

11th 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 NURail Center is a rail-focused university consortium led by the Rail Transportation and Engineering Center (RailTEC) at the University of Illinois at Urbana-Champaign (UIUC). NURail's principal goals are to achieve a set of Research, Education, Technology Transfer Collaboration and Leadership objectives that not only fulfill center objectives, but support and assist achievement of goals beyond the consortium members. These include the rail industry, AAR and FRA research and workforce development goals. They also include working with other colleges and universities, both domestically and internationally, to advance academic rail education and research quality and quantity.

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

NURail Consortium

- NURail Center partners met on Sunday, January 13, 2019 at the 98th Annual Transportation Research Board (TRB) meeting in Washington, DC. In addition to discussing remaining project funds, timelines and reporting requirements, meeting participants also discussed plans for future education, workforce development and outreach activities.
- Travis J. Watts, a Graduate Research and Teaching Assistant in the Department of Civil Engineering at the University of Kentucky, was named the 2018 NURail Center Student of the Year. He was recognized at the 2019 CUTC Banquet in Washington, D.C. at the 98th Annual TRB meeting.
- Twelve of the 28 total 2019 AREMA Educational Foundation scholarships given went to students attending NURail Center partner schools.
- Consortium partners wrote two final reports.

University of Illinois Urbana-Champaign

- For the sixth year in a row the NURail Center welcomed Hanson Professional Services Inc. and a group of middle and high school students from Springfield, IL to Engineering Open House (EOH) on the UIUC campus. This year's event was on Saturday, March 9, 2019. EOH is an annual student-led event featuring two days of exhibits and competitions that showcase the engineering students and is open to the public at no cost. Hanson's group of 36 students and adults spent the day examining a portion of the over 250 interactive exhibits on display spread throughout 17 different University buildings.
- One William W. Hay Seminar was held on March 31, 2019 and was available to on-campus participants only. The presentation was given by Dr. Allan Zarembski from the University of Delaware who spoke on the topic "Big Data in Railway Infrastructure and Rolling Stock".
- *Shared Rail Corridor Adjacent Track Accident Risk Analysis – Phase 2 (Shared Corridor)* - A segment-level train presence model has been developed to evaluate the probability of adjacent track collision on shared rail corridor. A dissertation document was completed and defended.

- *Railroad Grade Crossing Micro-Level Safety and Risk Analysis – Phase 2 (Grade Crossing)*- Final report was prepared (23/11/2018) and submitted to NURail for publication (3/21/2019).
- *Track Substructure Designs and Settlement due to Complex Dynamic Loads (Track Substructure)* - Project is complete pending final report. One journal paper has been published and one oral presentation was made at 2019 TRB annual meeting. Discrete element modeling of full-size one crosstie substructure performance under mixed freight and passenger traffic loading was completed, validated with laboratory test data. Analytical train-track model simulation was completed, validated with field data.
- *Numerical Investigation of Impact Load Effects on Railroad Track Systems (Load Effects)* - Completed analysis of field data for light rail transit, heavy rail transit, and heavy haul freight railroad systems for the flexural performance of crossties, to further the initial investigation into the wheel-rail interface loads. These data were compared to existing data from heavy haul freight systems and passenger data analyzed in previously. Installed new instrumentation on CTA in Chicago for measurement of loading condition on heavy rail transit provider.
- *Improved Concrete Crossties Design: Quantifying Cyclic Loading Failure Criteria (Concrete Crossties)* - Cyclic load test setup was continually improved and multiple tests with the addition of water were run. Additional prisms were cast. Met with key experts in materials and hydrology to develop comprehensive list of hypotheses.
- *Advanced Study of Resilient Materials Effects on Track (Resilient Materials)* - Developed laboratory experimental setup to statically test the influence of under tie pads on crosstie bending moment.
- *Schedule Flexibility and Railway Line Capacity (Line Capacity)* - Two journal papers have been published. Project is complete pending final report.
- *Capacity of Hump Classification Yards (Yard Capacity)* - Analysis of simulation results from the Belt Railway of Chicago hump yard model have been completed. A dissertation document was completed and defended.
- *Intermodal Terminal Capacity Factor Interactions (Terminal Capacity)* - AnyLogic models of various intermodal terminal layouts have been used to conduct capacity experiments. The results have been developed into a conference paper.

University of Illinois Chicago

- *Coupled Multibody and Finite Element Analysis of Rail Substructure Behavior (Substructure Behavior)* – Elements have been added for rail and fasteners to the finite element settlement model. This allows results to be applied from the multibody simulation at the rail rather than the sleeper.
- *History of the City of Chicago Central Area Transit Circulator Effort (Chicago Transit)* - Published its final report.

Michigan Tech University

- Submitted to FRA the final report on the research project “*Evaluation of Driver Behavior at Railroad-Highway Grade Crossings Using Naturalistic Driving Study Data*”, co-funded with the Federal Railroad Administration.

- Continued research project “*Log Movement in the Superior Region – Rate and Capacity Based Analysis of Modal Shares*”, co-funded collaboratively by the Michigan Economic Development Corporation, Michigan Department of Transportation, Michigan Department of Agriculture, Michigan Tech and NURail.
- Secured Summer Undergraduate Research Fellowship (Kyle Dick, ECE) for *Determining Whether Rough Grade Crossings Slow Drivers Down and If there is a Safety Advantage*.
- Presented papers/posters at TRB 2019 Annual Meeting.
- Presented grade crossing research work at UIC Level Crossing workshop.
- Started planning for 2019 Michigan Rail Conference and Summer Youth Program in Rail and Intermodal Transportation.
- Supported on-campus K-12 activities; Western UP Science Fair and STEM Festival, REAC provided a station with signal demos and our track-in-a-box. David Nelson was a judge for the science fair.

University of Kentucky

- Completed the experimental in-track tie/ballast pressure tests and evaluations at the trackbed test site on the NS Railway line at Mascot, TN. A detailed analysis of these test results for revenue trains is finished.
- Conducted a series of trackbed pressure tests using the Federal Railroad Administration’s DOTX 218/220 Track Quality Test Car on the NS Railway line at Mascot, TN. The pressure test results were compared to the wheel/rail impact loadings obtained from nearby wheel impact load detectors (WILDs). Analysis of the data is finished.
- Continued assembling several papers and presenting them at technical meetings as described subsequently.
- Prepared proposal for extending the trackbed testing at a historically low track modulus at a NS track site in Northern Kentucky.

University of Tennessee, Knoxville

- *Seismic Performance of Stone Masonry and Unreinforced Concrete Railroad Bridge Substructures* project is wrapping up and the Ph.D. student will defend on July 30, 2019.

b. How have the results been disseminated?

NURail Consortium

- Between October 1, 2018 and March 31, 2019, the NURail website had over 1,848 unique visits and 2,917 page loads.
- Two NURail final reports were written.

University of Illinois Urbana-Champaign

- *Shared Corridor* - A research update was prepared to be presented at the 2019 Joint Rail Conference and a conference paper has been accepted for presentation at an international conference in June.
- *Grade Crossing* - Project is completed and final report published.

- *Track Substructure* - One journal paper has been published. Project is complete pending final report. One oral presentation was made at 2019 TRB annual meeting.
- *Load Effects* - The latest results have been shared with multiple Class I railroads and transit agencies including BNSF Railway and Dallas Area Rapid Transit (DART). Presentations were given at the 2019 Industry Partners and AREMA Committee 30 Meetings, and 2019 TRB Annual Meeting. Journal paper developed and submitted for review focusing on a revised understanding of the flexural demands on crossties, and the lack of linearity between wheel loads and bending moment demands.
- *Concrete Crossties* - A presentation highlighting results from similar testing was developed and presented at the RailTEC Industry Partner's meeting in Bonita Springs, FL.
- *Resilient Materials* - A presentation highlighting results from preliminary testing was presented at the AREMA Committee 30 (Ties) meeting in Pueblo, CO.
- *Line Capacity* - Two journal papers were published.
- *Yard Capacity* - A research update was presented to the Association of American Railroads in October 2018 and at the INFORMS Annual Meeting in November 2018, and Conference papers have been accepted for presentation at two international conferences in 2019.
- *Terminal Capacity* - A research update was presented to the Association of American Railroads in October 2018 and at the INFORMS Annual Meeting in November 2018. A paper has been accepted for presentation at an international conference in June.

University of Illinois Chicago

- *Substructure Behavior* - One publication has been accepted and appeared online.
- *Chicago Transit* – Final report published.

Michigan Tech University

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

University of Kentucky

- RRIX18 Railroad Industry Exchange Conference Presentations and Posters – Penn State University, November 2018. Titles were:
 - Utilization of Asphalt Trackbeds for Rehabilitating Short Open-Track and Special Trackwork Sections of Poorly Performing Existing Trackbeds – Rose.
 - Longitudinal Crosstie-Ballast Pressure Measurements – Rose, Watts, Russell, and Clarke.
- TRB 2019 Transportation Research Board Annual Meeting Presentation and Poster – Washington, D.C., January 2019. Titles were:
 - Characterizing Track Performance under Variable Loads and Support Conditions – Event 1134 Workshop Presentation – Rose
 - In-Track Crosstie-Ballast Interfacial Pressure Measurements and Comparisons with WILD Measurements – Poster Session – Watts, Russell, Rose, and Clarke

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

NURail Consortium

- The NURail Center is planning for its annual meeting. The meeting will be held in St. Louis, MO and is scheduled for the week of July 23 in conjunction with Summerail 2019, which is sponsored by the Freight Rail Transportation Committee (AR040) of TRB.

University of Illinois Urbana-Champaign

- *Shared Corridor* - Prepare a draft to submit to an academic journal for the completed segment-level train presence and adjacent track collision probability assessment model. The draft dissertation defended in March 2019 will be deposited and developed into multiple conference and journal papers.
- *Track Substructure* - Consolidate the previous conference paper and journal paper into the final project report.
- *Load Effects* - Project complete, other than final processing and dissemination of data from CTA.
- *Concrete Crossties* - Continue to run cyclic tests on full-scale crossties. Continue testing of prisms. Present results from this work, as well as past work on the same topic, in multiple venues (AREMA C30, UIUC RailTEC IP Meeting, TRB, JRC, etc.)
- *Resilient Materials* - Continue to run laboratory tests. Continue tests on representative materials that could be used for under tie pads. Present results from this work, as well as past work on the same topic, in multiple venues (AREMA C30, UIUC RailTEC IP Meeting, TRB, JRC, etc.)
- *Line Capacity* - The two recently published journal papers will be consolidated with previous conference papers to form a final project report.
- *Yard Capacity* - The draft dissertation defended in March 2019 will be deposited and developed into multiple conference and journal papers, presented to various industry sponsors, and developed into a final project report.
- *Terminal Capacity* - The simulation model will be used to explore additional facility layouts and capacity factors. The conference papers and results of additional simulations will be developed into a journal paper and a final project report.

University of Illinois Chicago

- *Substructure Behavior* – Spend the summer calculating settlement by repeated runs of the finite element model.

Michigan Tech University

- Finalize final NURail report and submittal on the research project “*Evaluation of Driver Behavior at Railroad-Highway Grade Crossings Using Naturalistic Driving Study Data*”, co-funded with the Federal Railroad Administration.
- Develop draft and final reports for “*Log Movement in the Superior Region – Rate and Capacity Based Analysis of Modal Shares*”, co-funded collaboratively by the Michigan Economic Development Corporation, Michigan Department of Transportation, Michigan Department of Agriculture, Michigan Tech and NURail.

- Support 2019 Passenger Railroad Engineering Education Symposium.
- Conduct 2019 Michigan Rail Conference and 2019 Summer Youth Program in Rail and Intermodal Transportation.

University of Kentucky

- ASCE International Conference on Transportation & Development -- Technical Presentation, June 2019. Title is:
 - In-Track Measurements of Crosstie-Ballast Interfacial Pressure Magnitudes and Distributions with Varying Train Operational Conditions – Clarke, Rose, Watts, and Russell
- RE2019 Railway Engineering 15th International Conference, Edinburgh, Scotland – Five Technical Presentations, July 2019. Titles are:
 - Designs, Applications, and Performances of Asphalt Trackbeds in the United States – Rose
 - Designs, Applications, and Performances of Asphalt Trackbeds in European and Asian Countries – Cardona, Benedetto, Sauzeat, Calon, and Rose
 - Crosstie-Ballast Interfacial Pressure Tests: Development of a Procedure and In-Track Revenue Train Measurements – Rose, Watts, Russell, and Clarke
 - In-Track Crosstie-Ballast Interfacial Pressure Measurements and Wheel Impact Load Detector Readings: Relationships and Comparisons – Russell, Watts, and Rose
 - Static and Dynamic Crosstie-Ballast Interfacial Pressure Measurements using FRA Research Test Train – Watts, Russell, Rose, and Clarke
- Continue planning for the installation of trackbed pressure cells at a soft support/muddy track site to measure the magnitudes and distributions of trackbed pressures for revenue train operations and FRA test train.
- Prepare a series of instrumented ties for installation in the trackbed.
- Assemble strain gages for measuring strain in the rail for various degrees of soft support track and trackbed pressures.

University of Tennessee, Knoxville

- Project number NURail2014-UTK-R10 - “Seismic Performance of Stone Masonry and Unreinforced Concrete Railroad Bridge Substructures” is finishing and the student will defend his dissertation document on July 30, 2019. Then the final report will be submitted.

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)
Federal Railroad Administration	Washington, DC	Co-funded project	Starr Kidida

Michigan Dept. of Transp.	Lansing, MI	Co-funded project	Nikkie Johnson
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
University of Tennessee	Knoxville and Mascot, TN	In-Kind Support	David C. Clarke
Norfolk Southern Corporation	Atlanta, GA	In-Kind Support and Corporate Partner Funds	Philip Merilli
L.B. Foster (Salient Group)	Dublin, OH	In-Kind Support and Review Test Plan	Mike Handler
Belt Railway of Chicago	Chicago IL	In-kind support of base case for yard simulations	Nick Chodorow
Amtrak	Philadelphia, PA	In kind support, provision of WILD data	Steven Melniczuk
MetroLink	St. Louis, MO	In kind support, access to infrastructure for experimentation	Chuck Clemins
MTA New York City Transit Authority	New York, NY	In kind support, access to infrastructure for experimentation	Antonio Cabrera
Union Pacific Railroad (UPRR), Metra	Chicago, IL	In kind support, access to infrastructure for experimentation	Antonio Buelna
Chicago Transit Authority (CTA)	Chicago, Illinois	in kind support, access to infrastructure	Matthew Gibbs
Vossloh North America (Formerly Rocla Concrete Tie)		Supplying Ties	Rusty Croley
Getzner USA (Under tie pad manufacturer),		supplied under tie pads	Andreas Denk

b. Additional collaborators or contacts:

Name (First and Last)	Company, University, Organization Name	Location	Contribution to the Project
D. Ramirez Cordona, H. Di Benedetto, N. Calon	Eiffage Infrastructures, University of Lyon, SNCF Railway	Paris and Lyon, France	Collaboration on research findings and preparation of joint paper at RE 2019
Qingjie Liu	East China Jiaotong University	Nanchang, China	Review Test Plan and Contribute to Data Analysis

3. Outputs

a. Journal publications:

University of Illinois Urbana-Champaign

- Feng, B., Hou, W., & Tutumluer, E. (2019). Implications of Field Loading Patterns on Different Tie Support Conditions using Discrete Element Modeling: Dynamic Responses. *Transportation Research Record*, 0361198118821936.
- Dick, C.T., I. Atanassov, F.B. Kippen and D. Mussanov. 2018. Relative train length and the infrastructure required to mitigate delays from operating combinations of normal and over-length freight trains on single-track railway lines in North America. *Journal of Rail and Rapid Transit*.
- Dick, C.T., D. Mussanov and N. Nishio. 2018. Transitioning from flexible to structured heavy haul operations to expand the capacity of single-track shared corridors in North America. *Journal of Rail and Rapid Transit*.

University of Illinois Chicago

- A.I. El-Ghandour and C.D. Foster “Coupled finite element and multibody systems dynamics modelling for the investigation of the bridge approach problem” *Journal of Rail and Rapid Transit*, 2019. DOI: 10.1177./0954409719828599.

Michigan Tech University

- Dick, T., Lautala P., Schlake, B., STEM K-12 Outreach as the Root of Transportation Education: Experiences from the Railway Engineering Field, *Transportation Research Record: Journal of the Transportation Research Board*, No. NURail2014-UIUC-E09, 2019, pp. 96–104. <http://dx.doi.org/10.3141/2608-11>.
- Ko, S., Lautala P., Fan, J., Shonnard, D., Economic, Social and Environmental Cost Optimization of Biomass Transportation: A Regional Model for Transportation Analysis in Plant Location Process, *Biofuels, Bioproducts and Biorefining* (2019), <https://doi.org/10.1002/bbb.1967>.
- Jeon, M., Landry, S., Lautala P., Nelson, D., Design and Assessment of In-Vehicle Auditory Alerts for Highway-Rail Grade Crossings, *Transportation Research Part F: Traffic Psychology and Behaviour*, (2018) 62: 228-245, <https://doi.org/10.1016/j.trf.2018.12.024>.

University of Kentucky

- Application of Granular Material Pressure Cells to Measure Railroad Track Tie-Ballast Interfacial Pressures – Volume 2672, Issue 10, TRR Journal of the Transportation Research Board –Rose, Clarke, Liu, and Watt.

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

NURail Consortium

- Two project final reports were written.

University of Illinois Urbana-Champaign

- Quirós-Orozco, R.J. 2018. Prestressed Concrete Railway Crosstie Support Variability and its Effect on Flexural Demand. Master’s Thesis, University of Illinois at Urbana-Champaign, Department of Civil and Environmental Engineering, Urbana, IL, USA.
- NURail Final Report, NURail2013-UIUC-R07: Railroad Grade Crossing Micro-Level Safety and Risk Analysis - Phase 2 / Evaluation of Safety Risk at Highway Rail Grade Crossings.

University of Illinois Chicago

- NURail Final Report, NURail2017-UIC-R17: The History of the City of Chicago Central Area Transit Circulator Efforts Project.

Michigan Tech University

- Ko, S., *Woody Biomass Transportation and Logistics - Modeling Studies For The Great Lakes Region*, PhD Dissertation, Civil and Environmental Engineering, Michigan Technological University, December, 2019.

University of Kentucky

- Direct Measurement of Crosstie-Ballast Interface Pressures Using Granular Material Pressure Cells, MSCE Thesis, Department of Civil Engineering, December 2018.
- Modeling Crosstie-Ballast Pressure Distribution in a Railroad Trackbed Using RISA 3D, MSCE Research Report, Department of Civil Engineering, April, 2019.

c. Other publications, conference papers and presentations:

University of Illinois Urbana-Champaign

- Hou, W. (January 2019). Implications of Field Loading Patterns on Different Tie Support Conditions using Discrete Element Modeling: Dynamic Responses. Presented at 99th Transportation Research Board Annual Meeting. Washington D.C.
- Bastos, J.C., J.R. Edwards, M.S. Dersch, and C.P.L. Barkan. 2019. Water damage in cracked prestressed concrete sleepers. Accepted: Proceedings of the International Heavy Haul Association Conference (IHHA), Narvik, Norway.

- Dick, C.T. 2018. Interaction Between Yard and Mainline Capacity in Railway Network Performance. Presented at: INFORMS Annual Meeting, Phoenix, AZ, November 2018.
- Dick, C.T. 2018. Traffic Complexity and the Performance of Railway Classification Yards. Presented at: INFORMS Annual Meeting, Phoenix, AZ, November 2018.
- Chen, W.B. 2018. Investigating the Capacity of Different Intermodal Terminal Layouts with AnyLogic. Presented at: INFORMS Annual Meeting, Phoenix, AZ, November 2018.

Michigan Tech University

- Salim, A., Lautala, P., A Human Behavior Analysis Of Highway-Railroad Grade Crossings Based On Environmental Conditions And Driver Demographics, Transportation Research Board 98th Annual Meeting of the National Academies, Washington, DC, January 13-17, 2019.
- Dick, T., Lautala P., Schlake, B., *STEM K-12 Outreach as the Root of Transportation Education: Experiences from the Railway Engineering Field*, Transportation Research Board 98th Annual Meeting of the National Academies, Washington, DC, January 13-17, 2019.
- Lautala, P., *Driver Behavior at Level Crossings - In-Vehicle Auditory Alerts and Naturalistic Driving Data Research in the USA*, International Union of Railways (UIC) Level Crossing Workshop, Paris, France, March 26, 2019.

University of Kentucky

- In-Track Crosstie-Ballast Interfacial Pressure Measurements and Comparisons with WILD Measurements, Paper 19-01973, Transportation Research Board 2019 Annual Meeting Online – Watts, Russell, Rose, and Clarke.

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

University of Illinois Urbana-Champaign

- NURail Center consortium website: <http://www.nurailcenter.org>

Michigan Tech University

- 2019 Michigan Rail Conference, <http://www.rail.mtu.edu/mrc2019>
- 2019 Summer Youth Program Web site; <http://rail.mtu.edu/event/rail-intermodal-transportation-summer-youth-program-2019>

e. Technologies or techniques:

University of Illinois Chicago

- *Substructure Behavior* – Improved software for rail substructure analysis.

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

- *Track Substructure* - Increased understanding of the mechanism of substructure behavior under complex dynamic loading conditions; identified the most critical support condition under the crosstie that would cause higher stress and deformation in substructure layers; improved understanding of effect of train speed and train weight on track substructure responses.
- *Classification Yard Capacity* - Discussion of new content in AREMA Manual Chapter 16 on approaches to quantify yard and terminal capacity.
- *Shared Corridor* - Development of a risk assessment model, guidance, and procedure to assist in shared rail corridor planning and risk mitigation.
- *Concrete Crossties* - Presented preliminary data to AREMA Committee 30 (Ties) for consideration for future inclusion in the AREMA Manual.
- *Load Effects* - Discussion of inclusion of new content in AREMA Manual related to non-linearity between wheel loads and bending moments.
- *Resilient Materials* - Presented preliminary data to AREMA Committee 30 (Ties) for consideration for future inclusion in the AREMA Manual.

University of Illinois Chicago

- *Substructure Behavior* – Improved methodologies for predicting vibrations in buildings; improving processes for predicting soil settlement at transitions; improving methods for remediation techniques for settlement at transitions.

University of Kentucky

- Incorporation of research findings in trackbed structural designs.

5. Impact

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

University of Illinois Urbana-Champaign

- *Shared Corridor* - 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 effectively and efficiently manage the risk on shared-use rail corridors.
- *Track Substructure* - With increasing demands for rail passenger and freight operations, sharing a line or track is an economical solution if operational efficiency and track reliability challenges can be accommodated properly. Thus, it is important to understand and predict the structural responses in track substructure due to such complex dynamic loadings. Numerical modeling is an effective yet economical approach to conduct simulations for track substructure performance. Our numerical models, which are validated with field and laboratory data, can be utilized to analyze important structural features, including transient deformations, vibration velocities, and contact forces. With this powerful analysis tool, we can identify the most critical loading condition and support condition in the field. It can also be further utilized to optimize the structural design of track substructure, such as crosstie spacing, ballast layer thickness, etc.
- *Terminal capacity* - 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.

University of Illinois Chicago

- *Substructure Behavior* – The settlement analysis will help predict rates of settlement, especially near transitions, and examine potential remedies.

Michigan Tech University

- Michigan Rail Conference is an avenue for larger understanding of rail transportation and attracts participants from outside industry. Summer Youth Program and Rail Day and Expo expand the visibility among students.

University of Kentucky

- More efficient railway transportation system with increased safety and reduced maintenance costs.

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?

NURail Consortium

- The overarching objective of the NURail Center technical research plan is to sustain and expand U.S. freight railroad transportation safety, capacity, efficiency and reliability, while at the same time developing commuter and intercity passenger rail systems. The divergent needs of freight and passenger trains on shared corridors present complex infrastructure, rolling stock, operational and institutional problems, and drives research towards critical cutting-edge challenges and solutions that have a strong relevance to the rail community.

University of Illinois Urbana-Champaign

- *Track Substructure* - Gain deeper understanding of the mechanism of track substructure performance under complex dynamic loading.
- *Load Effects* - Discovery of new, non-linear element of track component behavior. Specifically, the non-linearity between wheel loads and bending moments.
- *Concrete Crossties* - Initial stages of some of the only work that has investigated the effects of water on the behavior and life cycle of prestressed concrete products.
- *Resilient Materials* - Initial stages of some of the only work that has investigated the effects of under tie pads on the reduction of flexural demand on concrete crossties.

University of Illinois Chicago

- *Substructure Behavior* – Improved numerical methods for analysis of rail substructure problems.

University of Kentucky

- Results can be utilized in specifying track structure design practices.

d. What is the impact on transportation workforce development?

NURail Consortium

- Beyond education, the NURail Center mission includes outreach to a wide range of stakeholders with the goal of developing the railway workforce of the future. Primary and secondary students are engaged through on-campus rail engineering education events, tours, presentations and summer programs hosted by NURail Center partner institutions. Undergraduate students gain valuable rail industry exposure and experience through student internships and co-operative industry programs. Experts from the railroad industry, government and academia are hosted on NURail campuses where they give presentations on a broad range of technical and policy topics. Their impact is further leveraged by offering these presentations to the entire rail community using web-based tools enabling broad participation.

University of Illinois Urbana-Champaign

- Student participation in rail-focused research helps develop the next generation of railway professionals and train them in the application of advanced modeling techniques and data analysis ability.

University of Illinois Chicago

- One MS student has graduated.

Michigan Tech University

- Numerous undergraduate and graduate students have been involved in the activities (such as Rail Day and Expo) and K-12 outreach. Most activities (student projects, rail conference, summer youth program, Rail Day) are designed for multiple disciplines. Transportation logistics research projects have helped to improve OSM 4700: Transportation Logistics and Management course materials. Summer Youth Program and Rail Day and Expo expand the visibility among students.

6. Changes/Problems

a. Changes in approach and reasons for change

University of Illinois Chicago

- *Substructure Behavior* – Adding rails and fasteners to finite element models improves model fidelity in load application.

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

Nothing to report.

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.