UTC-Semi-Annual Progress Report

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

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

Submitted to

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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 durability and sustainability of the railroad infrastructure in the United States. Forecasts call for the U.S. economy to continue to grow, which will cause 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 techniques, and application of new material 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, to workshops, to 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

Continue active research projects

Our consortium universities have continued 13 research projects in this reporting period, three at Virginia Tech, four at the University of Delaware, and six 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. Progress has been made toward designing a LIDAR-based measurement unit. A series of tests were performed with our industrial partner, Norfolk Southern Railroad. The mobile unit was tested on two different occasions in the field. The unit was able to identify highly lubricated sections of track commonly near wayside lubricant applicators. The mobile unit was also able to identify highly unlubricated track sections due to their distance from the applicators. Testing was performed beginning at a wayside applicator and worked down rail in the same direction of traffic as the ToR friction modifier faded out. The test covered both left-handed and right-handed curves as well as tangent track in between the two curves. The total distance covered was constrained by allowed time on the rail. Two lubricity conditions were considered: near clean (or very-lightly lubricated) and heavily lubricated. The gloss ratio data presents trends indicative of a reduction in rail lubricity as a function of distance from the applicator.

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 progress for this project continues, although several aspects of the project have proven far more challenging than initially envisioned. The simulation model was developed to represent 6,000 ballasts and a single tie (sleeper). Various aspects of the model, such as the choice of ballast formation, interaction between the tie and ballasts, and the required number of ballasts were evaluated (in order to ensure a reasonably accurate study of ballast dynamics) during a tamping cycle, through the use of the commercial software PFC3D. Part of the challenge stems from the fact that PFC3D is intended for geophysics studies of seismic wave progression in earth layers that commonly occur as a single burst of energy, as opposed to a short burst of reciprocating dynamics that repeat in a fraction of a second. The two dynamics are inherently different, and the available software is not well equipped with handling the dynamics associated with tamping. After much trial and error with various functions within the software, we are close to achieving a reasonably stable model for use in parametric studies after validation. The next steps in our efforts include: 1) validating the software against field data (very difficult to obtain) or empirically (through the first principals) and 2) applying the model for parametric studies. These efforts will be performed as part of the project in 2018 and 2019.

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 for assessing the existence of fouled ballast on tracks in its early fouling stages. We have made a significant amount of progress with assessing the applicability and utility of FLIR technology for the onset of ballast fouling, before it becomes a significant cost and nuisance to maintenance-of-way engineers. A slew of laboratory tests was performed under carefully controlled thermal conditions in the lab, as well as in ambient conditions outdoor. A large amount of ballast was acquired from our railroad partner, Norfolk Southern Railroad, for the tests. The ballast was placed in separate containers and the content of each container was mixed with a different volumetric percentage of dirt and/or coal (charcoal) dust to emulate fouling. The ballast containers were subjected to controlled radiant heating through use of a powerful heat lamp placed nearly four feet away from the surface. They were also subjected to sunlight for an extended period of time. For each test, temperature variations are measured carefully near the ballast surface. FLIR aerial technology is often referred to as the unmanned aerial vehicle (UAV) based FLIR camera technology. UAV enables the FLIR camera to take quick temperature measurements over large areas. Laboratory tests in a stationary configuration are conducted to determine whether the FLIR camera can detect the temperature difference. The temperature changes of the ballast with various fouling conditions are tested and compared with clean ballast. Among these tests, the clean and fouled ballast are exposed to naturally-occurring ambient temperature changes. A preliminary conclusion drawn is there is a temperature difference between clean and fouled ballast.

UD-1: Analysis of Wheel Wear and Forecasting of Wheel Life for Transit Rail Operations. We completed data analysis and modeling of transit wheel wear on the big data science application to multi-facet inspection data (in conjunction with FTA). The objective of this study was to calculate the wear rate of transit car wheels and to use these wear rates to project when the next maintenance event should occur. Based on the analyses results, we made the following conclusions:

- Exponential regression appears to be an appropriate method for calculating the wear rate of these particular wheels.
- Resulting wear rates allowed forecasting of when the next maintenance event is likely to occur.
- NYCT may be truing their wheels too early. Rather than allowing the wheels to wear until the threshold, these wheels are trued before reaching their actual maintenance limit. Altering these practices may prove economically advantageous.
- Within the overall population of wheels, there appears to be three different sub-populations based on their actual wear performance. In particular, one subpopulation of wheels exhibits a very high rate of flange wear and as such can be classified as “bad actors”. It is of practical significance to identify and understand these bad actor wheels, so that more regular inspections and maintenance can occur.

Thus, the research showed it is possible to forecast when a given wheel will reach the wheel flange maintenance limit and determine the time frame to the next required maintenance event. The research also resulted in identification of a sub-population of wheels with very high rates of flange wear.

UD-2 Cupola-Based Derailment Prediction Model. We completed a series of new railroad derailment prediction models using Copula-based regression models. In this study, we developed a mixed copula-based regression model which jointly analyzes and predicts train derailment severity outcomes, such as monetary damage and number of derailed cars, by considering their dependencies given a set of similar observed and unobserved factors potentially affecting both outcomes. A bivariate copula that characterizes the dependence between outcomes was used to combine their respective marginal regression models. The mixed copula also took into account endogeneity due to commonly unobserved or omitted factors which introduce correlations across error terms of different marginal regression models. The copula-based regression model was found to be more appropriate than the independent multivariate regression model. The incorporation of the copula to characterize dependence resulted in a greater effect on the dispersion estimate than the point estimates. Derailment speed was found to have the most pronounced effect on both response variables. This was followed by residual train length and finally loading factor. These covariates were found to have a greater effect on monetary damage than the number of derailed cars.

UD-3: Development and Validation of a New Generation Rail Wear Model Using Emerging Big-Data Analytic Techniques. Traditional methodologies would use a mean (or maximum) of the wear value in the full body of the curve and apply a linear regression based forecast. The approach developed here uses the actual wear through the full length of the curve, to include spirals and other transitions, and uses advanced stochastic forecasting processes, specifically the 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. Since the curve is a distribution of wear, the decision of when to replace the rail (first hit, 50%, 100%) can affect the rail life from 6 to 10 years, which has a significant economic impact. Also, portions of a curve may exhibit more severe wear rates, thus allowing the railway to replace a portion, or if intervening in a timely manner, adjust maintenance strategies to include lubrication, rail grinding, elevation adjustment, fastener upgrade, etc. This research showed that a more sophisticated stochastic technique, specifically ARIMA, can be used with well-aligned wear data to improve the forecast of the rail wear behavior, not just on an average basis, but as actually distributed throughout a segment of track. This allows railways to identify when a curve, for example, will first start to reach a rail wear threshold, and when 50%, 75% or 100% of the curve will exceed the defined threshold.

UD-4: Rail Fatigue Life Forecasting Using Big Data Analysis Techniques. Two active research projects deal with forecasting of rail fatigue failure using modifications of the traditional Weibull Analysis approach. In one of these activities, machine learning multi-layer stacking ensembles is used as an alternative to conventional Weibull Analysis in order to enhance the accuracy of predicting rail defects. Ensemble learning models combine several learning algorithms in order to achieve greater predictive performance than any of the individual machine learning techniques. This allows for iterative optimization of prediction performance by learning from the rail defect data and eliminates the deficiencies and biases associated with the assumption of lifetime probability distributions. The stacking ensemble model was found to perform better than several models including the 2-parameter and 3-parameter Weibull models which were found to underestimate the rate of rail defect at high tonnages. The enhanced prediction of rail defects as a result of agglomerated machine learning techniques offers more effective track component replacement and maintenance planning on the network level.

The second approach is a probabilistic approach to Weibull Analysis where the probability distribution of Weibull parameters is developed based on a statistically significant set of actual railroad data. 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.

UNLV-1: Mobile 3D Printing of Rail Track Surface for Rapid Repairmen. In this reporting time period, we established a three-dimensional, thermal-kinetic-mechanical finite element (FE) model to simulate an additive manufacturing process with a laser powder deposition (LPD) approach for rail repair. The process starts with laser power attenuation, solid-state transformation, microstructure distribution, and dilution with different depths. The model was calibrated and validated based on the experimental results of repairing two rails. Conclusions were derived from the impact of preheating, cooling, depth of dilution and additive materials. Our goal is for this model to provide the right 3D printing process to produce repaired rail that satisfies hardness and strength requirements.

UNLV-2: High-speed Rail Access Charge for the XpressWest of Nevada. This study developed a new framework to calculate a reasonable value of access charges for shared HSR systems. The study describes how to calculate access charge in terms of maintenance costs, congestion costs, and costs to install side tracks mathematically. The study also developed a theoretical capacity allocation model to calculate congestion costs. Based on the operation plans of both train systems, an operations delay was determined. The research used 18 different proposed train operating scenarios to calculate the value of access charges. Based on the scenarios, the access charges ranged from \$3.8 million to \$62 million per year, with a fixed one-time cost of \$56 million to \$84 million at the outset. The framework used in this research can also be adapted to other shared use track operation systems by changing the variable values.

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 has been 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 State Railroad Museum in Boulder City of Nevada. The team is actively working with the museum to arrange for the 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 museum for sensor testing and evaluation. Track installation and preliminary sensor testing are scheduled 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. The architecture design of the partial discharge (PD) detection system majorly includes two channels of PD detectors, a micro-controller unit (MCU) for the overall data flow control, a field-programmable-gate-array (FPGA) for data fusion, and terminals such as keyboard, display and memories for user interface, data visualization, storage, etc. We have completed the schematic design, PCB fabrication and assembly for the front-end circuit for the ultra-high frequency (UHF) signal detector as one channel of PD detection. This module is for collecting the analog PD impulse signal of over 300 MHz and converting it into digital form, feeding to the following data analysis and storage system on the MCU and FPGA, which are partially completed and waiting for detail configurations. We are also in the progress of designing the other lower frequency (< 300 MHz) signal detector. We may add a network module to realize the Internet of Things (IoT) function for cloud computing and data storage. In the end, we need to display the data for real-time on-site detections and external storage for further offline data analysis.

UNLV-5: Non-Propriety Ultra-High-Performance Concrete (UHPC) for Ballast-Track High-speed Railroad Sleepers. An experimental investigation was conducted to produce lower-cost UHPC which utilize locally available traditional fine aggregates. First, we conducted a comprehensive literature review on the current application of ultra-high-performance concrete for different transportation infrastructures. Next, we conducted material optimization based on standard tests. Silica fume, slag, industrial (Class F fly ash) and natural pozzolans were used at different replacement levels of cement content. More than 120 MPa compressive strength was attained using locally available fine aggregate. A comparable indirect tensile strength value was obtained for each studied concrete mixture. Fly ash seemed more effective than the natural pozzolan in producing higher compressive and tensile strengths. Incorporation of silica fume had a positive impact on the strength development of the studied UHPCs. However, silica fume increased the drying shrinkage of concrete. Based on the test results, the VFA/Vcm of 1.2 is recommended for long-term assessments. Among 22 combinations of binders, 12 of these satisfied the target mechanical requirements. For these selected mixtures, steel fiber will be used at different volumetric percentages to evaluate fresh properties, bulk properties, time-dependent properties, transport, and durability properties of optimized UHPC obtained from the previous task.

UNLV-6: Development of UAV-Based Rail Track Irregularity Monitoring and Measuring Platform. We developed a 3D-object model reconstruction method for UAV imaging. In particular, this model deals with object detection and segmentation using deep learning, and is capable of performing depth estimation from a 2D image. We then established a true 3D model by image stitching. We created and collected a UAV image database for 3D object training and performed some early testing/training for classification using the images and data from this database. We tested one UAV platform and determined it is in service condition. Our next task is to load LIDAR and camera sensors to the platform for flight test.

Initiating new research programs

Virginia Tech started two new research initiatives on the following topics:

1. Application of machine learning techniques toward time-based change in track condition using an on-board sensor in revenue-service rolling stock
2. Application of Doppler LIDAR sensors for assessing track gauge widening in curves and locations with high-lateral forces.

At the University of Delaware, a recently initiated research program models tamping recovery of track geometry using the copula-based approach. We examined railroad track surface maintenance data for tamping recovery (correction) of the track; i.e., how effective tamping is in corrected geometry degradation in the track. The approach will bypass traditional two-parameter normal distribution analysis and look at a three-parameter log-normal distribution which can better predict results of the track tamping operations. Copula analysis techniques will then be applied to model the recovery (correction) after tamping as a function of key input parameters. In the summer or fall of 2019, we expect to initiate two new research programs with new graduate students. One will involve the use of Bayesian Analysis in the analysis railway track geometry degradation and defect modeling. The aim of this project is to develop a likelihood-free method in Bayesian analysis of track data. The likelihood free method has a distinct advantage in that the analysis is strictly driven by the available data. A second project will look at railroad tie degradation as a function of the influence of adjacent failed ties.

Upgraded education opportunities

At Virginia Tech, we are planning a half day open short course titled "Introduction to Rail System Dynamics," at the Joint Rail Conference in Snowbird, Utah, on April 12, 2019. We are also preparing to offer a joint graduate level course between UNLV and Virginia Tech titled "Rail System Dynamics." The course is in the planning stages. We may offer the course as "Special Topics" in Fall 2019 at Virginia Tech and telecast it to UNLV for graduate student offering.

At the University of Delaware, a new professional development course is scheduled for April 2019, "Railroad Safety and Derailment Engineering." A second new course in "Railway Signals and Operating Safety" is scheduled for May 2019. A new professional development course was given in December 2018: "Application of Emerging Data Techniques in Railway Maintenance."

In this reporting time period, UNLV supported three online courses on the railroad and High-speed rail; they will be available as degree programs across the globe. We also offered CEE 462/662 Railroad Engineering Spring 2019 which is offered almost every year. We completed the senior design project and addressed the railroad fastener corrosion problem.

Opportunities for training and professional development

In this reporting period, Virginia Tech introduced a seminar "Introduction to Rail Dynamics" on October 15, 2018 which was attended by more than 30 engineers, students, and faculty members from industry, academia, and government organizations. In addition, we are preparing an open workshop on "Introduction to Rail System Dynamics," at the Joint Rail Conference in Snowbird, Utah, on April 12, 2019 for participants from industry, academia, and government organizations.

The University of Delaware's Professional Engineering Outreach has provided professional courses for practicing railroad and transit professionals. These professional development courses are: 1) Planning and Designing Rail Transit for Operational Performance, held August 2018 and 2) Application of Emerging Data Science Techniques for Railway Maintenance Planning (new course), December 2018.

Results disseminated

Two major activities were conducted to disseminate results to industry and academia. The annual "Big Data" in Railroad Maintenance Planning - last held in December of 2017 - was a resounding success, with more than 150 professionals from a spectrum of companies, universities, and government agencies attending the one and one-half day event. The next conference will be held

December 13-14 at the University of Delaware, in Newark, New Jersey. In 2018, we started another 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 Maintainability and Sustainability," 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 2019, 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, through all of the projects, 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 Maintainability and Sustainability Symposium. We intend to offer a one-day workshop at Norfolk Southern Research and Testing division in Roanoke, VA on contemporary topics of rail maintenance sustainability and predictability. The workshop is tentatively scheduled for May 2019. At UNLV, our UTC advisory board meeting was held on October 17, 2018 where research projects were presented.

Plan for the next reporting period

In the next reporting period, Virginia Tech intends to continue research activities toward improving the systems/technologies currently ongoing, as was eluded to earlier. We also intend to start a new project in the area of data analytics and machine learning for automated and more efficient analysis of a large volume of onboard data, with potential application toward early detection of track geometry changes.

At the University of Delaware, we plan to continue research activities with current graduate students and research scientists. At the same time, we anticipate one new graduate student in Fall 2019. We estimate to publish 2 to 4 journal papers and make 2-3 presentations. We anticipate teaching two professional courses.

The University of Nevada, Las Vegas will continue research activities, expecting completion of some research projects. From these completed projects, publications and presentations will be produced.

2.PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

Organizations involved as partners

During this reporting time period, Virginia Tech continued close collaboration with Norfolk Southern, Roanoke, VA, who provided track access, allowed access to the in-house laboratory for testing, provided material donations including rail, ballast, ties, etc., and gave engineering input for ongoing and future projects. Virginia Tech also collaborated with Amtrak, Philadelphia, PA who provided track data, access to track geometry car, and provided engineering input for ongoing and future projects. Another collaborator is Alstom, Hornell, New York, who provided manufacturing information and rolling stock information.

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). New York City Transit (NYCT), NY is another collaborator that provided extensive transit wheel wear data for big data analyses activities.

Nevada Southern Railroad provided UNLV space, tools, and staff time for conducting research supported by our UTC.

Other collaborators or contacts involved

None to report during this period.

3. OUTPUTS

Publications, conference papers, and presentations

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

Journal publications

1. Yurlov, D., Zarembski, A.M., Attoh-Okine, N., and Palese, J.W., Combinational Hybrid Analysis Approach to the Determination of a Probability Model for Development of Track Geometry Defects as a Function of Ground Penetrating Radar Measurements, accepted by Journal of Transportation Infrastructure Geotechnology, November 2018. (University of Delaware)
2. Lasisi, A. and Attoh-Okine, N., Network-level Infrastructure Management Tool for Rail Defect Prediction and Maintenance: An Ensemble Learning Methodology. 2019 Transportation Research Board Annual Meeting, DC (Accepted for presentation). (University of Delaware)
3. Zarembski, A.M., The Increasing Use of Data Analytics and Big Data in Railroad Maintenance Management, Railway Age, February 2019. (University of Delaware)
4. Lassi, A., Machine Learning: An Alternative to Weibull Defect Analysis of Rail Infrastructure, presented at the 2018 IEEE International Conference on Big Data (Big Data), Seattle WA, December 2018. (University of Delaware)
5. Attoh-Okine, N., keynote address, The Future of Blockchain Technology in Railway Track Engineering, presented in the 2018 Big Data in Railroad Maintenance Conference, Newark DE, December 2018. (University of Delaware)
6. Palese, J., Application of Data Analytics to Rail Wear Forecasting presented in the 2018 Big Data in Railroad Maintenance Conference, Newark DE, December 2018. (University of Delaware)
7. 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, US. (University of Delaware)

8. Lasisi, A., Martey, E., Guilloty, D., and Attoh-Okine, N., Three-step Agglomerated Machine Learning: An alternative to Weibull Defect Analysis of Rail Infrastructure, 2018 IEEE International Conference on Big Data (Big Data), Seattle, WA, December 2018. (University of Delaware)
9. 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, accepted by 2019 World Congress of Railway Research, October 2019, Tokyo, Japan. (University of Delaware)
10. Li, H., Chen, T., Teng, H., and Jiang, Y., A Graph-Based Reinforcement Learning Method with Converged State Exploration and Exploitation, Computer Modeling in Engineering Sciences, vol. 118, no. 2, pp. 253-274, February 2019, DOI: 10.31614/cmes.2019.05807. (UNLV)
11. Mortazavian, E., Wang, Z., and Teng, H., Thermal-Mechanical Study of 3D Printing Technology for Rapid Rail Repair, Oral presentation at and the proceeding of the ASME 2018 International Mechanical Engineering Congress and Exposition, IMECE 2018, November 9-15, 2018, Pittsburgh, PA. (UNLV)

One-time publications

Poster presentations at Railroad Infrastructure Diagnosis and Prognosis Symposium, Las Vegas, Nevada, October 16 – 17, 2018:

1. Fundamental Study on the Rolling Contact Fatigue (RCF) at the Microstructural Level (Virginia Tech)
2. Advanced Modeling of Railway Ballast for Improving Railroad Tamping Operation (Virginia Tech)
3. Monitoring and Detecting Fouled Ballast Using Forward Looking Infrared Radiometer (FLIR) Technology (Virginia Tech)
4. The Application of Laser Technology for Railroad Top of Rail (TOR) Friction Modifier Detection and Measurements (Virginia Tech)
5. Towards Automated Monitoring of Track Using Machine Learning (Virginia Tech)
6. VT-FRA Roller Rig: Designed and Commissioned to Serve the Railroad Industry (Virginia Tech)
7. Analysis of Wheel Wear & Forecasting of Wheel Life for Transit Rail Operations, (University of Delaware)
8. Mobile 3D Printing of Rail Track Surface for Rapid Repairment (UNLV)
9. Developing Acoustic Technology to Detect Transverse Defects in Rail at High-speed (UNLV)
10. Non-Propriety Ultra High-Performance Concrete for Ballast-Track High-speed Railroad Sleepers (UNLV)
11. UAV Applications to Track Inspection of Irregularity Measurement (UNLV)
12. 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 (UNLV)
13. High-speed Rail Access Charge for the XpressWest of Nevada (UNLV)
14. Corrosion Prevention of the Rail Tie Plate for High-speed Rail Applications (UNLV)

Presentations at the Railroad Infrastructure Diagnosis and Prognosis Symposium, Las Vegas, Nevada, October 16 – 17, 2018*:*

1. Keynote Lecture: Railroad Track Monitoring Technologies (Virginia Tech)
2. Qualitative Assessment of Rail Lubricity (Virginia Tech)
3. Developing Machine Learning Methods for Facilitated Track Condition Assessment Using Repeated Inspection Data (Virginia Tech)

Journal paper submitted:

4. Alsahli, A., Zarembski, A.M., Palsese, J., and Euston W., Investigation of the Correlation between Track Geometry Defect Occurrence and Wood Tie Condition, submitted to Journal of Transportation Infrastructure Geotechnology, January 2019 (University of Delaware)
5. Mortazavian, E., Wang, Z., and Teng, H., Thermal-kinetic-mechanical Modeling of Laser Powder Deposition Process for Rail Repair, Journal of Manufacturing Science and Engineering, March 2019 (UNLV)

Conference abstracts submitted:

1. Monitoring and Detecting Fouled Ballast using Forward Looking Infrared Radiometer (FLIR) Aerial Technology – Possibilities and Limitations (Virginia Tech)
2. Development of Vertical Force Control System for the Virginia Tech – Federal Railroad Administration Roller Rig (Virginia Tech)
3. Evaluating the Effect of Natural Third Body Layers on Friction Using the Virginia Tech Roller Rig (Virginia Tech)
4. Virginia Tech-Federal Railroad Administration Roller Rig Measurement Capabilities and Baseline Measurements (Virginia Tech)
5. Studying the effect of tangential forces on rolling contact fatigue in rails considering microstructure (Virginia Tech)
6. Automated Monitoring of Track through Historical Data Analysis (Virginia Tech)
7. Rail Defect Detection Technology: A Review of the Past and a Look to the Future, (UNLV)
8. Thermal-kinetic-mechanical Modeling of Laser Powder Deposition Process for Rail Repair (UNLV)

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 created a website for papers presented during December 2018 Big Data in Railroad Maintenance Planning Conference. All presentations made at the 2018 conference and approved by authors are on the website: http://outreach.engr.udel.edu/professional-development/conferences/big-data-in-railroad-maintenance-planning/. UD's Railway research and educational activities are also highlighted in the University of Delaware's Railroad Engineering and Safety Program website: railroadengineering.engr.udel.edu/. At the University of Nevada, Las Vegas, the website for the Railroad UTC was developed in March 2017 and was updated with information about our UTC: https://www.unlv.edu/railteam. For example, UNLV organized several seminars and posted the seminar announcements with the pictures of the seminars on the website.

New Methodologies, technologies or techniques

The research at Virginia Tech indicates that although the application of Forward Looking Infrared Radiometer (FLIR) Technology has been explored for military and some civilian applications, its adaptation for rail application is entirely new. The same is true for the application of optical sensors for measuring fine amounts of a third-body layer (most commonly, lubricants) on rail, which occurs in micron-thick layers.

The University of Delaware developed maintenance models that are noteworthy, these are: 1) Method/model for predicting wear life of railway wheels (paper under authorship), 2) Method/model for alignment of track geometry data (paper written and presented at AREMA September 2018), and 3) 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.

Other products: None to report.

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 time period, we had 11 papers published in peer-reviewed journals or series of conferences, far exceeding our target (6-8/2). We do not have any invention disclosures and provisional or utility patent applications filed in the last half year. We do have two patent applications filed in the last half year thus satisfying our target.

4. OUTCOMES

At Virginia Tech, the broad changes expected to result from our efforts include:

- Improved rail maintenance techniques that promise to significantly increase the effectiveness of maintenance for railroads
- Improved safety, on-time operation, and accessibility of rail transportation in both rural and metropolitan areas
- Significant cost savings resulting from automation of rail maintenance

The University of Delaware expects the changes resulting from our products to include the following three areas:

- Bringing railroad engineering instructor from the University of Kabul, Kabul Afghanistan, to the University of Delaware for research.
- Recognition of our current program and course of study is drawing global railway engineers to state of the art research and application of results.
- Increasing participation in the Big Data in Railway Maintenance Planning conference both domestically and internationally.

At UNLV, 3D printing, as a new manufacturing technology, is scheduled for continuous investigation in the form a broader application for the railroads. We will apply 3D printing technology to repair worn rail, turnout, and wheel, changing the current maintenance practice of the railroads. UAV will be applied more broadly for railroad application from simple site surveying and monitoring to track inspection and defect detection, hence enabling more extensive monitoring of railroad infrastructure.

Our 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 19 times, far more than our target. We had one news coverage event on our research, right at the range of our target.

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.

At Virginia Tech, both the FLIR and LIDAR technologies that we are currently working on as part of our DOT-UTC efforts, promise to have a significant impact on the rail industry. These technologies could result in many million dollars of annual savings in managing maintenance-of-way for the U.S. railroad industry.

The University of Delaware extended its developed method to predict the rate of wheel wear. The railways can directly apply the models to predict the wearing of railway wheels and predict when to either perform maintenance to extend life (e.g., wheel truing) or replace. The University of Delaware also developed new methods to predict the rate of rail wear across an entire curve in the track. The developed ARIMA model can be used directly by railways to predict the wearing of railway rail and predict when to either perform maintenance to extend life (e.g., rail grinding) or replace. Two new approaches to predicting rail fatigue defects are under development: 1) using machine learning multi-layer stacking ensembles and 2) using probability distribution of Weibull parameters.

At UNLV, 3D printing technology is applied to repair rail side wear. The interaction between wheel and rail cause deterioration, which needs maintenance and replacement. The cost of maintaining and replacing the wheel and rail is the highest in the railroad industry. 3D printing to repair rail is a fundamentally different approach compared to grinding and replacing rail. The success of research conducted in this program anticipates significant savings in railroad maintenance costs. In addition, railroad track inspection involves two generations of technologies: manual and vehicle carried. The UAV based track inspection is the third generation of track inspection technologies. The UAV track inspection system will complement the existing track monitoring system to make inspection more cost effective and reliable.

Impact on the adoption of new practices

Virginia Tech continues its effort toward ultimately transferring technologies currently under research to the U.S. rail industries. Significant advances of our FLIR system for detecting early stages of ballast fouling and LIDAR system for qualitative assessment of rail top lubrication have moved us closer to making these technologies feasible for their eventual transfer to the industry.

In this period the University of Delaware made two presentations at the Big Data in Railroad Maintenance conference as well as a third presentation at the IEEE Big Data Conference. Presentation of results at this meeting 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.

At UNLV, positive testing results from 3D printing applications in repairing rails in the laboratory and field can facilitate its adoption in the industry.

Impact on the body of scientific knowledge

Virginia Tech is developing a LIDAR system that promises to have significant applications for highway applications in assessing roadway surface conditions. Thus paving the way for a critical technology necessary for semi-autonomous and autonomous vehicles. The University of Delaware has developed approaches and methodologies for the maintenance of railroad infrastructure that are readily adaptable in the area of highway pavement and airport runway research and analysis. UNLV has investigated the solution to fastener corrosion that may address the corrosion issue of steel elements in concrete roadways.

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 started working for our rail partners. We have forged a close relationship with companies such as Alstom, Norfolk Southern, and Amtrak in providing some of our graduates who received a significant amount of rail engineering training as part of their university education.

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 condition.

During the reporting period, UNLV offered one railroad class: Railroad Engineering. We graduated our first female MS student who worked on the UTC program and three undergraduate students who researched the railroad fastener corrosion problem for their senior design project. They were introduced to the railroad industry for potential job opportunities.

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, we have six and two, respectively, for these two performance measures, far exceeding our targets.

6. CHANGES/PROBLEMS

No changes in approach. No actual anticipated problems or delays. No changes that have a 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.

ADDITIONAL INFORMATION REGARDING PRODUCTS AND IMPACTS

Outputs are the direct, tangible products of your research, education/workforce development, and technology transfer activities

At Virginia Tech, efforts during this period resulted in the following outputs:

- Development of a new professional development seminar on "Introduction to Rail System Engineering"
- Development of a new system for assessing rail lubricity using optics technology
- Development of a new system for fouled ballast detection using FLIR technology

The outputs from our efforts at the University of Delaware in this reporting period are:

- Anticipated follow-up research award from GREX (January 2019)
- Anticipated research award from MRS Logistica in Brazil (March 2019)

UNLV produced technical papers published in journals and conferences. More than 20 students in the Department of Civil & Environmental Engineering & Construction took railroad courses. The railroad infrastructure diagnosis and prognosis symposium held in October 2018 at the University of Nevada, Las Vegas attracted about 80 professionals, faculty and students across the country. In addition, we also attended a meeting with potential investors for commercializing our products.

7. SPECIAL REPORTING REQUIREMENTS

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