13th Semi-Annual Progress Report
for
National University Rail (NURail) Center:
Tier 1 University Transportation Center

National University Rail Center - NURail
US DOT OST-R Tier 1 University Transportation Center

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1. Accomplishments

The National University Rail (NURail) Center is a rail-focused seven-university consortium led by the Rail Transportation and Engineering Center (RailTEC) at the University of Illinois at Urbana-Champaign (UIUC). NURail is working to improve and expand rail education, research, workforce development, and technology transfer. This includes working with other colleges and universities, both domestic and international, the rail industry, AAR and FRA.

As we approach the end of our funding numerous projects from this grant have been completed, while some principal investigators (PIs) are still spending their final funds. Because there are a smaller number of active projects, there are fewer accomplishments, publications or other products that can be attributed to these expenditures.

a. What was accomplished under these goals? (major activities; specific objectives; significant results (positive and negative); key outcomes)

NURail Consortium

- Winners of the 2020 American Railway Engineering and Maintenance-of-Way Association (AREMA) Educational Foundation scholarships were recently announced. Fifteen of the 34 AREMA scholarships awarded went to students attending NURail Center partner schools and an additional four went to NURail affiliate members.
- NURail Center partners met during the 99th Annual Transportation Research Board (TRB) meeting in Washington, D.C. on January 12, 2020. Meeting participants discussed plans for current and future education, research, workforce development and outreach activities in addition to discussing remaining project funds, timelines and reporting requirements. Five NURail partner universities were represented at TRB with conference involvement that included: authors, session chairs, committee members, committee member chairs, and TRB Emeritus members.
- Two NURail partner schools are recipients of the 2019 National Railroad Construction and Maintenance Association's (NRC) Education grant. Tyler Dick, UIUC, and David Nelson, Michigan Technological University (Michigan Tech), were invited to attend the 2020 NRC conference in San Diego on January 5-8 to discuss their respective programs and how they plan to utilize the grant funds. Illinois plans to use the grant funds for outreach and recruiting of K-12 students that demonstrate key learning points related to railway transportation. Michigan Tech plans to use their grant funds for outreach and recruiting of pre-university students, which includes a rail tour with pre-K and kindergarten students, as well as for making the Rail and Intermodal Summer Youth Program accessible for underprivileged students in the Detroit Metropolitan area.
- On December 5, 2019 RailTEC hosted Dr. Maryam Allahyar, Director, Office of Research, Development & Technology, Federal Railroad Administration. Dr. Allahyar received an overview of both the NURail Center and RailTEC and was briefed on research and education projects. She also toured the Research and Innovation Laboratory (RAIL) and discussed infrastructure research being conducted

there. In addition, she visited the graduate students' office to talk and learn about their specific projects.

University of Illinois Urbana-Champaign

- *Shared Rail Corridor Adjacent Track Accident Risk Analysis – Phase 2 (Shared Corridor)* - A conference paper was presented, and a new journal paper is being prepared for submission. The previously developed train presence model has been deployed on several case studies to provide quantitative probabilistic corridor risk assessment.
- *Improving Track Substructure Designs and Settlement due to Complex Dynamic Loads from High-Speed Passenger and Freight Trains (Track Substructure)* - Based on individual ballast particle movement and force development obtained from validated Discrete Element Method (DEM) simulations, machine learning K-means clustering were performed on ballast layers with different tie support conditions. Also, mechanical behavior and movements of ballast particles among different clusters within the layer were studied to further quantify the effects of mixed traffic patterns and tie support conditions.
- *Schedule Flexibility and Railway Line Capacity (Line Capacity)* - Project is complete pending final report.
- *Capacity of Hump Classification Yards (Hump Classification)* - Multiple conference and journal papers are being prepared, presented to various industry sponsors, and developed into a final project report.
- *Intermodal Terminal Capacity Factor Interactions (Terminal Capacity)* - Results were presented at the 2019 INFORMS Annual Meeting in October. Project is complete pending final report.
- *Relative Capacity and Performance of Fixed and Moving Block Train Control Systems (Train Control Systems)* - Additional simulations of combinations of control systems, train fleeting and track layout strategies were completed. Results were published in two journal papers and presented at the TRB Annual Meeting. An additional journal paper was submitted for review.
- *Guidebook for Railway-themed K-12 STEM Outreach Activities (K-12 STEM)* - Draft descriptions of multiple activities were prepared for the guidebook. Results from the survey on activities influencing interest in railway engineering education and careers were compiled and analyzed.
- *Numerical Investigation of Impact Load Effects on Railroad Track Systems (Load Effects)* - Project is complete pending final report. Journal papers that stemmed from content in a recent dissertation were developed and submitted for review. Results were presented at the TRB 2020 Annual Meeting in January.
- *Quantifying Cyclic Loading Failure Criteria for Concrete Crossties (Concrete Crossties)* - Laboratory experiments were completed, and results were processed and documented in a forthcoming PhD dissertation. Results indicate that abrasion related hypotheses need further investigation, but all project findings indicated that water accelerates concrete degradation, and its effects are most pronounced in pre-tensioned members (as opposed to post-tensioned).

- *Advanced Study of Resilient Materials Effects on Track (Resilient Materials)* – Processed results and reviewed other (prior) experimental results related to under tie pads (UTPs) and how they influence ballast life and crosstie bending demands. A deeper literature review understanding current models representing track behavior was undertaken to ensure resources were used appropriately, and these findings governed the development of a modified beam on elastic foundation (BOEF) model.

University of Illinois Chicago
- *Coupled Multibody and Finite Element Analysis of Rail Substructure Behavior* - Run simulations for ballast settlement and have preliminary results, indicating that the model can effectively predict settlement. Simulations for longer time periods are under way.

Michigan Tech University
- *Log Movement in the Superior Region - Rate and Capacity Based Analysis of Modal Shares* – Report submitted to co-sponsors, waiting on approval. Co-funded with the Michigan Economic Development Corporation, Michigan Department of Transportation, Michigan Department of Agriculture, Michigan Tech and NURail.
- Presented conference paper at the TRB 2020 Annual Meeting.
- Started planning for 2020 Michigan/Midwest Rail Conference and Summer Youth Program in Rail and Intermodal Transportation.
- Performed invited speeches at Penn State Altoona and University of Nevada Las Vegas on grade crossing research.
- Initiated three exploratory research projects; NURail2019-MTU-R17 - Understanding attention management and driver decision behavior at short-storage rail grade crossings, NURail2020-MTU-R18 - Improvement on the eddy current measurement for rail flaw detection and signal processing, NURail2020-MTU-R19 - Computer Learning and AI-Based Investigation of Outward Facing Locomotive Videos for Trespassing Events and Behavior.
- Supported two undergraduate senior design projects, Intermodal Operations: Escanaba & Lake Superior Railroad and Escanaba & Lake Superior Railroad Storage Tracks.

University of Kentucky
- *Pressure distributions and magnitudes at the tie/ballast interface* - Continued in-track trackbed pressure measurements with revenue trains and the FRA's DOTX 218 Test Train at NS Railway test site. Continued to monitor trackbed design practices in Western European countries.

University of Tennessee, Knoxville
- One PhD dissertation was completed by Qiang Gui "Seismic Performance of Stone Masonry and Unreinforced Concrete Railroad Bridge Piers", December 2019. NURail final report is being proofed.

b. How have the results been disseminated?

NURail Consortium
- Between October 1, 2019 and March 31, 2020, the NURail website had over 2,285 page loads.

University of Illinois Urbana-Champaign
- *Shared Corridor* - A conference paper was presented at the World Congress of Railway Research in October 2019.
- *Load Effects* – Draft journal manuscripts related to this content have been developed and submitted for peer review.
- *Concrete Crossties* - Results were presented at the TRB 2020 Annual Meeting in Washington D.C. in January.
- *Resilient Materials* - A journal paper was published in the Journal of Rail and Rapid Transit titled, "Identification of Under Tie Pad (UTP) Material Characteristics for Stress State Reduction". Further, two ballots were accepted into North American recommended practices to be incorporated with AREMA C30 (Ties).
- *Line Capacity* - Final report is pending.
- *Hump Classification* - A paper was presented at the 12th World Congress on Railway Research in Tokyo in October.
- *Terminal Capacity* - The project was presented at the 2019 INFORMS Annual Meeting in Seattle in October.
- *Train Control Systems* - Two journal papers were published and one of the papers was presented at the TRB 2020 Annual Meeting in Washington D.C. in January.
- *K-12 STEM* - A project update was presented at the National Railroad Construction and Maintenance Association 42nd Annual Conference in San Diego in January.
- *Track Substructure* - Paper presented at the TRB 2020 Annual Meeting in Washington D.C. in January.

University of Illinois Chicago
- One conference paper.

Michigan Tech University
- Several publications/presentations were completed during the reporting period. See details below.

University of Kentucky
- One paper presented at 2020 TRB on January 12-16 in a poster session and is now being considered for publication in the TRB Journal. A second TRB paper was submitted for publication and revisions are now underway addressing reviewer's comments.
- Paper prepared and presented at AREMA Railway Roadbed & Ballast (RRB20) Symposium on February 10-12, 2020 in Kansas City, MO.

- Paper prepared and submitted for review for the International Conference on Transportation Geotechnics (ICTG) 2020 Conference scheduled to be held on August 30 – Sept 2, 2020 in Chicago, IL.
- Presentation at the Washington Area Railway Engineering Society Annual Meeting in Baltimore, MD on October 8, 2019.

c. What do you plan to do during the next reporting period to accomplish the goals and objectives?

University of Illinois Urbana-Champaign
- *Shared Corridor* - Refine train braking algorithms in the train presence model to account for advanced train control systems which improve the accuracy and practicality of the adjacent track accident risk assessment.
- *Load Effects* - Complete the final project report and incorporate any edits that are forthcoming from the peer review process for the draft journal articles.
- *Concrete Crossties* - Finish processing current laboratory results and carry out final experiments with post-tensioned concrete crossties (if possible due to Covid-19).
- *Resilient Materials* – Continued an in-depth literature review to ensure the current international state of practice is understood. Further, a preliminary model was developed to incorporate resilient materials, and studies will be run investigating their affects. Continue to partner with AREMA C30 (Ties) to incorporate findings into North American recommended practices.
- *Track Substructure* - Summarize current research findings into a publishable manuscript. Develop a data-driven machine learning algorithm to predict tie support conditions based on ballast particle mechanical behavior at different locations.
- *Line Capacity* - Complete final report.
- *Hump Classification* - Complete journal papers and final project report. Prepare paper for presentation at the AREMA Annual Conference in Dallas in September.
- *Terminal Capacity* - Complete journal paper and final project report.
- *Train Control Systems* - Pending review, finalize last journal paper and then complete final report.
- *K-12 STEM* - Continue project work to refine descriptions of rail-focused K-12 outreach activities and further analyze results of survey on activities influencing railway engineering education and careers. Prepare paper for presentation at the AREMA Annual Conference in Dallas in September.

University of Illinois Chicago
- Run simulations on settlement for longer time periods and process the results. After final simulations, will compile final report.

Michigan Tech University
- Finalize undergraduate student senior design projects.
- Organize both the Michigan/Midwest Rail Conference and Summer Youth Program in Rail and Intermodal Transportation (may be organized virtually due to COVID).

- Complete on-going research projects.
- Start preparations for grant closure.

University of Kentucky
- Prepare final version of papers as required.

University of Tennessee, Knoxville
- Submit two final reports for education projects: "Continuing Education for the Railway Industry" and "Railway Operations Class".
- Finish final proofing of the report for "Seismic Performance of Stone Masonry and Unreinforced Concrete Railroad Bridge Substructures".

2. Participants and Other Collaborating Organizations

a. What organizations have been involved as partners?

Organization or University Name	Location	Contribution to the Project	Name (First and Last)
NS Railway Corp.	Atlanta, GA	In-Kind Assistance	Ed Boyle
Federal Railroad Administration	Washington, DC	Co-funded project	Michael Jones
Michigan Dept. of Transportation	Lansing, MI	Co-funded project	Nikkie Johnson
Metra	Chicago, IL	Shared data	Hilary Konczal
Michigan Economic Development Corporation/Alger County	Lansing, MI	Co-funded project	Peter Van Steen (Alger)
Michigan Dept. of Agriculture	Lansing, MI	Co-funded project	Peter Anastor

b. Additional collaborators or contacts:

Name (First and Last)	Company, University, Organization Name	Location	Contribution to the Project
Diego Cardona	Eiffage Industries	Corbas, France	Data and Paper
Radim Bruzek	Ensco, Inc.	Falls Church, VA	In-Kind Test Equipment
Colin Brooks, Erick Vega, Richard Dobson	Michigan Tech Research Institute	Ann Arbor, MI	Leading projects that have built on NURail work.

3. Outputs

a. Journal publications:

University of Illinois Urbana-Champaign
- Diaz de Rivera, A., C.T. Dick and L.E. Evans. 2020. Potential for moving blocks and train fleets to enable faster train meets on single-track rail corridors. Journal of Transportation Engineering, Part A: Systems. (In Press).
- Diaz de Rivera, A., C.T. Dick and L.E. Evans. 2020. Improving railway operational efficiency with moving blocks, train fleeting and alternative single-track configurations. Transportation Research Record: Journal of the Transportation Research Board. 2674(2): 146-157.
- Edwards, J.R., Y. Liang, J.C. Bastos, and M.S. Dersch. 2019. Development of a Parametric Model for Prediction of Concrete Railway Crosstie Service Bending Moments. *Journal of Rail and Rapid Transit*. DOI: 10.1177/0954409719888068.
- Branson, J., M.S. Dersch, A.O. Lima, J.R. Edwards, and Bastos, J.C. 2019. Identification of Under Tie Pad (UTP) Material Characteristics for Stress State Reduction. *Journal of Rail and Rapid Transit*. DOI: 10.1177/0954409719890156.
- Bastos, J.C., M.S. Dersch, and J.R. Edwards. 2020. Statistical prediction of center negative bending capacity of pretensioned concrete crossties. In Press: *Journal of Transportation Engineering, Part A: Systems*.

b. Books or other non-periodical, one-time publications:

University of Illinois Chicago
- S. Kulkarni. Integration of Spatial Beam Elements in Large Displacement Multibody Analysis: Theory and Applications to Railroad Systems, Doctoral thesis.

Michigan Tech University
- Co-sponsor Report: Log Movement in the Superior Region – Rate and Capacity Based Analysis of Modal Shares, March 2020.

University of Tennessee, Knoxville
- Q. Gui. Seismic Performance of Stone Masonry and Unreinforced Concrete Railroad Bridge Piers, Doctoral thesis. December 2019.

University of Kentucky
- Designs, Applications and Performances of Asphalt/Bituminous Trackbeds in European, Asian and African Countries – D. Cardona, H. Benedetto, C. Sauzeat, N. Calon, and J. Rose, Revision of paper under final review for publication in TRB Journal.
- Modeling Crosstie-Ballast Pressure Distribution in a Railroad Trackbed using a Linear-Elastic Analysis – B. Thompson, D. Clarke, and J. Rose, Revision of paper under final review for publication in TRB Journal.

c. Other publications, conference papers and presentations:

University of Illinois Urbana-Champaign
- Lin. C-Y and Barkan, C.P.L. 2019. Modeling the Probability of Train Presence on Adjacent Tracks in Railway Vehicle Intrusion Scenarios. In: Proceedings of the World Congress of Railway Research (WCRR), Tokyo, Japan, October 2019.
- Dick, C.T. and N. Nishio. 2019. Influence of traffic complexity on railway gravity hump classification yard capacity. In: Proceedings of the 12th World Congress on Railway Research, Tokyo, Japan, October 2019.
- Bastos, J.C., M.S. Dersch, J.R. Edwards and C.P.L. Barkan. 2020. Water Damage in Cracked Prestressed Concrete Sleepers. Presented at: Annual Meeting of the Transportation Research Board (TRB), Washington, DC. January.
- Feng, B., Liu, Z., and Tutumluer, E. Effects of Mixed Traffic Patterns and Ballast Support Conditions on Track Performance Investigated through Discrete Element Modeling. Presented at: Annual Meeting of the Transportation Research Board (TRB), Washington, DC. January.

University of Illinois Chicago
- Foster, C.D. and S. Kulkarni. 2020. Coupled Multibody and Finite Element Modelling of Track Settlement. 16th International Conference of International Association for Computer Methods and Advances in Geomechanics. Torino, Italy. July 1-4, 2020. Accepted.

Michigan Tech University
- Ko, S., Lautala, P., and K. Zhang. 2020. Data-driven Study on the Log Movements for the Upper Midwest: Impact of Rail Car Fleet Size on Freight Storage and Car Idling, Transportation Research Board 99th Annual Meeting of the National Academies, Washington, DC, January 12-16, 2020.

University of Kentucky
- Cardona, D. and J. Rose. 2020. Improved Railway Trackbed Design with Asphalt Concrete in European Lines. Proceedings of the AREMA Railway Roadbed & Ballast (RRB20) Symposium, Kansas City, MO, February 2020.
- Russell, E., Rose, J. and D. Clarke. 2020. In-Track Timber Crosstie-Ballast Interfacial Pressure Measurements for Revenue Freight Trains and DOTX 2018/220 Test Train Operating Conditions. Proceedings of the AREMA Railway Roadbed & Ballast (RRB20) Symposium, Kansas City, MO, February 2020.
- TRB Poster session, Tuesday, January 14, 2020. Designs, Application, and Performances of Asphalt/Bituminous Trackbeds in European, Asian, and African Countries. Diego Ramirez Cardona, Eiffage; Hervé Di Benedetto, Ecole Nationale des Travaux Publics de l'Etat; Cedric Sauzeat, Ecole Nationale des Travaux Publics de l'Etat; Nicolas Calon, Societe Nationale des Chemins de Fer; Jerry Rose, University of Kentucky.

d. Website(s) or other Internet site(s):

University of Illinois Urbana-Champaign
- NURail Center website, http://www.nurailcenter.org/

Michigan Tech University
- Web links for Summer Youth - http://www.rail.mtu.edu/event/rail-and-intermodal-summer-youth-program-2020
- Midwest Rail Conference - http://www.rail.mtu.edu/MRC2020

e. Technologies or techniques:

- Nothing to report.

f. Inventions, patent applications and/or licenses:

- Nothing to report.

g. Other products (i.e. databases, audio/video products):

- Nothing to report.

4. Outcomes

a. List how the research outputs described in section 3 are being used to create outcomes.

University of Illinois Urbana-Champaign

1	*Yard Capacity* – Based on the research results, the PI developed a new description of approaches to quantify yard and terminal capacity and proposed it as new material for AREMA Manual Chapter 16. AREMA Committee 16 then voted to adopt the new content and publish it in the next edition of the AREMA Manual for Railway Engineering.
2	*Resilient Materials* - Based on the literature review and research results UIUC developed multiple ballots, two of which has been accepted for inclusion within the AREMA Chapter 30 (Ties) Recommended Practices which is updated/published each year and sets the track component (crosstie, fastener, UTP, etc.) design recommendations for all of North America.
3	*Concrete Crossties* – Additional results gathered this period have indicated that cracked pretensioned concrete crossties can have their capacity significantly reduced when moisture is present, thus increasing awareness of the relevance of flexural cracks. Additional study of post-tensioned crossties is needed.

4	*Track Substructure* - Brought insights on ballast particle dynamic responses in different clusters among the layer.
5	*Track Substructure* - Deepened understanding on the ballast particle mechanical behavior under complex tie support conditions and dynamic loading patterns.
6	*Shared Corridor* - Development of a risk assessment model, guidance, and procedure to assist in shared rail corridor planning and risk mitigation.

University of Illinois Chicago

1	Settlement analysis will help predict rates of settlement, especially near transitions, and examine potential remedies. The numerical methods developed have a wide variety of applications in the areas of geomaterial modeling, contact, and computational plasticity.

Michigan Tech University

1	Research work by NURail has supported successful proposals for external funding by faculty colleagues at Michigan Tech and a shift toward data-based analysis by the forest products industry.

University of Kentucky

1	Higher quality and safer railway trackbed designs.

5. Impact

a. What is the impact on the effectiveness of the transportation system?

University of Illinois Urbana-Champaign

- *Shared Rail* - Growth in passenger traffic on rail corridors shared with freight trains, and expanded rail transport of hazardous materials have both increased the imperative to understand the factors affecting railway transportation safety and risk. Adjacent track accident is identified as one of the top safety concerns for the implementation of shared-use rail corridors. Research on addressing the risk of adjacent track accident by developing a comprehensive risk assessment tool and guidance allows railroad practitioners to more effective and efficiently manage the risk on shared-use rail corridors.
- *Track Substructure* - Improving the safety and cost of railway track construction and maintenance has always been a challenge, especially in corridors where freight and passenger trains share the same track. Investigating the tie and ballast behavior under different support conditions and mixed traffic patterns is the crucial path towards the success of such improvement. Integrating Discrete Element Method (DEM) and machine learning techniques can grant researchers the power to thoroughly investigate the tie and ballast layer responses, which will eventually lead to valuable guidance for track structural design, construction and maintenance.
- *Terminal Capacity* - Constraints are a major issue for the railroads. With major investments in new hump yard and intermodal terminal projects underway, design and sizing of new yards and terminals is a growing need for the rail industry.

Research on interaction between yard and mainline capacity will allow railroad practitioners to make better capital investment decisions to maximize the overall capacity of the rail network through properly balanced investments in mainline and yard projects. Similarly, research to better understand the factors that control intermodal facility capacity will allow railroads to make prudent investments in new and expanded terminals to handle the fast-growing intermodal rail traffic market sector. Proper allocation of capital investments that minimizes delay, dwell and shipment transit time improves the overall effectiveness, efficiency and economies of freight rail transportation.

- *Resilient Materials* - Research, when adopted by the industry, will lead to reduced life cycle costs (LCCs) of components due to greater individual component resiliency, as well as increased track resiliency. Implementation of recommendations will lead to fewer service disruptions, greater capacity, increased safety, and longer time periods between maintenance cycles; all of which have a positive effect on the safety, reliability, and efficiency of our transportation system. There has recently been strong emphasis by Class I railroads on evaluation and potential adoption of these materials.
- *Concrete Crossties* - Better understanding the failure mechanisms of concrete crossties can lead to improved railroad practices that extend their service life, which contributes to more efficient and safer operations.

University of Illinois Chicago
- Potential to improve economy of rail systems, reduce maintenance, and possibly increase safety.

b. What is the impact on the adoption of new practices or instances where research outcomes have led to the initiation of a start-up company?

- Nothing to report.

c. What is the impact on the body of scientific knowledge?

University of Illinois Urbana-Champaign
- *Track Substructure* - Initiate a new research perspective on ballast layers by treating ballast particles as clusters instead of individuals or an integral entity.
- *Concrete Crossties* - A new degradation mechanism is being identified for pretensioned concrete beams, such as concrete railroad crossties. Additional hypotheses in need of experimental investigation are also being documented.

d. What is the impact on transportation workforce development?

University of Illinois Urbana-Champaign
- Student involvement, especially graduate researchers, in timely and advanced research topics in railroad engineering contributes to scientific discovery and educates the next generation of railroad experts.

- Developing rail-focused K-12 student outreach activities is essential to attracting a new generation of youth to develop an interest in railway transportation and engineering at earlier stages of their education. Based on experience in other STEM fields, students that are aware of railway technology and engineering concepts earlier in their K-12 education are more likely to enroll in rail-focused education programs and ultimately pursue careers in the railroad sector.
- Student participation in rail-focused research helps develop the next generation of railway professionals and trains them in the application of advanced technologies and techniques.
- Multiple student placements within the Class I railroad and supplier communities.

University of Illinois Chicago
- One doctoral student graduated.

Michigan Tech University
- Most NURail research projects at Michigan Tech are cross-disciplinary. Numerous undergraduate and graduate students have been involved in the activities (such as Railroad Night) and K-12 outreach.

University of Tennessee, Knoxville
- One doctoral student graduated.

6. Changes/Problems –

a. Changes in approach and reasons for change

- Nothing to report.

b. Actual or anticipated problems or delays and actions or plans to resolve them

University of Illinois Urbana-Champaign
- Some delays due to COVID-19 and inability to access laboratory and field experimentation locations. Anticipated that delays will be 2-3 months maximum.

Michigan Tech University
- COVID-19 lockdown may impact laboratory testing schedules.
- COVID-19 restrictions may force conferences to be to be held virtually instead of in-person.

c. Changes that have a significant impact on expenditures

- Nothing to report.

d. Significant changes in use or care of human subjects, vertebrate animals and/or biohazards

- Nothing to report.

e. Change of primary performance site location from that originally proposed

- Nothing to report.