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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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, which will cause demand for both intra- and inter-city passenger and freight travel to significantly increase. Railroads will play a larger role than ever in carrying this demand. Such increased use, in turn, will expedite the deterioration of the railroad system. The 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 is to focus on four areas of research that are critical to railroad system operations and safety:

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

Virginia Polytechnic Institute and State University (Virginia Tech) focuses on condition monitoring, remote sensing, and the use of laser- 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, five (5) at Virginia Tech, four (4) at the University of Delaware, and six (6) at UNLV. Significant advances were made in each project. The project progress is described below.

VT-1: Determination of Top of Rail (ToR) Lubricity using Stationary and Moving Contacting and Non-Contacting Devices. The primary objective of this study is to design and build highly-accurate contacting and non-contacting devices for use in measuring the presence or absence of ToR friction modifiers that are applied in extremely thin layers — commonly in microns — with stationary and moving devices. Two new generations of LIDAR-based measurement units were designed and partially evaluated during this reporting period. Both new units use lasers with different optical frequency characteristics than the previous units. Their selections stemmed for a large amount of tests that we had conducted on the earlier units that showed unwanted sensitivity to ambient light during daytime measurements. In order to reduce this sensitivity and improve the accuracy and practical application of the measurement units, we use blue lasers in our new measurement units. The initial stationary testing with the new units has been encouraging. Efforts are underway to fabricate a remotely-controlled rail cart that can be operated at speeds up to 10 mph, for on-track field testing of the new units. Additional efforts are underway to evaluate the sensitivity of the measurement devices to heat, contaminants, and other elements that exist in a typical railroad environment. The power consumption of the units is also monitored and some effort in the future will be devoted to ensuring that the systems can sustain continuous testing for up to two hours in the field. Two papers are being prepared for presentation and publication at the 2020 ASME Joint Rail Conference (JRC) in Saint Louis.

VT-2: Dynamic Analysis and Process Improvement for Tamping Practice. The primary objective of this study is to develop an accurate dynamic model to study the factors that influence tamping practices adopted by the U.S. railroads. The dynamic model that was under development in the earlier parts of this study was completed during this reporting period. This process proved to be quite challenging due to the use of non-spherical clumps as the ballast and the limitation of the software (PFC-3D) in simulating a large number of irregularly-shaped particles. Each simulation run took several days to converge. This limitation severally hindered our ability to run a large number of parametric studies. Nonetheless, we succeeded in running a limited number of parametric studies. The Taguchi method was used to minimize the number of individual runs needed for the study. The main emphasis of the study was to evaluate how the tamping tine motion (linear, circular, or elliptical) and frequency can affect the ballast liquefaction and compaction, while minimizing damaging (crushing) the ballast. A final report is being prepared on this project, which we intend to submit by the end of 2019. Additionally, a paper that summarizes the findings is under preparation for presentation and publication at the 2020 ASME Joint Rail Conference (JRC) in Saint Louis.

VT-3: Monitoring and Detecting Fouled Ballast using Forward Looking Infrared Radiometer (FLIR) Aerial Technology. The primary objective of this study is to explore the application of FLIR technology for assessing the early stages of ballast fouling (due to fine particles such as coal, soybean, grains, etc.) before they lead to track pumping (clogged water that leads to significant track damage). The earlier tests were continued for determining the extent to which a mid-priced, off-the-shelf FLIR camera can be used for measuring track surface temperature fluctuations during naturally-occurring heating up and cooling down daily cycles. The track and ballast were presented in controlled boxes that could be placed outside in conditions similar to what railway tracks undergo. Each ballast box was instrumented in four layers, at varying depths, from the surface to allow evaluating changes in temperature with the ballast depth. Additionally, each ballast box was set up with a controlled amount of fouling that simulated light to severe fouling. The surface temperature measurements by the FLIR camera and thermocouples were recorded during daily cycles over multiple days. Additionally, the tests were performed with dry and ballast with different amount of fouling to determine the effect of moisture content on the surface temperature measurements by the FLIR camera. The results proved to be moderately successful. They indicate that although the camera used for this study can measure some differences in temperature stemming from ballast fouling and increased moisture content, a more expensive camera is recommended to achieve the sensitivity needed to reach more conclusive results. The findings of the study will be documented in a final report. Additionally, a paper that summarizes the findings is under preparation for presentation and publication at the 2020 ASME Joint Rail Conference (JRC) in Saint Louis.

VT-4: Application of machine learning techniques toward time-based change in track condition using an onboard sensor in revenue-service rolling stock. The primary objectives of this study are to:

1. Develop an automated platform for defect identification and localization by leveraging historical onboard rolling stock data
2. Develop a defect annotation approach to predict the defect level
3. Integrate an intuitive visualization platform to assist human operators for track monitoring

Condition monitoring of rail infrastructure is vital to ensure safety and ride quality. Increasing travel demands of the rail network due to higher miles traveled requires regular monitoring of the infrastructure and efficient processing of the data for timely decision-making. Despite the regular data collection on different parameters, such as acceleration and track geometry, data processing is commonly performed to document track performance and maintenance without further knowledge discovery to realize all potential from historical data. Motivated by the wealth of historical track data in practice, in this project, we summarize our findings on using machine learning for track monitoring using onboard rolling stock data. In contrast to methods that typically rely on installing instrumentation wayside (which hinders covering a large spatial area for monitoring, or employing specific data sources), we leverage onboard rolling stock data, such as acceleration and track geometry, that are more accessible to the rail industry. We have provided applications such as enhanced visualization tools for assisting human operators for defect flagging and automated defect identification and level classification. The frameworks are evaluated on segments of Class I railroad, which shows the applicability of using machine learning methods for successful defect identification and localization. This study is performed in collaboration with Amtrak who is providing some track data needed for the study.

We have introduced a track monitoring framework through mining various repeatedly collected data between distinct locations to monitor any gradual changes that may occur over time. The process is somewhat similar to the process followed by the railroads in analyzing their track geometry data with an experienced track engineer, except with far less manual effort. We introduced a change index (CI) that searches in the spatial data from repeated runs over a span of time to highlight the potential changes that occur in the track and flag defects. Using the repeated data collections in the approach could result in automated knowledge discovery that helps human operators make better decisions. To overcome the challenges involved with asynchronous data, the concept of matrix profiling was employed. The preliminary results on a segment of class I railroad shows the promising capability of the CI for identifying and localizing defects. Some of the results of this study are being prepared for presentation at the University of Delaware's Big Data conference in December 2019. Additionally, a paper that summarizes the findings is under preparation for presentation and publication at the 2020 ASME Joint Rail Conference (JRC) in Saint Louis.

VT-5: Application of Doppler LIDAR Sensors for Assessing Track Gauge Widening in Curves and Locations with High-Lateral Forces. This effort has revitalized an extensive laboratory and field study by Virginia Tech toward the application of laser-based measurement units that provide the ability to measure track speed and changes in track geometry in motion. A prototype unit intended for track geometry car installation proved to be successful as a replacement to wheel-mounted tachometers that are often used for determining distance travelled on track and track curvature. The same unit proved effective in measuring variations in track geometry such as gage widening. This effort has renewed our past study toward a simpler system for use onboard a locomotive or hyrail truck for determining any track gage widening that may exist. The system previously used for our prior studies was tested in the laboratory for proper optics and analog/digital functioning. A few improvements were made to the system. A mounting unit was designed for the laser heads to enable mounting them onboard a hyrail truck operated by Norfolk Southern (NS). The system was installed and underwent initial functional testing. The necessary training was provided to NS engineers for operating the system. The data collected by NS was evaluated and discussed at length with track engineers. The preliminary results indicate a strong potential for the application of laser-based systems for onboard measuring of gage widening in the field. The future of this project, however, is currently in doubt. This is mainly due to change of priorities and personnel at NS. It is not clear if we will be receiving any future support from NS for track testing the prototype system that has been used for data collection. Absent of such support, we will not be able to evaluate the practical application of this technology beyond the laboratory evaluations already done. A determination will be made to continue or sunset this project for next year by the end of 2019.

UD-1: Analysis of Wheel Wear and Forecasting of Wheel Life for Transit Rail Operations. This project was completed in Spring of 2019 and a final UTC report submitted. The results were also shared with New York City Transit (NYCT) and provided to both their Research Group and their Car Equipment group together with recommendations for implementation on NYCT. A paper and presentation of the results were made at the 2019 ASMEE-IEEE Joint Rail Conference, April 9-12, 2019, Snowbird, Utah. Results of the project include determination of a wheel-wear algorithm which can be used for forecasting wheel flange wear and determination of when the next maintenance event is likely to occur. Results also included identification of three different sub-populations of rail cars within the analysis fleet, based on their actual wear performance. In particular, one subpopulation of wheels exhibits a very high rate of flange wear and was classified as "bad actors". This is of real practical significance and the information provided to NYCT can help identify and understand these bad actor rail cars, so that more regular inspections and maintenance can occur.

UD-2: Cupola-Based Derailment Prediction Model. This project is complete and UTC report submitted. Results included a model to predict the severity of train derailments using Copula-based regression techniques. The results were published in a paper for ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering (2018).

UD-3: 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 is beginning. The results of Phase I included the development of a new methodology for alignment of continuous track inspection data to overcome issues associated with variation in location data, missed data, and non-uniform data set length. It also included the development of a new generation rail wear forecasting algorithm using Auto Regressive Integrated Moving Average (ARIMA) approach to forecasting 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. These results were presented (and published) at the American Railway Engineering Association Annual Conference at Chicago, IL. in September 2018 and published in the Journal of Rail and Rapid Transit (2019).

Phase II, started in 2019, will extend 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 railroads to more accurately predict rail replacement. Amtrak has agreed to participate in this Phase II activity and provide additional wear (and other data) to support the activity. The resulting model will be implemented on Amtrak's high-speed Northeast Corridor and used in conjunction with their rail maintenance planning and budgeting activity.

UD-4: Rail Fatigue Life Forecasting Using Big Data Analysis Techniques. This activity is ongoing and its focus is to develop an alternate probabilistic approach to the traditional Weibull Analysis of rail defect data where the probability distribution of Weibull parameters is developed based on a statistically significant set of actual railroad data. This led to the use of 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 rate of defects for track segments without any prior defect data. This by itself allows far more data to be analyzed, and to be accounted for in maintenance planning efforts. In addition, there are a range of values to use in the 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 the development of fatigue defects. While the basic theoretical approach has been developed, the focus is now on developing an application approach for direct application of fatigue defect forecasting and associated rail life prediction.

UNLV-1: Mobile 3D Printing of Rail Track Surface for Rapid Repairmen. In this reporting time period, we analyzed the data from testing the railhead repaired using the submerge arc welding (SAW) technique coupling with the quenching post processing method. We found the quenching method is very effective in increasing the hardness of the repaired railhead above the AREMA standard. A journal paper was written based on this research work. By comparing the lab testing results from the laser cladding and SAW method, we identified another 3D printing technique that can repair the worn railhead. We have been preparing the relevant materials for the new 3D printing technique and have contacted manufacturers to conduct 3D printing based on our designed procedure.

UNLV-2: High-speed Rail Access Charge for the XpressWest of Nevada. We have been developing a VISSIM-based simulation model for analysis of HSR operations on the California high speed rail (CA-HSR) Network. The objective of the study is to evaluate the impact of XpressWest (XW) train operations on CA-HSR train operations. The simulation model developed will measure excess delays on CA-HSR operations due to interaction with XW trains that will run on portions of the same network. We will evaluate excess delays during planned normal operations as well as during incident scenarios. Results of this study will be used to obtain more accurate estimates of the access charge fees that XW may pay to be allowed to operate on the network. This model will also be used to develop timetables that can minimize these interaction delays between the two train systems on the CA-HSR network.

UNLV-3: Development of Acoustics Technology to Detect Transverse Defects in Rail at High-speed (220 mph). This project has made great strides in developing the prototype sensor as the Electrical Engineering team completed the design of the sensor boards. Each board was manufactured and initially bench tested. Work is ongoing to fabricate the enclosure to house the electrical components including the microcontroller, data storage, communication, and power devices. The Civil Engineering team has completed the train mount to connect the sensor and enclosure to the rolling stock for preliminary testing. Initial testing will be conducted at the Nevada Southern Railway Inc. The team is actively working with the Railroad to arrange for installation of a test track to evaluate the sensor. A line of track was donated that includes typical in-service damage. The track will be installed on an isolated line at the Railroad for sensor testing and evaluation. Track installation and preliminary sensor testing completed during Summer 2019.

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. Research staff is still working on the circuit design and simulation for ultra-high frequency (UHF) (>300 MHz) signal sampling and storing on the field-programmable-gate-array (FPGA) and micro-controller unit (MCU). The overall circuit architecture for the UHF detector is completed, but delicate reconfiguration is still required as onboard memory and data process capability could be overwhelmed with the huge amount of data generated coupled with a high sampling rate for the UHF signal. Meanwhile, a lower frequency (<300 MHz) signal detector is also under progress. Additional research staff is continuing what was started by the first researcher, and they are exploring other design options with lower circuit and design complexities, along with higher data collection efficiency and accuracy.

UNLV-5: Non-Propriety Ultra-High-Performance Concrete (UHPC) for Ballast-Track High-speed Railroad Sleepers. The final task of the project was carried out. Experimental works included mechanical and durability properties of Ultra-High-Performance Concrete, associated with evaluation of the selected optimized UHPCs. The test includes compressive strength, stress-strain response, elastic modulus, indirect tensile strength, flexural strength, abrasion, drying shrinkage, and freeze-thaw resistance of the studied concrete.

UNLV-6: Development of UAV-Based Rail Track Irregularity Monitoring and Measuring Platform. One Ph.D. student has researched and developed an object classification and segmentation for 2D images collected from a high-definition (HD) camera, and stitching 3D cloud-point images gathered from LiDAR. This procedure is essential to measure rail track irregularity. Deep learning (DL) and convolutional neural network (CNN) are employed to improve the outcome accuracy. Object classification and segmentation would also be applied to 3D cloud-point images later, and then fused with 2D images to further elevate the final outcome. A graduate student and an undergraduate student were hired during the summer 2019 to write programs on object annotation for the training process. A research specialist, on the other hand, has completed building the full-customized octocopter, and is continuously working on configuring and practicing operating the octocopter. The octocopter carries both the HD camera and LiDAR system flying along the rail track to collect measurement data. He also works with the Ph.D. students in creating the 2D image and 3D cloud point database on rail tracks, and exploring more advanced algorithms for object classification and segmentation.

Initiating new research programs

In this reporting period, two new research projects were initiated, one by the University of Delaware and the other by UNLV. These two projects are described as follows.

UD-5: Load Transfer from Track to Bridge Structure on Curves. This new project, beginning in September 2019, 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 behavior of the track structure under vehicle and thermal loading. This difference is further enhanced on curves, where the bridge is supporting a track with curvature. These differences include thermal forces generated by the Continuously Welded Rail (CWR) on the track which can generate well over 220,000 lbs. of longitudinal force per rail; thus on the order 900,000 lbs. for double track on a bridge. The presence of a curve results in this force having a lateral as well as longitudinal component. In addition, the dynamics of a railway vehicle going around a curve can generate significant wheel/rail forces. This includes vertical dynamic forces on the order of 35,000 to 70,000 lbs. per wheel and lateral dynamic curving forces on the order of 20,000 to 40,000 lbs. per wheel depending on the type of vehicle, speed, degree of curvature and other operating parameters. This activity will develop a load transfer model from the track to the bridge structure to identify the vertical, lateral and longitudinal forces transmitted from the track structure to the bridge structure to aid the bridge design of the railway bridge. We expect the resulting model will be used in bridge design as well as maintenance planning and management of both the track structure and the bridge structure. It should be noted that SEPTA is partnering with the University of Delaware and will provide engineering and technical support.

UD-6: Track Geometry Models using "Small Data" Algorithm. This new project addresses the use of "small data" algorithms for track geometry modeling. The quality of track geometry is directly linked to vehicle safety, reliability and ride quality. Track performance is therefore considerably hindered when track geometry indicators deviate from the specified and approved limits due to loads and continuous usage. Information obtained from the analysis of track geometry data can inform the prompt application of preventive and corrective maintenance measures, like tamping, to increase track lifespan and allow higher train speeds, optimizing track performance. Recently, Bayesian statistical methods were applied to track degradation models. However, most models rely heavily on likelihood functions which are intractable. The aim of this project is to apply Approximate Bayesian Computation (ABC), also known as the likelihood-free method, in predicting Track Quality Indices (TQIs), which are essential for track degradation modeling. ABC is rooted in methods like the rejection algorithm and Markov Chain Monte Carlo (MCMC). In ABC, summary statistics are computed from the observed data followed by the simulation of summary statistics for different parameter values. This approach will provide a framework for working with small data sets to generate an efficient geometry model.

UNLV-7: UNLV started a new project: Transit Degradation Monitoring and Failure Prediction of Carbon Strip in Pantograph. The weakest link in powering high-speed rail locomotives is the carbon strip of a pantograph collector 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. We hypothesize that the transient distribution of the current flow around the locomotive's input power line provides a unique signature that can be mapped back to the transient real time degradation properties of the pantograph's carbon strip, thus allowing prediction of the strip's lifetime in real time. We propose monitoring the current distribution with existing and next generation electromagnetic dots (EM dot). The EM dot is a sensor that measures the electric and magnetic fields at a single macroscopically small point in space simultaneously in time. The sensor design will be examined in two pulsed power test stands. In one test stand configuration, we expose the carbon strip to a single high-voltage, high-current pulse. In the second test stand configuration, we will expose the carbon strip to a continuous repetition of high-voltage, high-current pulses. The dot sensor will be located in the ground line. Features of the measured fields will be examined and related back to the carbon strip. Up to the current reporting time, the following work was performed:

- Built and calibrated four EM dots with coaxial configuration

- Calibrated four EM dots (coaxial configuration)
- Partially designed and tested an EM dot based on one type of stripline/microstrip configuration
- Designed, built, and partially tested the single-pulse power test stand
- Designed and ordered parts for the multi-pulsed test stand monitor carbon strip degradation
- Designed tunable liquid resistors to support high currents and high voltages

Upgraded education opportunities

Virginia Tech plans to offer a distance learning graduate course on "Rail System Dynamics" continue. This course could potentially be broadcast to the University of Delaware and UNLV. Additionally, we are planning on repeating the one-day professional development seminar on Fundamentals of Rail System Dynamics on May 18, 2020, the day before the 2nd RailTEAM Symposium on Track Maintenance Diagnostics and Prognostics on May 19 – 20, 2020 in Roanoke, Virginia. This event will be hosted by Virginia Tech with collaboration with the RailTEAM consortium universities: the University of Delaware and UNLV.

At the University of Delaware, a new professional development course "Railway Signals and Operating Safety" was given in May 2019. UNLV offered "Railroad Engineering" in the Spring of 2019, attended by 20 graduate and undergraduate students. In the summer of 2019, a graduate student took independent study where light rail was considered an important mode of transportation that connects the new Raider Stadium and the rest of Las Vegas, Nevada. Some graduate and undergraduate students volunteered to set up rail track for detection of rail defects at the Nevada Southern Railway, Inc.

Opportunities for training and professional development

As mentioned earlier, there are ongoing efforts to offer a professional development seminar on May 18, 2020 in Roanoke, Virginia, in conjunction with the 2nd RailTEAM Symposium on Track Maintenance Diagnostics and Prognostics. Additionally, the symposium, held for the second time by RailTEAM, will 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 has provided professional courses for practicing railroad and transit professionals. These professional development courses are: 1) Railway Signals and Operating Safety, given in May 2019, and 2) Application of Emerging Data Science Techniques for Railway Maintenance Planning, given in December 2018 and offered again in December 2019.

The Big Data in Railroad Maintenance Conference has been 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 2018, featured a keynote speech by the

Administrator of the US Federal Railroad Administration (FRA) and 30 technical presentations. The upcoming December 2019 conference will feature a keynote speech by the General Manager of SEPTA together with 30 technical presentations.

On high-speed rail, UNLV invited a speaker with experience working in GE, Siemens and Thales. He shared his insider knowledge of the development of high-speed rail in China: history, strategy, technology policy, and impact to the global market. A researcher attended the Transportation Technology Center, Inc. (TTCI)'s second annual University Days on July 18 and 19, 2019 where he learned the state-of-the-art railroad practice and technologies.

Results disseminated

At Virginia Tech, beyond the ongoing meetings with our industrial partners (Norfolk Southern and Amtrak), we have attended conferences, such as the AREMA annual meeting and conducting technical discussions with potential future industrial partners, such as Wabtec-GE, Plasser American, Alstom, and Ensco regarding the results of our study. Ensco and Alstom visited us during this reporting period and Wabtec-GE and Plasser American are planning visits in November and October, 2019, respectively. We are actively seeking new industrial partners that can benefit from our research.

In 2018, we started our annual symposium called "Railroad Infrastructure Prognosis and Diagnosis," in an effort to communicate our research results to the rail industry, foster an active dialogue on the main theme of our DOT-UTC, "Rail Infrastructure Sustainability and Durability," and promote additional research and engineering activities on related topics. The symposium was attended by more than 60 participants from industry, academia, and government organizations. In 2020, the symposium will be held on the campus of Virginia Tech in Blacksburg, Virginia. The dates for the event are currently being planned.

In addition to these two major activities, Virginia Tech has been in contact with our industrial partners and research results were disseminated to them on a continual basis. Additionally, we have participated in and presented our research results at various industry-based conferences such as the ASME Joint Rail Conference and the Rail Infrastructure Sustainability and Durability Symposium. We offered a one-day workshop (May 2019) at Norfolk Southern Research and Testing division in Roanoke, VA on contemporary topics of rail maintenance sustainability and predictability.

The University of Delaware conducted two major activities to disseminate results to industry and academia. The annual "Big Data" in Railroad Maintenance Planning, organized by the University of Delaware and last held in December of 2018 was 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 will be held December 11-12, 2019 at the University of Delaware in Newark, Delaware. During the 2018 conference, the presentations by Joe Palese of the University of Delaware and Mehdi Ahmadian of Virginia Tech dealt directly with UTC projects. During the upcoming 2019 conference, presentations by Joe Palese of UD, Kyle Ebersole (formerly of UD and now with SEPTA) and Mehdi Ahmadian will include results from two recently concluded UD projects (Rail wear model by Palese and wheel wear modeling by Kyle Ebersole).

Likewise, the University of Delaware has been in contact with industry partners and its own railway advisory board to present results of the UTC projects. In particular, the recently completed wheel wear project was delivered to New York City Transit with the report disseminated to the Rolling Stock (mechanical) Department as well as a presentation of results to the ASME Joint Rail Conference in April 2019. In addition, early results of the wheel wear project were presented at the September 2018 American Railway Engineering and Maintenance of Way Association conference. A UD Rail Program Advisory Board is currently scheduled for December 10, 2019 where results from several active UTC projects will be presented.

At UNLV, a technical paper was produced from the 3D printing project and registered for presentation and publication at the ASME 2019 International Mechanical Engineering Congress and Exposition scheduled for November 11-14, 2019 at Salt Lake City, UT. Three research projects have been on the agenda for the Fall Transportation Conference to be held on October 30 and 31 in Las Vegas, Nevada. A researcher who attended the TTCI's second annual University Days on July 18 and 19, 2019 shared his research on UAV with the TTCI staff and others who attended the symposium.

Plan for the next reporting period

Virginia Tech intends to continue its research activities on all projects mentioned earlier. We are continuing Projects VT-1, VT-4, and potentially VT-5. We have stopped VT-2 for now. We intend to continue VT-3, if there is interest on the part of Plasser American to collaborate on the project, when they visited us on October 8, 2019. For Projects VT-1 and VT-5, we intend to pursue field testing of developed technologies in collaboration with Norfolk Southern. For VT-4, we are in discussions with Amtrak to potentially receive more field data to better tune the machine learning algorithms that were developed as part of the project.

At the University of Delaware, we plan to continue research activities with current graduate students and research scientists. including two new graduate students who started in Fall 2019. We estimate publishing 2 to 4 journal papers and making 2 to 3 presentations. We anticipate teaching two professional courses. The 2019 Big Data in Railroad Maintenance conference will be held on December 11-12, 2019 at the University of Delaware.

In the next reporting period, UNLV will continue all current research projects. The new 3D printing technique will be applied to the heavy rail at UNLV and relevant tests will be conducted on campus at the identified locations. We will complete the simulation model emulating the operation of high-speed rails in California and Nevada. Delays caused by the Nevada trains to California trains will be derived. We will test the acoustic sensor detecting the internal defects in the rail in Nevada Southern Railway, Inc. and we will prepare the field tests at TTCI. The developed sensors detecting the high-voltage faults will continue to be fine-tuned, and lab test will be prepared. We will develop software to measure the irregularities of track geometrics in the next six months. Calibration of the measurements will be conducted correspondingly. We will start the second phase of the ultra-high performance concrete project where extensive lab tests will be conducted to determine the ballast properties. The carbon strip monitoring project will build the multi-pulsed power test stand and test both the single- and multi-pulsed test stands. We will design, build and test a variety of stripline / microstrip EM dots. The carbon strips will be mounted in the test stands. Preliminary carbon strip tests with calibrated, if possible, or un-calibrated sensors will be conducted.

2. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

Organizations involved as partners

Virginia Tech is continuing our 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 also providing us field data to evaluate the effectiveness of data analysis methods developed in some of our projects, such as VT-4 and VT-5. Both NS and Amtrak have provided engineering time. NS has provided track access to VT-5.

At the University of Delaware, the new track-bridge interaction project will have 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. The University of Delaware collaborated with CSX Transportation at Jacksonville, Florida who provided extensive data for big data analyses activities (including rail wear data, rail fatigue data, track geometry data, and traffic data). This data is still applied for both the Rail Wear and Rail fatigue projects. New York City Transit (NYCT), NY is another collaborator who provided extensive transit wheel wear data for big data analyses activities. The relevant project was completed in Spring of 2019.

Nevada Southern Railway (NSR) has provided assistance in setting up track for testing the acoustic internal defect detector we are developing at UNLV. A section of track in NSR was dismounted and replaced with the rails with internal defects. NSR staff worked using their tools and equipment with our researchers, including students and faculty, in setting up the track. We will install our sensor on their rail cars and test whether the sensors can detect defects in the rail correctly at low speed. NSR also provides space for our researchers testing our UAV at their facility: taking photographs of tracks for cloud based learning.

Other collaborators or contacts involved

None to report during this period.

3. OUTPUTS

Our performance measure in outputs are: 1) Number of publications in peer-reviewed conferences or journals targeted at 6-8 per year, 2) Number of invention disclosures filed estimated at 1-2 annually, and 3) Number of provisional or utility patent applications filed targeted at one per year. In this reporting period, we have seven peer-reviewed conference or journal papers published or prepared, which is more than the target we set for our center. We do not have any new invention disclosures and patent applications during this time period. However, UNLV does have three on-going research projects with the potential to produce patents based on their research work.

Publications, conference papers, and presentations

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

Journal publications

1. Palese, J. W. and Zarembski, A. M., Methods for Aligning Near Continuous Railway Track Inspection Data, Proceedings of the Intuition of Mechanic Engineering, Part F: Journal of Rail and Rapid Transit, pp. 1-13, July 2019**,** DOI: 10.1177/0954409719860718207. UTC support acknowledged. (University of Delaware)
2. Lasisi, A. and Attoh-Okine, N. An Unsupervised Learning Framework for Track Quality Index and Safety, Journal Transportation Infrastructure and Geotechnology, pp. 1-12, July 2019. UTC Support acknowledged. (University of Delaware)
3. Lasisi, A. and Attoh-Okine, N., Machine Learning Ensembles and Rail Defects Prediction: A multi-layer Stacking Methodology, ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering, 2019. UTC support acknowledged. (University of Delaware)
4. Palese, J.W., Zarembski, A.M., and Ebersole, K., Stochastic Analysis of Transit Wheel Wear and Optimized Forecasting of Wheel Maintenance Requirements, Proceedings of the 2019 Joint Rail Conference, JRC2019, April 9-12, 2019, Snowbird, Utah. UTC and FRA support acknowledged. (University of Delaware)
5. Lasisi, A., Li, P. and Attoh-Okine, N., Risk Assessment Framework for Train Accidents in the United States: A Case Study of California Rail Network (2008-2017)" AREMA Railway Interchange Conference, Minneapolis, MN, September 2019. (University of Delaware)
6. Mortazavian, E., Wang, Z., and Teng, H., Repair of Rail Track through Restoration of the Worn Part of the Railhead Using Submerged Arc Welding Process, written for the Journal of Wear, September, 2019. UTC Support acknowledged. (UNLV)
7. Ghafoori, N. and Hasnat A., Properties of Ultra-high-performance Concrete, paper 5112, pp. 1-7, Fifth International Conference on Sustainable Construction Materials and Technologies, London, UK, July 14-17, 2019. (UNLV)

Conference abstracts submitted

1. Considerations for sensor selection for detecting Top-OF-Rail (TOR) Lubrication, ASME 2020 Joint Rail Conference, April 20-22, 2020, St. Louis, MO. (Virginia Tech)

2. Lessons Learned from Development of Optical Sensors for Top-of-Rail (ToR) Lubricity Condition Monitoring, ASME 2020 Joint Rail Conference, April 20-22, 2020, St. Louis, MO. (Virginia Tech)
3. Simulation Evaluation of Fouled Ballast Thermal Characteristics, ASME 2020 Joint Rail Conference, April 20-22, 2020, St. Louis, MO. (Virginia Tech)
4. Discrete Element Modeling of Railway Ballast for Studying Railroad Tamping Operation, ASME 2020 Joint Rail Conference, April 20-22, 2020, St. Louis, MO. (Virginia Tech)
5. Surface Profile and Third-Body Layer Accumulation Measurement Using a 3D Laser Camera, ASME 2020 Joint Rail Conference, April 20-22, 2020, St. Louis, MO. (Virginia Tech)
6. Influence of Angle of Attack on Wheel-Rail Interface (WRI) Dynamics, ASME 2020 Joint Rail Conference, April 20-22, 2020, St. Louis, MO. (Virginia Tech)
7. Forward-Looking Infrared Radiometry (FLIR) Application for Detecting Ballast Fouling, ASME 2020 Joint Rail Conference, April 20-22, 2020, St. Louis, MO. (Virginia Tech)
8. Rail Track Quality and T-Stochastic Neighbor Embedding for Hybrid Track Index, accepted to IEEE Big Data 2019 Conference, December 2019, Los Angeles, CA. (University of Delaware)
9. Development of UAV-based rail track irregularity monitoring and measuring platform, the Fall Transportation Conference, October 31, 2019, Las Vegas, NV. (UNLV)
10. Non-Proprietary Ultra High-Performance Concrete for Ballast-Track High Speed Railroad Sleepers, the Fall Transportation Conference, October 31, 2019, Las Vegas, NV. (UNLV)
11. Transit Degradation Monitoring and Failure Prediction of Carbon Insert (Strip) in Pantograph Shoe, the Fall Transportation Conference, October 31, 2019, Las Vegas, NV. (UNLV)

Presentations

1. Palese, J.W., Zarembski, A.M., and Ebersole, K., Stochastic Analysis of Transit Wheel Wear and Optimized Forecasting of Wheel Maintenance Requirements, Presentation at the 2019 Joint Rail Conference, JRC2019, April 9-12, 2019, Snowbird, Utah. UTC support acknowledged. (University of Delaware)
2. Lasisi, A., Li, P. and Attoh-Okine, N., Risk Assessment Framework for Train Accidents in the United States: A Case Study of California Rail Network (2008-2017), Presentation at the AREMA Railway Interchange Conference, Minneapolis, MN. September 2019. UTC support acknowledged. (University of Delaware)

Magazine articles

1. Zarembski, A. M., The Evolution of Data Analytics and its Potential for Safety, Railway Age, April 2019. (University of Delaware)
2. Zarembski, A. M., Big Data in Railroad Maintenance; Application of Data Analytics in Railroad Track Maintenance, Railway Track & Structures, March 2019. (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 keeps updating the RailTEAM website with information from the partnering universities.

Technologies or techniques

LIDAR technology developed by Virginia Tech for detection of third-body layers on top of the rail (such as Top of Rail (ToR) Friction Modifiers) presents a novel technology that has not existed in the railroad industry. Additionally, the development of machine learning techniques for early and accurate detection of track flaw from unsynchronized and repeated measurements represents a new approach to the application of data analytics technologies for rail applications.

The University of Delaware developed noteworthy maintenance models and these are:
1. Method/model for predicting wear life of railway wheels (paper written and presented at ASME-IEEE Joint Rail conference, April 2019).
2. Method/model for alignment of track geometry data (paper written and presented at AREMA September 2018; journal article published in the Proceedings of the Institution of Mechanical Engineering, Part F: Journal of Rail and Rapid Transit, 2019).
3. Preliminary rail wear forecasting model, to be presented at Big Data conference, December 2019.
4. Copula model for ballast recovery (paper written and submitted to the Journal of Rail and Rail Transit)

Inventions, patent applications, and/or licenses: None to report.

4. OUTCOMES

Passage of new policies, regulation, rulemaking, or legislation

The University of Delaware has passed along wear degradation and vehicle performance results to NYCT to help them modify and upgrade maintenance standards and policies.

Increases in the body of knowledge

The body of knowledge related to the application of FLIR technology for railroad/transportation applications (VT-3) has increased through our efforts at Virginia Tech. Our study has scientifically highlighted the 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 technology in VT-1 and VT-5 projects for track applications has significantly improved our understanding of 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 analyze increasing amounts 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: wear of railway wheels, wear of railway rails, railway rail fatigue, track geometry degradation, and derailment forecasting.

UNLV is making the first effort in applying 3D printing technology to repair railhead in the U.S. Initial results show it is possible to repair railhead to the same performance point as the original rail. Finding the right recipe to make repair feasible on-site is crucial and requires extensive lab and field tests.

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

Early results from the VT-2 project has 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 location of application 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 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 resulted in further training for their engineers who are involved with projects in the area of optics sensors and machine learning techniques. 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. The former UNLV UTC Program Coordinator graduated with a Ph.D. degree and landed a job as an Associate Transportation Researcher at the Texas Transportation Institute. The railroad research at UNLV has a lot of involvement of the professionals at the Nevada Southern Railway Inc. who provided assistance of setting up field tests in their facilities. They were exposed to the new technologies in railroad operations.

Adoption of new technologies, techniques or practices

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).

Our outcome performance measures are: 1) Number of citations of research papers in technical journals and conference proceedings (target at 6-8 annually) and 2) Number of news media coverage (estimated at 2-3 each year). In this reporting period, our research work was cited 23 times, far more than our target. Virginia Tech architecture and design students recently created conceptual models of a possible future Amtrak station in the New River Valley which was broadcast by WDBJ, a local news agency. This news coverage event demonstrated our performance achieved our target range.

5. IMPACTS

Impact on the effectiveness of the transportation system

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 that are 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 are currently working on as part of our DOT-UTC efforts, promise significant impacts on the rail industry. These technologies could result in many million dollars in annual savings in managing maintenance-of-way for the U.S. railroad industry.

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 University of Delaware extended its developed method to predict the rate of wheel wear. The railways can directly apply the 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.

The University of Delaware also developed new methods to predict the rate of rail wear across an entire curve in the track. Railways can apply the developed ARIMA model to predict rail wearing. 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 the rate of defects for track segments with no prior defect data, allowing far more data analysis, accounting for in-maintenance planning efforts, thus increasing rail forecasting effectiveness.

Internal defects are difficult to detect. Currently, no reliable technique is available to detect internal defects at high speed. UNLV is developing an acoustic sensor that can detect internal rail defects, thereby improving railroad safety significantly. Instead of replacing worn rail with new rail, repairing railhead using 3D printing techniques will reduce costs significantly.

Impact on the adoption of new practices

Our projects at Virginia Tech have not reached a point where the technologies are ready for commercialization. The closest to potential commercialization is the LIDAR technology being developed in VT-1 and VT-5. 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 lubricant on the rail will enable the 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 gage onboard a locomotive or hyrail vehicle. Gage 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.

In this reporting period, the University of Delaware made presentations at the ASME-IEEE Joint Rail Conference and the American Railway Engineering and Maintenance of Way (AREMA) Conference. Presentation of results at these meetings is one of the most effective means of dissemination of research information to the railway industry. In addition, two articles on the application of Big Data in Railroad Maintenance were published, one in Railway Age magazine, the most widely read railway industry magazine in the US and the second in Railway Track and Structures magazine, the primary magazine for railway track infrastructure in the US. The results to date and anticipated future results will allow railways to take advantage of current inspection data, and foster development and adoption of new inspection technologies.

3D printing for repairing railhead is one of the first attempts in maintaining railroad infrastructure using 3D printing technology. With the success of 3D printing application in repairing railhead, we will apply it to repair other railroad infrastructure, such as turnouts, bridges, and wheels, potentially improving maintenance practices in a revolution way in the railroad industry.

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 be used to assess road surface conditions by detecting black ice and other events not readily visible by drivers.

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

At Virginia Tech, efforts continue to educate undergraduate and graduate students for the rail industry. In the past six months, three of our graduate students have found employment with our rail partners. We forged a close relationship with companies, such as Alstom, Norfolk Southern, Amtrak, Amsted Rail, and others in providing some of our graduates who received a significant amount of rail engineering training as part of their university education.

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 some technologies, being 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 supports three online courses: Introduction to Railway Transportation, Railroad Engineering, and High-Speed Rail. These courses will be offered online for global access. UNLV is also in the process of offering railroad seminars to high school students. The PhD student from our UTC program, who found a job as an Associate Transportation Researcher, is an underrepresented minority in the U.S. The graduate student, who conducted an independent study on light rail as a major mode of transportation connecting Raider Stadium, is an African American working in the Air Force.

Our performance measures on research impact are: 1) Number of stakeholders requesting RailTEAM expertise in the application of research products and/or results estimated at one per year and 2) Number of results transferred to companies, adoption of new practices, or the initiation of new startups targeted at one per year. In this reporting time period, the Norfolk Southern Railroad and Amtrak consulted with Virginia Tech on applying the technologies they developed. The University of Delaware transferred the methodology results to predict the rate of wheel wear and identify bad acting rail vehicles to New York City Transit. This information is being examined by NYCT as to how it can be incorporated in their wheel maintenance and car safety programs.

6. CHANGES/PROBLEMS

No changes in approach. No actual anticipated problems or delays. 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.

8. SPECIAL REPORTING REQUIREMENTS

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