Program Progress Performance 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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Content

Program Progress Performance Report for University Transportation Centers

ACCOMPLISHMENTS

Major goals and objectives of the program

The goal of this program is to conduct research, promote education and technology-transfer activities to improve the durability and sustainability of the railroad infrastructure in the United States. It is forecasted that the U.S. economy will continue to grow rapidly, which will cause both intra- and inter-city travels for passenger and freight travel to significantly increase. Railroads will play a larger role in carrying this demand; in turn this will potentially expedite the deterioration of the railroad systems. In addition, new railroad infrastructure such as high-speed rail will be built to sustain the increased travel demand.

The first objective of the program is to focus on four areas of research that are critical to the safety and operations of railroad systems:

- 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 technique and application of new material and technologies. The University of Nevada Las Vegas is engaged in technologies and construction methodologies that can better enable further development and implementation of HSR in the U.S.

The second objective of the program is to develop railroad degree granting courses, certificate programs, and short courses that will promote and increase workforce development, for both the new generation of engineering students that intend to join the railroad industry, as well as professionals already working for the industry. To this end, all three partnering universities are engaged in complementary activities that range 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 such as seminars and conferences for disseminating the research results to railroad industry. The Big Data Workshop held in December of 2017 was a resounding success, with more than 150 professionals across the railroad industry and academia attending the one and one-half day event. Another workshop on the "Railroad Infrastructure Diagnosis and Prognosis" under the development for October 2018 is for sharing the results of the DOT-UTC research efforts, and also fostering information exchange among the researchers and industry practitioners.

This report will include the details of the RAILTeam DOT-UTC achievements from June 1, 2017 to March 31, 2018.

Accomplished under goals

Virginia Tech

1. **Continuing active research efforts**
   Continued active research activities in the area of railway vehicles and infrastructure maintainability and sustainability through the following activities:
   - Research projects related to improving tamping dynamics, top-of-rail lubrication practices, and managing vehicle-rail interface (VRI) dynamics and mechanics
   - Mentoring graduate students (both MS and PhD) on projects related to railroad infrastructure maintainability and sustainability
   - Advising undergraduate students on railroad-related projects
   - Holding special sessions with students on rail vehicle dynamics topics, toward advancing their understanding and interest in railroad engineering
   - Serving as faculty advisor for the VT AREMA Student Chapter, one of the most active AREMA student chapters in the U.S.

2. **Initiating new research programs**
   The on-going activities listed earlier are further advanced through initiating new projects, specifically in the following areas:
   - Monitoring and Detection of Fouled Ballast using Forward Looking Infrared Radiometer (FLIR) Aerial Technology. FLIR is a technology that has been used for military and non-railroad civilian applications. Early research into the technology indicates that it holds significant promises for railroad applications, in areas such as detecting and monitoring the presence of fouled ballast.
   - Initiated a new research project in the area of machine learning for more accurate and faster processing of infrastructure data, in an automated fashion. This project takes advantage of significant advances in the area of machine learning to bring automation to processing field data that is collected by the railroads with vastly increasing frequency. The project aims at taking the process of collecting data beyond just acquiring data. It intends to extract useful information from the collected data.

3. **Dissemination of Results to Industry and Academia**
   The Virginia Tech team has been proactive in disseminating the results to the railroad industry and peers at other academic institutions. A selection of activities has included:
   - Submitted four journal papers for publication consideration. One of the papers have been accepted and published, the other three are under review
   - Presented a paper at the 2018 JRC in Pittsburgh PA
   - Participated in the student poster session at the 2017 AREMA conference in Indianapolis

- Participated in Joint Rail Conference (JRC) in Pittsburg, PA, and presented and published one paper
- Held meetings with FRA and various Class I railroads and suppliers, including Norfolk Sothern, Amtrak, Standard Steel, Alstom, and Amsted Rail
- Presenting at Railroad UTC reception at TRB in January 2018

4. Upgraded education opportunities
The activities that are being pursued include both in-class and in-the-field education opportunities, particularly in the following areas:
- Revamping a graduate level course in the area of Rail Vehicle Dynamics to be offered in 2019.
- Encouraged additional coverage of railway engineering in transportation courses taught traditionally in Civil Engineering curriculum.

University of Delaware

1. Continued current research activities
- Development of a new generation of rail wear model
  - Continued algorithm and data process development to increase understanding of rail profile/wear degradation
  - Actively working with one US Class 1 railroad
- Development of a new generation of rail fatigue model
  - Developed algorithms for understanding occurrence of rail fatigue defects
  - Actively working with one US Class 1 railroad
- Relationship between subsurface track conditions and development of track geometry defects.
  - Big Data Analysis studying the relationship between geometry defects, GPR data, M-Rail data, etc.
  - Several relationships discovered and the process of implementation under development
  - Actively working with FRA and two US Class 1 railroads.
- Working with Georgetown Rail on research projects.
  - Relationship between track geometry defects and tie conditions.
  - Several relationships discovered and the process of implementation under development
  - Actively working with Georgetown Rail and one US Class 1 railroad.

2. Initiated two new research programs
- Big Data science application to multi-facet inspection data (in conjunction with FTA.)
  - Utilizing inspection data (both on-board and wayside), develop and apply data science algorithms to monitor track and vehicle performance, degradation and safety.
- Data science application to track geometry data analysis using multiway data analysis factorization.

- Use multiway data analysis techniques to generate new insights from track geometry data.
- New senior scientist started on September 1, 2017 and actively engaged in all related research activities

3. Continued dissemination of research results
- Big Data 2017 conference was held on December 14-15, 2017. Approximately 200 people attended, and 35 technical papers presented. Keynote address was made by Wick Moorman, President of Amtrak. Presentations were given by railroads, railroad suppliers, data science companies and universities. New Big Data conference planning has begun for a December 2018 conference.
- Published two papers in peer reviewed journals and two papers accepted for 2018 industry conferences.
- Gave six presentations at various venues with several more scheduled for 2018.
- Gave presentation at Railroad UTC reception at TRB in January 2018

4. Continued and upgraded education opportunities
- Offer four courses at the 400/600 (senior/graduate) level: average 12 students per class. At the graduate level. Completing three of the four courses result in a Certificate in Railway Engineering. Courses are available for remote attendance through UDCapture.
  - Introduction to railway engineering
  - Introduction to railway safety and derailment analysis
  - Railway geotechnical engineering
  - Construction management in railways
- Offer one course at the 300 (junior) level to develop interest in railway engineering.
  - Introduction to railway engineering
- Graduate certificate program in Railroad Engineering
  - Award 4 to 8 certificates per year
- Expanding professional education courses in railroad engineering through UD's Professional Engineering Outreach (POE)
  - Transit Operations (new)
  - Management Essentials for the Railroad Industry (new)
  - Rail, Rail Problems, Rail Maintenance
- Developed one new POE course based on industry demand to be offered in the fall
  - Advanced Data Science Techniques in Railway Engineering: Theory and Application

University of Nevada, Las Vegas

1. Continued the current research activities
- The current research projects were conducted in various phases.
  - Mobile 3D printing of rail track surface for rapid repairment: two rail segments with side wears were repaired using 3D printing for which lab tests are being performed. Finite element analysis was performed to see the impact of preheat on the side wear.

- High speed rail access charge for the XpressWest of Nevada: The proposed California and Nevada high speed rails were designed with alignment and geometric features. A simulation model was developed with the design of these two systems; the interactions of these two systems are being studied to develop the access charge.
- Development of acoustics technology to detect transverse defects in rail at high speed (220 mph): The acoustics sensors were developed and will be tested at the Nevada Southern Railroad, and also possibly at the TTCI and our partnering institution in China.
- 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: Sensors are being developed and will be tested in the lab.

2. **Initiated new research projects**
   - Lab Test of 3D Printed Side-Wear Rail: Continued the 3D printing project with the objective of building a customized 3D printer for repairing side wear rail. The special features of the 3D printer include: making channel on rail, preheat, cooling, laser and powder feeding, ultimately making metallurgical bond feasible. This customized 3D printer will manufacture the 3D printing with cost effectiveness for this study.
   - Non-Propriety Ultra-High-Performance Concrete for Ballast-Track High Speed Railroad Sleepers*:* the objective of the project is to develop a railroad tie that is strong and a low cost for high-speed rail.
   - Development of UAV-Based Rail Track Irregularity Monitoring and Measuring Platform*:* The UAV system will be the new generation of a track monitoring system that can measure the track condition in a cost-effective manner.

3. **Continued and upgraded education opportunities**
   - Organized a 3-day high-speed rail seminar in December 2017. Forty attendees participated in the seminar, from a cross spectrum of stakeholders in rail industry: professionals, faculty, and students.
   - Support three online courses on railroad and high-speed rail; these will be available as degree programs across the globe.
   - Offered railroad courses every semester.

4. **Continued dissemination of research results**
   - Presenting and publishing work at conferences.
   - Organizing UTC reception at TRB for disseminating our research work.
   - Organizing conference in October 2018 on railroad monitoring and maintenance.

Opportunities for training and professional development

Virginia Tech

Plans are being put in place to offer a professional development course in the area of Rail Vehicle Dynamics.

University of Delaware

Working with the University of Delaware Professional Engineering Outreach to provide professional courses for working railroad and transit professionals. Professional development courses offered are:

- Management Essentials for Railroad Industry.
  - Steve Ditmeyer, Robert Gallamore, AMZ.
  - April 16-20, 2018.
- Planning and Designing Rail Transit for Operational Performance.
  - March 7-8, 2018.
- Rail, Rail Problems and Rail Maintenance.
  - August 2017.
- Track Inspection.
  - April 2-3, 2018.
- Application of Emerging Data Science Techniques for Railway Maintenance Planning (NEW COURSE).
  - December 2018.

University of Nevada, Las Vegas

A 3-day seminar on high-speed rail was held at UNLV from December 18 to 20, 2017. Forty individuals attended the seminar, including industry professionals, faculty, and students from domestic and international organizations. The speakers were well-known scholars and professionals from universities and industries including: Siemens, CRSC, and Bombardier. The lecture notes were developed and distributed to the attendees. Continuing Education Units (CEUs) and Professional Development Hours (PDHs) were granted to the attendees as well.

Results disseminated

Virginia Tech

The research team at Virginia Tech have held frequent meetings with the railroads in extended sessions, to share the results of this research and provided an opportunity for technology transfer. Specifically, the VT activities included:

1. Organized and conducted the Railway Technologies Laboratory (RTL) Annual Review on November 6 – 7, 2017, in which various Class I railroads and their suppliers participated in a day-long, on-campus oral and poster presentations of rail projects at Virginia Tech.
2. Published a chapter in Mark's Standard Handbook for Mechanical Engineers, 12th Edition (a seminal publication used by practicing engineers) on "Railway Engineering."

3. Made more than 10 presentations to the railroad industry on various research topics, pursued at the Railway Technologies Laboratory (RTL).

Published Papers
1. Hawthorne V. T., Hawthorne, K. L., and Ahmadian, M., "Railway Engineering," Mark's Standard Handbook for Mechanical Engineers, 12th Edition, Section 11.2, 2017.
2. Hosseinipour, M., Naderi-Soorki, M., and Ahmadian, M., "On Effective Electromagnetic Shielding of Modern Pulse Width Modulating Adjustable Speed Drives," IEEE Transaction on Electromagnetic Compatibility, Vol. 60, Issue 4, October 2017, pp. 875 – 884. (DOI: https://doi.org/10.1109/TEMC.2017.2738840)
3. Ghodrati, M., Ahmadian, M., and Mirzaeifar, R., "Investigating the rolling contact fatigue in rails using finite element method and cohesive zone approach," Proceedings of the 2018 ASME Joint Rail Conference, JRC2018, April 18-20, 2018, Pittsburgh, PA.

University of Delaware

Presentations:
1. Poster session at TRB conference in Washington DC in January 2018.
   o Three posters presented based on UTC related projects.
2. University of Delaware Big Data in Railroad Engineering December 13-14, 2017
   o Presentation on Rail Wear analysis (UTC sponsored).
3. Poster session at UD Big Data in Railroad Engineering December 13-14, 2017
   o 6 posters presented based on UTC related projects.
4. Paper on Principal Component Analysis in the evaluation of Track Quality Indices presented at the Annual Inter-University Symposium on Infrastructure Management, Purdue University, June 2017.
5. Paper on Track Geometry Big Data Analysis: A Machine Learning Approach presented by IEEE International Conference on Big Data, Boston Massachusetts, December, 2017.
   . Seminar presentation on Principal Component Analysis and Track Quality Index: A Machine Learning Approach presented at Transportation and Civil Infrastructure Seminar, November, Fall 2017.
7. Poster presentation at Delaware Data Science Symposium, University of Delaware, May 2017.
8. Presentation scheduled for UIUC Crosstie and Fastener Conference May 2018 in Urbana IL.
9. Two papers to be presented at AREMA in September 2018.
   o Rail wear-forecasting model.
   o Relationship between Ballast Condition measurements and development of track geometry defects.

Publications
1. Principal Component Analysis and Track Quality Index: A Machine Learning Approach, accepted at Elsevier Special Issue on Big Data in Railway Transportation, December, 2017.
2. "Modeling tamping recovery of track geometry using the copula based approach." Journal of Rail and Rapid Transit.

University of Nevada, Las Vegas

Presentations
1. E. Mortazavian and Z. Wang, Mobile 3D Printing of Rail Track Surface for Rapid Repairment, Oral Presentation – presented at the 27th Annual Fall Transportation Conference, Las Vegas, NV, October 12, 2017.
2. Choi, J. O., Sapkota, S., Kaseko, M. S., & Teng, H., High speed Rail Access Charge for the XpressWest of Nevada. Oral Presentation – presented at the 27th Annual Fall Transportation Conference, Las Vegas, NV, October 12, 2017.
3. Ryan Sherman, Developing Acoustic Technology to Detect Transverse Defects in Rail at High Speed, Oral Presentation – presented at the 27th Annual Fall Transportation Conference, Las Vegas, NV, October 12, 2017.
4. Yingtao Jiang, 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, Oral Presentation – presented at the 27th Annual Fall Transportation Conference, Las Vegas, NV, October 12, 2017.
5. E. Mortazavian and Z. Wang, Mobile 3D Printing of Rail Track Surface for Rapid Repairment, Oral Presentation – presented at the Seminar in Railroad Infrastructure, Las Vegas, NV. June 23, 2017.
6. Choi, J. O., Kaseko, M. S., and Teng, H. High speed rail access charge for the XpressWest of Nevada. Seminar – presented at the Seminar in Railroad Infrastructure, Las Vegas, NV. June 23, 2017.
7. Ryan Sherman, Developing Acoustic Technology to Detect Transverse Defects in Rail at High Speed, Oral Presentation — presented at the Seminar in Railroad Infrastructure, Las Vegas, NV. June 23, 2017.
8. Yingtao Jiang, 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, Oral Presentation – presented at the Seminar in Railroad Infrastructure, Las Vegas, NV. June 23, 2017.
9. E. Mortazavian and Z. Wang, Mobile 3D Printing of Rail Track Surface for Rapid Repairment, poster at the Railroad UTC Reception, Washington, D.C., January 2018.
10. Choi, J. O., Kaseko, M. S., and Teng, H. High speed rail access charge for the XpressWest of Nevada. Seminar – poster at the Railroad UTC Reception, Washington, D.C., January 2018.
11. Ryan Sherman, Developing Acoustic Technology to Detect Transverse Defects in Rail at High Speed, Oral Presentation — poster at the Railroad UTC Reception, Washington, D.C., January 2018.
12. Yingtao Jiang, 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, Oral Presentation – poster at the Railroad UTC Reception, Washington, D.C., January 2018.

Publications
1. E. Mortazavian, Z. Wang, and H. Teng, Thermal-Mechanical Study of 3D Printing Technology for Rapid Rail Repair, accepted for the Proceedings of the ASME 2018 International Mechanical Engineering Congress and Exposition, IMECE 2018, November 9-15, 2018, Pittsburgh, PA, USA.

Plan for the next reporting period

Virginia Tech

The Virginia Tech research team intends to continue research activities that are ongoing, and add the two new research projects mentioned above. It is intended to continue outreach activities to inform the rail industry of our findings. During the coming year, plans have been made to offer a professional development course in the area of Rail Vehicle Dynamics for practicing engineers in rail industry. There are also plans to publish two journal papers and six conference publications and presentations.

University of Delaware

- Continue research activities with current graduate students and research scientist. Anticipate one new graduate student.
- Expect to publish three to five journal papers and make two or three presentations.
- Anticipate one professional course.

University of Nevada, Las Vegas

UNLV will continue research activities, expecting the completion of various research projects. From these projects that will be completed, publications and presentations will be produced. New patents will be filed based on the new projects. A railroad conference will be held for disseminating the research results from this research. This will create an enhancement of collaborations with the high-speed rail industry.

PRODUCTS

Publications, conference papers, and presentations

Virginia Tech

Publications
1. Hawthorne V. T., Hawthorne, K. L., and Ahmadian, M., "Railway Engineering," Mark's Standard Handbook for Mechanical Engineers, 12th Edition, Section 11.2, 2017.
2. Hosseinipour, M., Naderi-Soorki, M., and Ahmadian, M., "On Effective Electromagnetic Shielding of Modern Pulse Width Modulating Adjustable Speed Drives," IEEE Transaction on Electromagnetic Compatibility, Vol. 60, Issue 4, October 2017, pp. 875 – 884. (DOI: https://doi.org/10.1109/TEMC.2017.2738840).
3. Ghodrati, M., Ahmadian, M., and Mirzaeifar, R., "Investigating the rolling contact fatigue in rails using finite element method and cohesive zone approach," Proceedings of the 2018 ASME Joint Rail Conference, JRC2018, April 18-20, 2018, Pittsburgh, PA.

University of Delaware

Publications

1. Zarembski, A. M., Palese, J. W. and Euston, T. E., "Correlating Ballast Volume Deficit with the Development of Track Geometry Exceptions Utilizing Data Science Algorithm," Journal of Transportation Infrastructure Geotechnology, Vol 4 No 2 pp 37-51, September 2017, DOI 10.1007/s40515-017-0039-05.
2. Zarembski, A. M., "Improving Railroad Safety with Risk Management," Civil Engineering Research Journal, Vol 1 Issue 4
3. Zarembski, A. M. and Attoh-Okine, N., "Big Data in Railroad Engineering: The Challenge of Vast Amounts of Data," Railway Track & Structures, November 2017 pp. 28-30.
4. Zarembski, A. M., "Using Data Science to Establish Relationships between Key Railroad Engineering Parameters and Behavior," Trends Tech Sci Res. 2018; 1(1): 555552.
5. Zarembski, A. M., "The Emerging Role of Data Science in Railroad Maintenance Management" Railway Age, May 2018.
6. Ahmed Lasisi and Attoh-Okine Nii (Best Paper Award): Principal Component Analysis in the evaluation of Track Quality Indices, Annual Inter-University Symposium on Infrastructure Management, Purdue University, June 2017.
7. Ahmed Lasisi and Attoh-Okine Nii: Principal Component Analysis and Track Quality Index: A Machine Learning Approach, Elsevier Special Issue on Big Data in Railway Transportation, December 2017.
8. Martey, E. N. and Attoh-Okine, N.O. "Modeling tamping recovery of track geometry using the copula based approach." Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit, 0(0), 1–18, 2018. DOI: 10.1177/0954409718757556.
9. Martey, E. N., Lasisi A.O. and Attoh-Okine, N. O. "Track Geometry Big Data Analysis: A Machine Learning Approach," 2017 IEEE International Conference on Big Data, Boston, MA, USA, Dec 11-14, 2017. DOI: 10.1109/BigData.2017.8258381.

University of Nevada, Las Vegas

Publication
1. E. Mortazavian, Z. Wang, and H. Teng, Thermal-Mechanical Study of 3D Printing Technology for Rapid Rail Repair, accepted for the Proceedings of the ASME 2018 International Mechanical Engineering Congress and Exposition, IMECE 2018, November 9-15, 2018, Pittsburgh, PA, USA.

Website

Virginia Tech

- http://www.me.vt.edu/research/centers/cvess/, website for the Center for Vehicle System and Safety in the Mechanical Department at Virginia Tech
- http://www.me.vt.edu/vt_rail/, Virginia Tech's Railroad Advanced Initiatives Lab (VT RAIL) is an industrial affiliate group seeking to serve the railroad community

- http://www.me.vt.edu/vt-fra-roller-rig/, features Roller Rig, an experimental evaluation of the wheel to rail contact mechanics and dynamics of railway vehicles. It consists of a wheel, and a roller in a vertical configuration to simulate the wheel-rail interaction. Many sensors measure the contact patch parameters with accuracy, making it ideal for scientific studies.

University of Delaware

- Website created for papers presented at the December 2017 Big Data in Railroad Maintenance Planning Conference. All presentations given at the 2017 conference were approved by the authors and are on the website. The website was set up for 60 days and then taken down - currently showing information on 2018 Big data conference. The website is:
  http://outreach.engr.udel.edu/professional-development/conferences/big-data-in-railroad-maintenance-planning/

University of Nevada, Las Vegas

- The website for the Railroad UTC was developed in March 2017 and has been 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.

- Developed a website for the UNLV Railroad Program: https://www.unlv.edu/engineering/railroad. This website carries all the information about the program, such as the AREMA student chapter at UNLV, chapter officers at UNLV, railroad courses offered at UNLV, and an international program.

Technologies or techniques

Virginia Tech

The technologies created as a result of the research at the Railway Technologies Laboratory include:
1. LIDAR-based systems for measuring the extent of lubrication of top of rail.
2. Forward Looking Infrared Radiometer (FLIR) Aerial Technology for monitoring and detection of fouled ballast (currently underway).

University of Delaware

Nothing to report

University of Nevada, Las Vegas

Nothing to report

Inventions, patent applications, and/or licenses

Virginia Tech

 Nothing to report

University of Delaware

 Nothing to report

University of Nevada, Las Vegas

 Two patent applications:
- Provisional Application No. 62/613,877, Mobile 3D Printing of Rail Track Surface for Rapid Repair, December 2017.
- Provisional Patent Application No. 62/613,895, Acoustic Detection of Transverse Defects in Rail at High Speed, December 2017.

Other products

Virginia Tech

The VT Team has engaged in the development of the following products:

1. Novel machine learning techniques for high-fidelity and automated processing of large data for railway applications.
2. LIDAR-based methods for establishing rail lubricity.
3. Detection and monitoring of fouled ballast through aerial means that use infrared radiometry techniques.

University of Delaware

1. Method/Model for identifying the probability of a track geometry defect occurring in the wood tie track as a function of the wood tie condition, using automated tie inspection techniques. Paper currently being written.
2. Method/Model for identifying the probability of a track geometry defect occurring in high speed track based on ballast fouling index and depth of ballast, using GPR data. Paper currently being written.

University of Nevada, Las Vegas

Three online course developments:

1. Online Course Development on "High Speed Rail."
2. Online Course on "Railroad Engineering."
3. Online Course Development on "Introduction to Railroad Transportation."

PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

Organizations involved as partners

Virginia Tech

The Virginia Tech research team has been working closely with the following organizations:
1. Norfolk Southern, Roanoke, Virginia. Contributions: Rail pieces; track access for testing; engineering time.
2. Amtrak, Philadelphia. Contributions: test data; engineering time.
3. Alstom, Hornell, New York. Contributions: engineering time.
4. Standard Steel, LLC, Standard Steel, LLC, Burnham, PA. Contributions: scaled wheels; engineering time.

University of Delaware

1. CSX Transportation, Jacksonville, Florida.
   - Extensive data for Big Data analyses activities to include:
   - Rail wear data.
   - Rail fatigue data.
   - Track geometry data.
   - Traffic data.

2. GREX Georgetown Rail Equipment Company, Georgetown Texas.
   - Location of Organization: Georgetown Texas.
   - Partner's contribution to the project:
   - Financial support: $50,000.
   - In-kind support: Extensive Data on railroad tie condition.

University of Nevada, Las Vegas

1. Norfolk Southern Railroad: donations: four 39' worn rails.
2. Nevada Southern Railroad: contributions: space, tools, and staff time.
3. California High Speed Rail Authority: contribution: proposal review, problem identification.
4. Siemens, CRSC, and Bombardier, contributions: time in seminar activities.
5. Beijing Jiaotong University of China, scholars/staff working on research.
6. China Central University, scholars/staff working on research.

Other collaborators or contacts involved

Virginia Tech
- Standard Steel has provided technical assistance
- Norfolk Southern has provided access to their revenue-service track for the purpose of field testing

University of Delaware

- Amtrak has provided data on track geometry and ballast conditions
- Federal Railroad Administration has provided support and data

University of Nevada, Las Vegas

- California State University at Bakersfield for education and research collaboration. They have a high speed rail locomotive simulator that is the only one in the U.S.
- Beijing wowjoint machinery Co., LTD, communications on high speed rail construction equipment

IMPACT

Impact on the development of the principal discipline(s) of the program

Virginia Tech

The methods being developed at Virginia Tech have the potential to significantly improve the means for operation, maintainability, and sustainability of railway structures. Specifically, these methods will help with:

1. Providing devices that can be used for repeatedly and accurately measuring the extent of rail lubricity well beyond the empirical means that are currently available, thereby enable the railroads to monitor the lubricity of their tracks and more efficiently manage their assets.
2. Investigating more effective and efficient data analytics techniques that can be used for processing the large amount of data that is being acquired by the railroads, but often go unprocessed.

University of Delaware

1. Development of new methods to assess the probability of a track geometry defect occurring based on underlying conditions of the track structure, specifically ballast fouling condition. This will allow for the prediction of safety related defect development, such that safety can be increased and efficient maintenance activities defined.

2. Development of new Data Science applications for large data populations such as track geometry data. These applications include:
   o Copula based approach
   o Machine Learning Approach
   o Principal Component Analysis
   o Multiway Data Analysis Factorization

University of Nevada, Las Vegas

1. The interaction between wheel and rail cause the wearing of both elements, which needs constant maintenance and replacement. The cost of maintaining and replacing the wheel and rail is the largest in the railroad industry. 3D printing to repair the rail wear will add the materials that are worn out, which is a fundamentally different approach to repairing rail. The success of the research conducted in this program will provide a significantly different approach on rail maintenance, saving the cost of maintenance significantly to the railroad industry.

2. Railroad track inspection has gone through two generations of technologies: manual and vehicle carried. The UAV based track inspection is the third generation of the track inspection technologies, which is critical to high-speed rail because of the higher safety requirement of high-speed rail systems. The UAV track monitoring system will complement the existing track monitoring system, making the inspection more cost effective and reliable.

Impact on other disciplines

Virginia Tech

Some of the methods developed in our rail effort could have applications for heavy trucks. Such a determination is currently underway.

University of Delaware

Approaches and methodologies developed can readily be adapted in the area of highway pavement and airport runway research and analysis.

University of Nevada, Las Vegas

1. Researchers in this team are writing proposals to apply the 3D printing technology tested in this study to repair highway steel bridges. In addition, this team is writing proposals to repair other railroad elements such as switches and steel wheel.
2. Highway inspection has also experienced two generations of technologies, manual and vehicle based automation. The UAV technology developed in this study for inspecting track can be easily applied to inspecting highway infrastructures.

Impact on the development of transportation workforce development

Virginia Tech

Virginia Tech has placed more than 10 graduate and undergraduate students with the railroad industry in the U.S. It has provided unprecedented access to students for the rail companies that have selected to recruit on Virginia Tech campus.

University of Delaware

Opportunities for research in the area of data Sciences application to railway degradation analysis and maintenance planning, dubbed as State of Good Repair. Both undergraduate and graduate students are being brought into this area under the UTC program. The Students are provided with specialized skill sets such as data analytics with applications to infrastructure condition monitoring.

University of Nevada, Las Vegas

1. The attendees to the high-speed rail seminar in December 2017 included professionals, faculty members, and students from different parts of the nation. The instructors were from world-class industries and universities. The professionals taking this class will find jobs in high-speed rail. Some attendees were from Caltrans, and may apply for promotion positions in the California High Speed Rail. The faculty from the seminar may offer similar classes in other universities. The students from the seminar were equipped with better knowledge on high-speed rail and work on relevant projects. These students could find jobs in this area of expertise.

2. During this reporting period, UNLV offered two railroad classes; Introduction to Railroad Transportation, and Railroad Engineering. The attendees were offered the chance to become AREMA student members in addition to learning railroad knowledge. UNLV also requested the recruiting office to invite railroad companies to attend career fairs. With these connections, students will have greater opportunities to work in the railroad profession.

Impact on physical, institutional, and information resources at the university or other partner institutions

Virginia Tech

- Virginia Tech committed to increasing the lab space dedicated to the Railway Technologies Laboratory by 30%. The expansion of the lab facility was initiated in early March, 2018, and is currently underway.
- Additionally, the university has made substantial cost-sharing commitments for supporting the PI.

University of Delaware

- This program allows for the expansion of the Railroad Engineering and Safety Program, by which the program can hire a Senior Scientist level person, effective September 1 2017.

University of Nevada, Las Vegas

- This UTC program provides an opportunity to develop a website for the railroad program at UNLV, which will provide interested parties to explore this program and access the information provided on the website.
- In addition, the UTC program allows UNLV to explore the opportunity to sign a MOU with the Nevada Southern Railroad, making it an official railroad education, research and outreach infrastructure to UNLV.

Impact on technology transfer

Virginia Tech

Significant progress has been made this year toward making the U.S. industry aware of the technologies that are under development at the Railway Technologies Laboratory, toward successfully transferring them to the industry. Our initial discussions have included the possibility of commercializing the technologies that hold a higher promise, for use by the U.S. rail industry.

University of Delaware

The results to date and anticipated future results can be transferred globally, to allow railways to take advantage of current inspection data, and foster the development and adoption of new inspection technologies.

University of Nevada, Las Vegas

The better testing results in lab and field from 3D printing application in repairing rail can facilitate its adoption in industry.

Impact on society beyond science and technology

Virginia Tech

The DOT-UTC program has resulted in significant awareness of the student community to the rail industry. Whereas the U.S. rail industry had been out-of-sight and out-of-mind for decades among the students and educators, the DOT-UTC has brought new awareness to the exciting initiatives underway in the industry.

University of Delaware

In general, much of the research conducted under this activity lends itself to a safer, 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.

University of Nevada, Las Vegas

It is expected that the high-speed rail seminar will educate and expand understanding of this technology; with this information, more high-speed rails will be produced in the U.S.

CHANGES/PROBLEMS

Changes in approach and reasons for change
No changes at any consortium university.

Actual or anticipated problems or delays and actions or plans to resolve them
No changes at any consortium university.

Changes that have a significant impact on expenditures
No changes at any consortium university.

Significant changes in use or care of human subjects, vertebrate animals, and/or biohazards
No changes at any consortium university.

Change of primary performance site location from that originally proposed
No changes at any consortium university.

ADDITIONAL INFORMATION REGARDING PRODUCTS AND IMPACTS

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

Virginia Tech

- Have placed more than 10 undergraduate and graduate students with the railroad industry

- Actively participated in field testing of some of the technologies that are under development at the lab, toward product commercialization in the future.

University of Delaware

- Anticipated follow up research award from GREX. (May 2018).
- Anticipated research award from MRS Logistica in Brazil. (May 2018).
- Probability prediction models for track geometry defect occurrence based on track condition using automated inspection equipment.

University of Nevada, Las Vegas

- There undergraduate students in Mechanical Engineering participated in a senior design project on Zinc coating steel rail pad that are usually corroded and then shorten the life of fastening system. From communicating with relevant industry like Pandrol Manufacturing Company, they have a better understanding of railroad and potentially find jobs in railroad.

Outcomes are broader changes that are expected to result from the products

Virginia Tech

- It is expected that our research will results in significant improvements in the way the rail industry currently measures Top of Rail (ToR) lubricity
- Also, the results of our projects will lead to significantly improving the railroad's ability to detect ballast contamination (commonly known as fouled ballast)

University of Delaware

- New Research fellow from Brazil working on UTC related research activities.
- Placed recent PhD graduate at Transportation Test Center (TTCI, Pueblo Colorado) to specialize in data science research.
- Current programs and course of studies are drawing international railway engineers to learn state of the art research and to apply the results globally.
- Increasing participation in Big Data in Railway Maintenance Planning conference both domestically and internationally.

University of Nevada, Las Vegas

- 3D printing, as a new manufacturing technology, will be investigated for broader application in railroad.
- UAV will be given a border application in railroad from simple site surveying and monitoring to track performance monitoring and defect detection.