currently work on as part of our DOT-UTC efforts, promise significant impacts on the rail industry. These technologies could result in many millions of dollars in annual savings in managing maintenance-of-way for the U.S. railroad industry.

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. As this model gets fine-tuned and validated, we expect implementation on many major US rail systems, including freight railways, passenger and commuter railways and rail transit systems.

Also, as reported previously, the University of Delaware extended its developed method to predict the rate of wheel wear. The railways can directly apply models to predict 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 as to how it can be incorporated in their maintenance and safety programs.

A new method of predicting development of rail fatigue defects by the University of Delaware examined 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 rail forecasting effectiveness.

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

Impact on the adoption of new practices

Projects at Virginia Tech have not reached a point where the technologies are commercialization ready. The closest is the LIDAR technology being developed in VT-1 and VT-3. This technology could have a significant impact on improving safety and operational efficiency for the rail industry. For instance, the ability to measure the existence or lack of rail lubricant will enable railroad systems to better manage wheel-rail friction at the running surface, hence reduce fuel costs due to rolling resistance at the wheel and also reduce wheel/track wear (and even damage) due to unnecessarily high friction. An additional impact of the technology is in its ability to provide in-situ measurement of track gauge onboard a locomotive or Hy-rail vehicle. Gauge widening under high-lateral loads is often the cause of derailment on curves. This technology will enable the railroads to detect and fix “soft” spots on the track, before they become a costly derailment. Again, this will have a significant operational safety and cost impact.

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

Impact on the body of scientific knowledge

Virginia Tech is developing a LIDAR system that promises significant highway applications for assessing roadway surface conditions, thus, paving the way for a critical technology necessary for semi-autonomous and autonomous vehicles. LIDAR system technology could potentially impact the transportation industry by improving driving safety. For instance, the same technology we use for lubricity detection can potentially assess road surface conditions by detecting black ice and other events not readily visible by drivers. The FLIR cameras being evaluated as part of VT-2 can also detect the presence of trespassers at railroad crossings, beyond what is possible with surveillance cameras installed at some locations. Whereas optical cameras need light to see, FLIR cameras can detect the presence of a warm object, such as a trespasser under all conditions, day or night.

The University of Delaware has developed approaches and methodologies for maintenance of 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

We are continuing our efforts to educate undergraduate and graduate students for the rail industry, at Virginia Tech. In the past six months, one of our graduate students found employment with our rail partners. Two undergraduate students were offered summer internships at Amtrak and CSX, but those internship offers were rescinded in April due to the rapid increase in workforce attrition. The current economic downturn due to COVID-19 is expected to increase challenges associated with partnering with the public and private sector for educational purposes, at least in the near future.

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

The UTC program at UNLV continues to provide railroad education by offering courses and holding seminars. More students have become interested in railroad and take railroad classes and develop senior design projects. They have found jobs in the railroad industry. The program also provides support for students to attend conferences, such as AREMA conference and the TTCI workshop which provides opportunities to relate to the railroad society.

In this reporting period, both Amtrak and Norfolk Southern indicated a strong interest in the research conducted at Virginia Tech. Amtrak and NYC Transit have been interested in their research on wheel life studied at the University of Delaware. The City of Seattle interviewed UNLV about how to establish a high-speed rail authority in the northwest corridor where a super high-speed rail is in the planning phase. We have at least five cases where stakeholders requested RailTEAM expertise in the application of research products and/or results, more than we planned, which is one per year.

In addition, both Amtrak and NYC Transit have taken results of the UTC research at the University of Delaware and worked to introduce these research results into their day-to-day and annual maintenance and planning activities. This performance is exceeding our expectations, one transfer per year. Note that meeting performance objectives in the future, however, is expected to be a major challenge due to the COVID-19 related economic downturn.

6. CHANGES/PROBLEMS

No changes in approach.

Actual and anticipated problems or delays

COVID-19 has disrupted our research, education and information dissemination activities. The RailTEAM Railroad Infrastructure Symposium originally scheduled for May 19-20, 2020 has been postponed to 2021. Funding from our partnering railroad industry may not be realized. Some students working on research projects left the program due to COVID-19. The purchase of some hardware was delayed several months, which is expected to delay some of the deliverables for the program.

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

7. SPECIAL REPORTING REQUIREMENTS

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