# MPC-549
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**Project Title**

Benefit Cost Analysis of Railroad Track Monitoring Using Sensors On-Board Revenue Service Trains

**University**

North Dakota State University

**Principal Investigators**

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**Research Needs**

Seven Class I railroads (railroads with operating revenues of $433.2 million or more), 21 regional railroads, and 510 local railroads operate 140,000 miles of rail in the United States (FRA, 2017). The railway track geometry determines the quality and the safety of routes. Traffic across railroad tracks deteriorates their geometry over time. Therefore, regular evaluations are necessary to ensure safe and efficient operating conditions throughout the network. Inspections are also necessary for reporting compliance with federal safety guidelines. The industry as well as the Federal Railroad Administration (FRA) employs track inspectors and use automated inspection vehicles to evaluate rail geometry for compliance.

The traditional evaluation approaches, including manual inspections, are slow, potentially unsafe, and requires vast resources. Therefore, the availability of low-cost fault identification and evaluation technologies will help the industry more efficiently allocate finite and expensive inspection resources. In particular, autonomous track geometry monitoring using wireless sensors on board hi-rail vehicles and revenue service trains could save the industry billions of dollars if they could continuously scan the infrastructure for faults. Such a solution would provide asset managers with an ability to focus inspections on areas of high fault likelihood without closing lines to search for developing faults. An autonomous track geometry monitoring system will require periodic sensor data uploading to remote computing facilities. The data will consist of geo-tagged inertial and rotational responses, as well as train speed, heading, temperature and other information. Remote algorithms will combine and process the data from multiple train traversals to boost the accuracy and precision of fault detection and identification.

Railroad organizations often deter spending or investments on technologies that have not yet been deployed and proven. Hence, the results of a detailed analysis of costs relative to benefits could provide inputs to such decision-making. A Benefit-Cost Analysis (BCA) is a widely accepted method to quantify an objective metric that could aid the decision-making process. BCA accounts for the time value changes in costs and benefits. BCA requires cost and benefits to be quantifiable and transformed into financial terms (Tornquist and Gustafsson, 2004). The monetary value helps to quantitatively compare the aggregate cost and benefits of a deployment (over some period) to determine whether the proposed solution is economically viable to move forward. A BCA will also help developers to identify alterations and system cost targets that could increase the benefits or reduce the cost to attractive levels.

**Research Objectives**

1. Develop and implement a benefit-cost analysis method to assess the benefits and costs of implementing an autonomous track geometry monitoring system to screen the network for faults during normal train operations
2. Identify and quantify the technology deployment benefits as a function of its performance expectations
3. Identify and quantify the technology deployment costs as a function of its performance expectations
4. Determine and justify an appropriate discount rate for the model
5. Determine and justify the lifetime of the deployed technology
6. Quantify the benefit-cost ratio as a function of technology implementation and deployment options
7. Publish at least three conference and three journal papers summarizing the study
8. Publish a project report that details the research, the findings, and the conclusions
9. Incorporate appropriate project results and materials into curricula refinements that focus on intelligent transportation solutions

This study will develop, implement, and evaluate a model that quantifies the benefits and costs of implementing an autonomous track geometry monitoring system to screen the network for faults during normal train operations. The technology performance will affect anticipated benefits such as time savings, risk reduction, and a safer work environment for inspection personnel. Similarly, the technology performance will affect the anticipated costs such as initial investments in equipment, installation, ongoing maintenance, recurring operating costs, and reporting services. Therefore, the researchers must develop and exercise the model in conjunction with choices in the design and implementation of the technology that can affect both its performance and cost. The design and implementation will also affect the anticipated lifetime of the deployment, which in turn will affect the discount rate for the model. Subsequently, the model must consider and account for interdependencies on the technology implementation, and non-linear cost trends that affect hardware and software commoditization. Another key objective of this research is workforce development and technology transfer. Therefore, students on the project (Neeraj Dhingra and Bhavana Bhardwaj) will work closely with the PIs to develop and publish at least three conference and three journal papers that summarize the study and its findings. In addition, the research team will publish a project report and incorporate appropriate materials into curricula refinements that focus on intelligent transportation solutions.

### Research Methods

The benefit-cost model will quantify and monetize all potential costs and benefits of the technology deployment, as a function of its design and implementation options. Cost estimates will include research to obtain volume dependent pricing for equipment from key manufacturers of all the required system components. A complete autonomous track geometry monitoring system will include wireless sensors, energy harvesting devices, wireless access points, cloud computing resources, and maintenance. Costs such as a first installation may be one-time and other costs such as wide-area network communications and a cloud-service subscription may be recurring. Hence, some of the cost changes may be non-linear over time because of technology commoditization and the dynamic costs for cloud computing services. Quantifying the benefits will involve research and analysis to estimate time and monetary savings for track inspections and the reduction of track closures. Other potential benefits are from derailment risk reduction due to more regular inspections. The study will also describe any benefits that are not quantifiable in monetary terms, such as the use of standard web interface tools, the convenience of data visualization, and the modernization of asset management systems that incorporate the technology. In addition, this study will conduct an uncertainty and sensitivity analysis of the BCA under various scenarios proposed by FRA stakeholders.

### Expected Outcomes

The expected outcomes will be workforce development and technology transfer to advance the state of the art of the railroad industry. This project will include two graduate students. Neeraj Dhingra will work towards a Ph.D. in Transportation and Logistics. Bhavana Bhardwaj will simulate modifications to the various signal processing and computing modules of the fault detection and classification system to evaluate the benefit-cost ratio under different conditions of technical implementation and practical deployment. For example, a trade-off in computing resources between the sensor and the cloud can significantly affect the benefit-cost ratio as well as the overall performance of the solution. Therefore, the overall solution may require a system optimization that produces both good performance and a compelling benefit-cost ratio. The broader educational benefits will be knowledge products and tools that feed into curricula development and laboratories in multimodal intelligent transportation systems. In terms of technology transfer, the research team will utilize the research methods developed and the benefit-cost models to prepare publications and outreach material that would encourage further adoption and further development to refine and commercialize the technology for large-scale deployment. Other methods of technology transfer will include journal papers, conference presentations, project reports, web page postings, and other marketing or outreach materials.

### Relevance to Strategic Goals

- State of Good Repair
- Safety

Quantifying the benefit-cost ratio for an autonomous track geometry monitoring system could lead to implementation decisions that will reduce the probability of missed faults and potentially prevent derailments. Students trained will be prepared to enter a workforce that can evaluate the cost-effectiveness of technologies that will further enhance railroad safety. The expected findings and models of this research will enable agencies to select the most cost-effective technologies to detect railroad infrastructure issues, reduce false positives, and improve their decision-making to optimize repair and maintenance.

**Educational Benefits**

As noted in the expected outcomes, two students will work with the PIs to conduct research that they will incorporate into journal papers and their PhD dissertations. Neeraj Dhingra will conduct the benefit-cost analysis and associated modeling. Bhavana Bhardwaj will simulate modifications to the various signal processing and computing modules of the fault detection and classification system to feed the benefit-cost analysis. Together, this will yield a better understanding that will inform the system design options to maximum both performance and benefit-cost ratio. The PIs intend to incorporate knowledge and models from this research into curricula focused on intelligent transportation solutions.

**Technology Transfer**

As noted in the expected outcomes, the research team will utilize the project findings and models to prepare publications and outreach material that would encourage further adoption in the real world. The team will utilize traditional methods such as journal papers, conference presentations, project reports, web page postings, and other marketing or outreach materials. In addition, the team will engage railroad representatives throughout the project to provide guidance and to achieve buy-in. Furthermore, the PI will engage with sensor manufacturers to explore the potential for product refinements and cost reduction of the technology. In particular, Meggitt Sensing Systems (one of the project reviewers) has already been working with the PI to explore technology transfer and commercialization opportunities. All publications will acknowledge this award. The PIs will notify the progress-reporting system (PPPR) of any publications generated from this project, as well as technology transfer activities.

**Work Plan**

1. Literature Review (Months 1 - 12)
    a. Conduct literature search to identify the scope of the benefits and costs
    b. Develop a classification of the benefits and costs
    c. Develop a framework to narrow the benefits and costs to those that are directly relevant
    d. Develop a review paper for publication in a journal and/or conference proceedings
2. Framework Development and Modeling (Months 12 - 24)
    a. Develop a model to quantify benefits that include statistical risks (e.g. derailment risk reduction)
    b. Develop a framework to quantify benefits where a direct monetary equivalent is unavailable
    c. Assure consistency of the framework with the TIGER Grant framework
    d. Research and develop justifications for the modeling time-horizons and discount rate
    e. Develop a model to quantify the benefits and costs under different scenarios of system implementation and practical deployment

3. Data Collection and Findings (Months 24 - 36)
    a. Research data sources to evaluate and refine the model
    b. Fuse the data sources to exercise and test the model
    c. Evaluate the benefit-cost ratio across different scenarios of deployment and adoption
    d. Develop a journal paper to describe the model development, the data, and the findings
4. Curriculum Development and Technology Transfer (Months 24 - 36)
    a. Publish conference and journal papers summarizing the study
    b. Publish a project report that details the research, the findings, and the conclusions
    c. Incorporate results of the project into curricula development on intelligent transportation solutions

As detailed in the itemized task list, the work plan consists of four main tasks with subtasks. The first year involves a broad literature review that will inform the scope of the benefit-cost analysis.

The PIs will guide the students towards one journal paper that incorporates the literature search. In another separate project, researchers will be using smartphones to collect data from railroads to develop the signal processing, technology implementation, and technology deployment options. Therefore, the team will have established options relating to the technology itself before the second year of this research. Therefore, the team on this project will develop the benefit-cost models to account for the various technology implementation options. Subsequently, the third year of this project will involve model evaluation and refinement in conjunction with an assessment of the technology performance under various options of design. Researchers will spend the last part of the final year of the project developing the project report, finalizing journal papers, and shaping material for incorporation into selected courses.

## Project Cost

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| Total Project Costs: | $129,022 |
| MPC Funds Requested: | $ 64,511 |
| Matching Funds: | $ 65,511 |
| Source of Matching Funds: | North Dakota State University |

## References

P. Lu and R. Bridgelall, “MPC - Research Projects (2016),” 2016. [Online]. Available: http://www.mountain-plains.org/research/projects/downloads/2016-mpc-505.pdf [Accessed 1 August 2017].

J. Törnquist and I. Gustafsson, “Perceived benefits of improved information exchange–a Case Study on Rail and Intermodal Transports,” *Research in Transportation Economics*, no. 8, pp. 415-440, 2004.

Y. Shafahi and R. Hakhamaneshi, “Application of a Maintenance Management Model for Iranian Railways Based on the Markov Chain and Probabilistic Dynamic Programming,” *International Journal of Science and Technology*. Transaction A: Civil Engineering, vol. 16, no. 1, pp. 87-97, 2009.

A. R. Andrade and P. F. Teixeira, “A Bayesian model to assess rail track geometry degradation through its life-cycle,” *Research in transportation Economics*, vol. 36, no. 1, pp. 1-8, 2012.

J. Andrews, D. Prescott and F. De Rozières, “A stochastic model for railway track asset management,” *Reliability Engineering & System Safety*, vol. 130, pp. 76-84, 2014.

M. Chambers, J. Goworowska, C. Rick and J. Sedor, “Freight Facts and Figures 2015,” 2015.

Federal Railroad Administration, “Rail Safety Fact Sheet,” 2016.

G. A. Grimes and P. B. Christopher, “Cost-effectiveness of railway infrastructure renewal maintenance,” *Journal of Transportation Engineering*, vol. 132, no. 8, pp. 601-608, 2006.

A. Hamid and A. Gross, “Track-quality indices and track degradation models for maintenance-of-way planning,” *Transportation Research Board*, vol. 802, pp. 2-8, 1981.

N. Lyngby, P. Hokstad and J. Vatn, “RAMS management of railway tracks,” *Handbook of performability engineering*, pp. 1123-1145, 2008.

M. J. Pierro and W. R. Schneider, “Vehicle maintenance management system and method.” U.S. Patent 6,301,531, 9 October 2001.

L. Podofillini, E. Zio and J. Vatn, “Risk-informed optimization of railway tracks inspection and maintenance procedures,” *Reliability Engineering & System Safety*, vol. 91, no. 1, pp. 20-35, 2006.