U.S. Department of Transportation
Research and Technology
University Transportation Center Grant Agreement

Grant No. 69A3551747108
Mountain-Plains Consortium, North Dakota State University
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April 30, 2023

DUNS: 803882299 and EIN: 45-6002439

North Dakota State University
Upper Great Plains Transportation Institute
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Grant period: June 30, 2016 – September 30, 2024

Reporting Period End Date: March 31, 2023
Semi-Annual Progress Report #12

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1. Accomplishments: What was done? What was learned?

A. What are the major goals of the program?

The overall program objectives are to: (1) conduct basic and applied research, the products of which are judged by peers or other experts in the field of transportation to advance the body of knowledge in transportation; (2) offer educational programs in transportation that includes multidisciplinary course work and participation in research; (3) conduct workforce development activities and programs to expand the workforce of transportation professionals; and (4) provide an ongoing program of technology transfer to make transportation research results available to potential users in a form that can be readily used.

Other program goals are to select projects and activities using peer review principles and procedures and client input that (1) address the secretary's five strategic goals, and (2) leverage UTC funds with matching funds from state and local governments and private industry. The chief operational goals are to make important contributions to research and technology transfer in key areas related to the secretary's goals of State of Good Repair, Safety, Economic Competitiveness, Environmental Sustainability, and Livable Communities while addressing critical issues of the region and stakeholder groups.

The MPC research program theme, "Preserving the Existing Transportation System," will focus on: (1) cost-effective preservation and maintenance practices for highways and freight rail lines; (2) tools to evaluate the effects of tolling and highway investments; (3) inspecting, evaluating, and designing bridges to promote longevity and cost-effective maintenance; (4) the resilience of highway infrastructure to wildfires, floods, earthquakes, and other natural disasters; and (5) workforce development and capacity building. In addition, some related safety research will be conducted to address regional needs.

MPC projects that have been selected since the award of this grant include **MPC-533 through MPC-701**, which can be found on the Mountain-Plains Consortium website.

B. What was accomplished under these goals?

I. Project selection

There were 168 research projects selected, and each have undergone a rigorous peer review process, which is required to meet the requirements for selection. The projects reflect substantial input and matching resources from state departments of transportation and MPOs in the region. Collectively, this set of projects addresses all five of the secretary's strategic goals and several of USDOT's requested emphasis areas under State of Good Repair, e.g., (1) bridge condition monitoring, (2) locating critical infrastructure defects, (3) identifying tools to prevent and detect corrosion in transportation infrastructure, (4) analytical tools for infrastructure performance management, and (5) methods and criteria to measure performance of new materials and methods. Some MPC projects relate to more than one USDOT Strategic Goal and thus will be listed more than once in Appendix A.

II. Programmatic milestones

In addition to the programmatic milestones described below, several milestones embedded within individual projects have been achieved. Most of the research projects call for literature reviews. The literature reviews for those projects with the earliest starts are substantially complete. Interim reports are not required after the literature review stage. At this time, all projects are on schedule to be completed as planned during the grant period. The program accomplishments to date are summarized in Table 1 by reference to milestones.

Table 1: Program Milestones

Milestone	Description	Start Date	End Date
Execution of Grant Agreement	The grant was received from RITA and executed by NDSU's Sponsored Programs office. All the necessary internal accounting and financial procedures were established, including subcontract agreements with consortium universities. No cost extension to end date of 09/30/2024.	11/30/2016	09/30/2024
	Mod 1, Grant No. 69A3551747108 (Year 2)	10/01/2017	09/30/2023
	Mod 2, Grant No. 69A3551747108 (Year 3)	10/01/2018	09/30/2023
	Mod 3, Grant No. 69A3551747108 (Year 4)	10/01/2019	09/30/2023
	Mod 4, Grant No. 69A3551747108 (Year 5)	10/01/2020	09/30/2023
	Mod 5, Grant No. 69A3551747108 (Year 6)	10/01/2021	09/30/2023
Site Visits	Site visits to all MPC universities are being conducted annually by the MPC director.	11/30/2016	09/30/2024
UTC/CUTC Meeting	The director and administrative staff attended the UTC/CUTC meeting at TRB and received guidance from RITA regarding the forthcoming grant.	11/30/2016	09/30/2024

III. Educational accomplishments

The transportation and transportation-related courses offered during this reporting period are in Appendix B due to the page limit constraints of this document; they are organized by major subject area. In some cases, courses with the same titles were offered at more than one MPC university. Altogether, **164 transportation and transportation-related courses** were offered this reporting period, for a **total of 1,434 transportation courses offered since the beginning of this grant**. In addition to the courses listed in Appendix B, foundational courses in engineering materials, mechanics, structural analysis, and geotechnical engineering were offered at most MPC universities.

C. What opportunities for training and professional development has the program provided?

I. Workforce development accomplishments

Altogether, **62 training sessions** were offered during this reporting period for a **total of 734 offered under this grant period.** Due to the page limits of this document, we have listed all workforce development activities in Appendix C. The Appendix C listing of workforce development activities illustrates the diversity of our workforce offerings for transportation professionals. In addition, we have had **147 online training modules** and **121 recorded sessions** that **5,145 transportation professionals** utilized to strengthen their workforce skills.

D. How have the results been disseminated?

The research results are being disseminated in a variety of ways, including: (1) workshops and conferences; (2) videoconferences; (3) online modules; (4) presentations at conferences; (5) publications; (6) internet-based dissemination including broadcast emails, website postings, webinars, and social media postings.

E. What do you plan to do during the next reporting period to accomplish the goals/objectives?

All projects are on track to be completed, and research results disseminated through different technology transfer means before the end life of the grant. Typically, a project is completed in 12 to 18 months with dissemination of results 18 to 24 months from the start of the research. We continue to closely monitor the progress of the work plans as reported for each project in the Semi-Annual Progress Reports. Also, monthly communication, at a minimum, are made with each MPC university director to ensure the success of our investigators.

2. Participants and Other Collaborating Organizations: Who has been involved?

A. What organizations have been involved as partners?

As projects are selected and work plans completed within the timing of match funding, the commitments of collaborators will vary widely throughout the life of the grant. During this period, we had **84 committed collaborators**, who provided different support, such as financial, in-kind, equipment, supplies, software, or data support. In addition, many collaborators provide direct links for collaboration in research, survey mechanisms, and project activities. A list of organizations that have been involved as partners can be found in Appendix C2.

B. Have other collaborators or contacts been involved?

USDOT's continued support with the award of this grant has allowed us to encourage and support **94 principal investigators, faculty, and administrators at eight universities in Region 8.** In addition, we have been able to support, mentor, and develop research skills and knowledge in transportation for **179 students from the U.S. and countries around the world. These include seven post-doc students, 79 doctoral students; 61 master's students; and 32 undergraduate students.**

(1) The principal investigators, faculty, administrators, and students listed below, who work within the MPC universities have participated in MPC research projects this reporting period.

Sixteen principal investigators, faculty, and administrators are participating in MPC projects at **Colorado State University**: Rebecca Atadero, Jubaer Ahmed, Suren Chen, Yanlin Guo, Gaofeng Jia, Jeffrey Niemann, Joseph Scalia, Chris Bareither, Thomas Bradley, Paul Heyliger, Peter A. Nelson, Karan Venayagamoorthy, Erin Anderson, Erika Miller, Mahmound Shadouri,and Mehmet E. Ozbek. In addition, 42 students are working on MPC research projects: Abdelrahman Abdallah, Chao Jiang , Mahmound Elnahla, Fawzi Khalife, Momammad Teymouri, Ziluo Xiong,Wael Abdalrwaf, Avital Breverman, Ibrahim Bouzaid, Bharath Anuradha, Elizabeth Byron,Wei-Hsiang Chen, Ben Irvin, Abdullah Asiri, David Trinko, Yangyang Wu, Kaisen Yao, Craig Staples, Brandon Perry, Min Li, , Daniel Sanchez, Aaron Rabinowitz, Emma Adams, Cooper Bisset, Hope Carlson, Maddie Collins, Will Davis, Jack Derbique, Bridget Ediger, London Kubicec, Elizabeth Lacey, Jillian Lukez, Christopher Mullen, Elliot White, Shelby Oke, Connor Strizich, David Thormosgood, Abby Wright, Angie Robinson, Zana Taher, Celie Brockett, and Agnes Mhlanga.

Twenty-one principal investigators, faculty, and administrators are participating in MPC projects at **North Dakota State University**: Ying Huang, Pan Lu, Raj Bridgelall, Kelly Bengtson, Dinesh Katti, Kalpana Katti, Denver Tolliver, Kimberly Vachal, Ihsan Khan, Jeremy Mattson, Yun Zhou, Alan Dybing, Leanna Emmers, Ron Hall, Jill Hough, Megan Orr, Hamad Al Qublan, Seguy Tchakounte-Wakem, Xianfeng (Terry) Yang, Fanzheng Yuan, and Sharma Kshitij. In addition, 23 students are working on MPC projects: Yaobang Gong, Bahar Azin, Zhao Zhang, Xinyi Yang, Heshani Manaweera, Salman Ahmed, Keshab Thapa, H M Nasrullah Faisal, Yihao Ren, Sajad Ebrahimi, Asad Ali, Taraneh Azkarzadeh, Gul Badin, Hanmant Gaikwad, Baishali Rahman, Nazia Riasat, Jia Chong, Tanner Isom, Erik Johnson, Cybele Nilimoh, Hailun Wang, and Aaron Wang.

Ten principal investigators, faculty, and administrators are participating in MPC projects at **South Dakota State University**: Junwon Seo, Nadim Wehbe, Guanghui Hua, Kyungnan Min, Christopher Schmit, Mostafa Tazarv, Francis Ting, Michael Pawlovich, Aritra Banerjee, and Rouzbeh Ghabchi. In addition, 27 students are working on MPC research projects: Peng Diai, Zangyue Wang, Euiseok Jeong, Ibin Amatya, Marco Paulo Pereira Castro, Bipin Adhikari, Evan Greenway, Maryam Mihandoust, Abdoul Kouanda, Matthew LaVoy, Theodore Surest, Selene Tinklenberg, Kallan Hart, Rosanna Novellinio, Brenden Olevson, Aric Jensen, Rahat Rashedi, Debbrata Datta, Ankur Debnath, Debayan Ghosh, Monika Kafel, Foysol Mahmud, Akosua-Ofosua Okyere-Addo, Siavash Ebrahimzadeh, Ethan Jensen, and Muhammad Jamil.

Ten principal investigators, faculty, and administrators are participating in MPC projects at the **University of Colorado Denver**: Wesley Marshall, Bruce Janson, Moatassem Abdallah, Caroline Clevenger, Jimmy Kim, Kevin Rens, Aditi Misra, Mehmet Ozbeck, Manish Shirgaokar, and Farnoush Banaei-Kashani. In addition, 18 students are working on MPC research projects: Ibrahim Bumadian, Mohamed Mesbah, Shahryar Monghasemi, Ali Alatify, Wajdi Ammar, Aliasghar Hasani, Robert Fitzgerald, Mahdi Ghafoori, Nick Coppola, Khang Nguyen, Yuto Suzuki, Carrie Tremblatt, Chris Cameron, Molly Wagner, Masoumen Abolfathi, Rumana Sultana, Rachel Barham, and Jun Wang.

Four principal investigators, faculty, and administrators are participating in MPC projects at the **University of Denver**: Patrick Sherry, Ruth Chu-Lien Chao, Julia Roncoroni, and Andi Puavat. In addition, nine students are working on MPC research projects: Sree Sinha, Emma Porter, Kailey Painter, Catherin Bianci, Matthew Cole, Sandra Bertram Grant, Jessica Salazarr, Desiree Martin, and Jessica Mantia.

Ten principal investigators, faculty, and administrators are participating in MPC projects at the **University of Utah**: Xiaoyue Cathy Liu, Chris P. Pantelides, Steven Bartlett, Evert Lawton, Pedro Romero, Mark Bryant, Nikola Markovic, Abbas Rashidi, Jianli Chen, and Xuan Zhu. In addition, 31 students are working on MPC research projects: Abdulla Mamun, Pouria Mohammadi, David Sacharny, Dan Seely, Duc Tran, Keping Zhang, Dylan Brown, Henrik Burns, Tatiana de Camargo, Emad Ghodrati, Carlos Hermoza, Yaqi Huang, Adam Jones, Saisravan Maringanti, Swastik Pohdrel, Remy Thigpen, Dylan Briggs, Boe Erickson, Kaden Harris, Cyrus Safai, Nadereh Adham, Ali Hassandokht, Biao Kuang, Junwei Liu, Shouzheng Pan, Moein Ramazanpourkami, Behnam Sherafar, Zhiyan Yi, Yirong Zhou, Sushant Tiwari, and Sarah Strokai.

Five principal investigators, faculty, and administrators are participating in MPC projects at the **University of Wyoming**: Khaled Ksaibati, Ahmed Farid, Suresh Muknahallipatna, Marwan Hafez, and Muhammad Tahmidual Haq. In addition, five students are working on MPC research projects: Vincent Ampadu, Benjamin Fosu-Saah, Zephaniah Connell, Imran Reza, and James Mock.

Eleven principal investigators, faculty, and administrators are participating in MPC projects at **Utah State University**: Ziqi Song, Patrick Singleton, Abilash Kaminemi, Nick Roberts, Andrew Sorensen, Michelle Mekker, Srishti Barneji, Brady Cox, Keuhyun Park, Mohsen Zaker Esteghamati, and Marvin Halling. In addition, 15 students are working on MPC research projects: Ikwulono Unobe, Pouyan Saeidian, Suman Roy, Pilaiwan Vaikasi, Sailesh Acharya, Nick Langford, Niranjan Poudel, Zach Benson, Abdullah Al Sarfin, Yiming Zhang, Jinghui Jiang, Megh Bahadur, Fariba Soltani Mandolakani, Amir Rafe, Ashikur Rahman, Mahyer Vahedi Saheli, Israi Abu Schanab, Prachanda Tiwari, Atul Subedi, Thad Hansen, and Tyler Jackson.

(2) The following other collaborators have been identified and are working with our PIs on MPC projects that are outside of our consortium:

North Dakota State University

- Jianbang Du, Texas A&M Transportation Institute
- Harold Frazier, Standing Rock Sioux Tribe
- Clarence Greene, Spirit Lake Nation
- Brenda Red Wing, BIA Great Plains Region
- Scott Satermo, Three Affiliated Tribes

University of Colorado Denver

- Nick Ferenchak, University of New Mexico

University of Denver

- Chris Harrington, Keolis Commuter Services
- Marty Jimenez, Metrolink SCRRA
- Jeff Moller, Association of American Railroads
- Keith Ratner, Salem State University

Utah State University

- Prasanna Humagain, Purdue University
- Shuna Ni, University of Maryland

3. Outputs: What has the program produced?

Due to the length constraints of this document, a listing of conferences and workshops; publications; conference papers; and presentations from MPC principal investigators have been consolidated into Appendix D.

A. Publications can be found in Appendix D

During this period MPC faculty and investigators have published **54 peer-reviewed articles or papers** in scientific, technical, or professional journals. Since the beginning of this grant, **we have published 496** different peer-reviewed articles or papers.

B. Conference papers can be found in [Appendix D]

This reporting period **we have published 14 conference papers and 208 total since the grant began**.

C. Presentations can be found in [Appendix D]

MPC faculty and investigators **have presented at 52 different** scientific, technical, or professional conference this period. In total, we have **had 299 presentations on MPC research**, results, and outcomes.

D. Other outputs to include but not limited to website(s) or other internet site(s).

(1) The MPC website is fully operational at: https://www.mountain-plains.org/
(2) The MPC Key Personnel can be found at: https://www.mountain-plains.org/personnel/
(3) Other **outputs** that are university specific:

Colorado State University

A new class on Material Point Method was developed and taught during fall 2022 to 12 students at the graduate level. The material point method is an alternative to the more widely used finite element method and directly solves the equations of motion at specific discretized mass points (the "material points") that change location over a fixed background grid. It is ideal for studying natural hazards applied to transportation systems since it can represent both the hazard (e.g., mudflow, rockslides) and the fixed transportation infrastructure (e.g., a bridge, culvert, or wall).

North Dakota State University

A website is under construction for the Northern Tribal Technical Assistance Program (https://www.northernttap.org/). This website will serve as a one-stop portal for tribal transportation practitioners to quickly identify training, technology transfer, best practice, and federal/state program updates and opportunities. It will facilitate a two-way dialogue to support sharing of local tribal program accomplishments and self-subscription to the Northern TTAP email list. The website will provide useful analytic tools to see which digital products are accessed and downloaded, what pages are viewed, and serve as a platform for periodic surveys and polls.

Outreach events to YMCA afterschool programs December 19-26 for six days of four-hour hands-on workshops for the elementary school kids for transportation engineering projects.

South Dakota State University

Methodologies for clustering crashes and examining crash distributions, including the use of radial methods (akin to kernel density estimation [KDE]), elliptical (along the roadway network), and standard segment and point (intersection)-based. The code was developed using one year of data but rerun for five years of data and, based on this, these methodologies are not finalized but may be adjusted based on development of the outputs and are thus pending. The resulting clustering and preliminary crash distributions are currently undergoing analysis to test validity and determine statistical clustering. These methods will be disseminated via a master's thesis (perhaps multiple theses) as well as planned paper submissions concerning the methods and results.

The course CEE 340 Engineering Geology has been modified to include information regarding the presence of sulfate-rich soils in the region, and a module on climate change and its potential effects has been included in the revised curriculum.

A new course, CEE 792 Slope Stability and Earthen Structures, was introduced; the curriculum includes the effects of climate change on embankments and a design project on these concepts.

University of Colorado Denver

A new ensemble unsupervised method for anomaly detection in bridge performance has been developed. With continual use, bridge structures deteriorate over time due to factors such as material, design, daily traffic, and weather conditions. After a certain period of time has passed, the deterioration processes accelerate, and in a relatively short time the components can lose the capacity to carry the loads they were designed to support. In normal conditions, the deterioration rates follow a predictable trend. However, in some cases, the deterioration rate of a bridge may be anomalous due to factors such as structural damage or irregular weather conditions. In developing the proposed anomaly detection method, focus was on identifying anomalies of bridge performance by applying unsupervised anomaly detection models to analyze condition ratings over time. The project incorporated statistical density-based techniques as well as a deep-learning neural network model into an ensemble approach to find the intersection set of common anomalies between models. Participants introduced improved anomaly detection methods for timely and accurate management and monitoring of bridge performance by analyzing quantitative descriptors for the structural deterioration pattern of bridge structures. A version of this work was presented at TRB 2023 as a lectern presentation to disseminate the results.

Seven machine learning models were developed and tested.

University of Denver

The project website (https://www.du.edu/ncit/autonomous) has been updated to include additional information and presentations.

Training materials and an intervention model for suicide prevention training for railroad workers have been updated. Videos describing successful interventions for suicide prevention have been developed.

University of Wyoming

The development of Prototype 2 will utilize the latest ITS technologies/sensors in identifying the leading vehicle. The developed technology will result in reducing the testing team from four to two individuals. In summary, Prototype 2 will be more accurate in identifying passing zones on two-lane highways in addition to being cost effective.

4. Outcomes:

(1) **A summary of significant outcomes** by selected members of the consortium universities during this rating period are as follows:

University of Colorado Denver: During this reporting period, a considerable number of papers and presentations were presented across diverse platforms.

University of Denver: Provided training materials and an intervention model for suicide prevention training for railroad workers. Also developed videos describing successful interventions for suicide prevention.

University of Utah: The paper on “An Agent-Based Modeling Approach for Public Charging Demand Estimation and Charging Station Location Optimization at Urban Scale” is relevant and of great importance for the changing landscape of electric cars versus gas-powered cars.

Utah State University: A particular highlight is the work completed by Dr. Ziqi Song during this reporting period. Dr. Song is focusing significant effort in the optimization of the future transportation system with an assortment of electrified vehicles that are becoming more widely adopted. He is publishing in this area and is becoming well known for his work.

5. Impacts:

A. What is the impact or expected impact on the effectiveness of the transportation system, the adoption of new practices, or instances where your university’s MPC research outcomes may have led to the initiation of a start-up company?

The projects at **Colorado State University** will have the following impacts:
(1) The series of studies on infrastructure monitoring, damage detection, and deterioration modeling will generate significant impacts. First, multiple options are evaluated in terms of how to assess and predict the condition of bridges, with an emphasis on how data from NDE inspections can be used to provide knowledge not only about the exact bridge being inspected but also other similar bridges. Developing methods to leverage all data collected about bridges can help the transportation system become more effective by improving our knowledge of structural conditions and supporting better decision making. Second, the developed deterioration models can be incorporated in existing bridge management systems to guide risk-informed, cost-effective maintenance and inspection decision making for better bridge preservation. The predicted bridge condition from the models can be used to estimate risk quantities (e.g., failure, damage, or repair costs) to guide decision making. Therefore, these deterioration models can be used to provide inspection and maintenance plans tailored for each bridge to not only ensure the preservation of bridges but also reduce unnecessary inspections and

reduce cost. Third, a portable sensing technique for measuring displacement was developed. This technique does not require the instrumentation of the structure or interruption of traffic, thus is more convenient and cost-effective. Finally, the non-contact 3-component (3c) displacement measurements with a dual-stereo vision enabled uncrewed aerial system (UAS) will help to streamline the inspection planning process, avoid unnecessary or delayed bridge inspections, and utilize inspection resources more efficiently. It will help optimize logistics and resources of inspecting bridges that require different inspection intervals and inspection types to further reduce costs. The saved resources from inspections can be directed to other assets in need or to repair projects.

(2) The studies on transportation system safety and resilience under various hazards and incidents will have the following impacts. First, the landslide hazard study can improve the ability of transportation management agencies plan for and respond to rainfall-triggered landslides, which may lead to road closures. This work may help transportation agencies plan for and manage landslide hazards where transportation infrastructure intersects with potential landslide areas. Second, the developed new disruption modeling techniques can provide more accurate prediction of possible damages and disruptions to transportation infrastructures during hazards, which can potentially save many lives by warning of hazards and incidents such as crashes and fallen trees. Third, by improving the model parameterizations and better representing the nonlinear behavior of watershed response, stream flows are expected to be more accurately estimated in bridge scour applications. More accurate flows are expected to reduce the potential for bridge failures due to unexpected scour. With fewer bridge failures, the transportation system is expected to be more reliable and effective.

(3) The studies on traffic safety under adverse driving environments and railways will have the following impacts. First, the new network modeling methods proposed will combine flow-based traffic performance simulation and graph-based network modeling techniques to provide more comprehensive and accurate coverage of traffic network performance under natural hazards. Second, with the improved understanding of crash risk of high-sided vehicles under wind conditions, the overarching impact of this study is tied to improved safety guidance to mitigate crash risks for high-profile vulnerable vehicles. Third, the expected impact of this project on railway trespassing will be to improve the effectiveness of transportation signage related to railroad trespassing and crossing, such that users more accurately understand and adhere to what is being asked of them at railroad rights-of-way.

The roadway-related projects at **North Dakota State University** will include the following impacts:
(1) Increased reliability for swelling clay predictive models. A coarse-grained model of clay that has been developed with a collaborator will be an important contribution to the geotechnical field. This technique will allow for upscaling of the clay models while maintaining the effect of the clay-fluid molecular interactions. This technique will be superior to the discrete element modeling for clays. (2) Improved knowledge on how environmental effects on WIM data can assist pavement design planning for traffic impacts on pavement condition and a greater awareness of WIM data quality issues. (3) Future transportation professionals trained in machine learning algorithms and at-grade crossing safety performance evaluations while contributing knowledge regarding highway-rail grade crossing safety and countermeasure effectiveness. A journal article was published that increased the body of knowledge and technical understanding of HRGC crash prediction accuracy and precision performance with AI-based methods. These methods include convolution neural network, linear discriminant analysis, K-nearest neighbors, classification and regression trees, and naïve Bayes classifier, and their performance comparisons especially considering extremely imbalanced datasets. (4) Improved algorithm to improve understanding of the mixed environment for human factors and autonomous vehicle/smart infrastructure environment. (5) Reduced crash risk for Native Nations in training and utilization of traffic safety planning tools and countermeasure implementation; and reduced risk for teen drivers by utilizing parental engagement in driver safety during novice driving experiences. (8) Enabling of rail rolling stock within the Internet-of-things (IOT) as relevant in connected vehicle technology and big data processing. (9) The collaborative COVID-19 traffic investigation, which proposed a new streaming learning model to significantly improve the physics regularized Gaussian process training time, thus reducing the computational complexity and maintaining reliable and accurate prediction performance.

The 13 active projects at **South Dakota State University** will have the following anticipated impacts:
(1) Promote sustainable biomaterials and agricultural byproducts for the production of bio-asphalt binders. (2) Improve laboratory techniques for measuring the critical shear stress in cohesive soils to better predict bridge scour. (3) Develop a new filtration technology for stormwater runoff using steel byproducts. (4) Improve the selection process of deicing agents. (5) Recommend guidelines on bridge deck sealant applications. (6) Develop a network screening method for an improved safety remediation measure. (7) Reduce the possibility of insufficient field soil compaction. (8) Develop a new stormwater filtration technology using drinking water treatment residual coated woodchips. (9) Develop a novel technique

for recycling waste PET in asphalt mixes to address an important environmental challenge. (10) Minimize repair and rehabilitation of pavement with expansive and unsaturated soil substrates including climate change effects. (11) Enhance prediction of sediment erosion and scour. (12) Promote sustainability of pavement using reclaimed asphalt pavement. (13) Improve the management and quality of stormwater.

The projects at the **University of Colorado Denver** will have the following impacts:
The 13 projects listed cover various aspects of transportation systems, such as improving route planning for ride sourcing, ridesharing and fleet services, studying low-cost sensing devices to report roadway pavement conditions, improving accuracy of bridge deterioration forecast models, exploring new ways to evaluate ADA compliance in pedestrian infrastructure, and others. The overall impact of these projects is to enhance the efficiency of transportation services, reduce their carbon footprint, and improve safety, accessibility, and cost-effectiveness of transportation infrastructure. These projects are expected to contribute to the development of a better-trained workforce, prevention of crashes and cost savings for transportation agencies.

The projects at the **University of Denver** will have the following impacts:
(1) Provide transportation organization leaders with information about how to reduce costly crashes and injuries, improve safety culture and operational fatigue levels, and reduce crashes and injuries. (2) Provide transportation organization leaders with a safety leadership training model to improve safety culture, the results of which are expected to refine and improve methods to develop safety culture, which will lead to fewer crashes, accidents, and injuries, resulting in greater safety and reduced costs. (3) The validation of a mobile hand-held alertness measuring device, integrated into existing mobile phones, will significantly improve access to fatigue information and increase ability to better manage fatigue, potentially saving lives and money. This will also improve transportation system effectiveness by reducing fatigue and crashes among vehicle operators. (4) The increased awareness, self-confidence, and skill in dealing with persons who might be at risk for intentional death using a railroad or suicide by rail. In addition, there will be an increase in public awareness and understanding of the risks of trespassing on or near railroads. (5) The safety of the system will be improved through an increased knowledge and understanding of the effects of emergency conditions on the health and safety of drivers. (6) Potential for a reduction in trespass fatalities associated with intentional self-harm. The anticipated impact on the effectiveness of the transportation system will be to increase the likelihood of identifying risks associated with involvement with railroad trespass fatalities and railroad-related suicides.

In the material, geotechnical, and structural areas, the **University of Utah** will have the following impacts:
(1) The extended durability of materials used to construct roads will reduce construction delays and maintenance costs. (2) The ability to perform a life-cycle cost analysis on pavement designs that incorporate site-specific materials, which will lead to innovation in both materials and structural design. (3) Reducing the differential settlement of bridge approach slabs to improve the rideability and safety of the bridge system and eliminate potential remediation and repair of the approach slabs. (4) The improved understanding of the significant influence of native subgrade and fill materials on the performance of pavement systems constructed on soft subgrades, which will result in roadway systems that perform better and require less maintenance than current practice. (5) The significant reduction of settlement/heave of approach embankments for bridges will mitigate problems with bumps at the ends of newly constructed bridges. (6) A better understanding of the performance of pavement systems constructed on soft subgrades, both without and with geogrid reinforcement, will result in roadway systems that will perform better and require less long-term maintenance. (7) The improved effectiveness of rail and transit systems by enabling condition-based maintenance rather than a time-based approach. (8) The development of new methods of reinforcing bridge columns with glass fiber reinforcement for conventionally reinforced bridges and bridges with post-tensioned columns in seismic regions. (9) The increased confidence regarding the use of hybrid reinforcement and buckling restrained braces for designing bridges in seismic regions. (10) The results of the finite element analyses of partial depth panel bridge decks combined with experiments carried out for the Utah DOT will result in cost-effective strengthening methods for bridge decks.

In the cyber-infrastructure and transportation area, the **University of Utah** will have the following impacts:
(1) Provide the state of Utah with more clarity about the energy impacts of large-scale drone delivery, as well as a viable airspace network. (2) Enable auto-detection of pavement marking issues, traffic signs, and litters and trash on the road using AI algorithms in anticipation of adoption of autonomous driving. (3) The computer-vision-based system developed for rural roadways creates a cost-effective and accurate safety ranking system that will improve knowledge and reduce the number of crashes, ultimately benefiting the public and private sectors. (4) Utah DOT can allocate less funding for inspections and reactive maintenance of culverts and instead focus on proactive maintenance, resulting in a higher-quality

culvert network and a safer transportation system. (5) An improved understanding of drivers' daily activities and public charging demand at city-scale, which is paramount to electric vehicle charging station deployment. (6) An improved effectiveness of the transportation system and enhanced winter safety using intelligent infrastructure and connected vehicles. (7) Estimating the queue length on access ramps, which prevents the generation of shockwaves in ramp-highway merging points and decreases the emissions levels and traffic mishaps on ramps and highways.

The projects at the **University of Wyoming** will have the following impacts:
The projects completed and the ones in the process of being completed will help transportation engineers in designing a safe and cost-effective infrastructure.

The projects at **Utah State University** will have the following impacts on the effectiveness of the transportation system: (1) Reduced petroleum consumption and reduced local emissions. (2) Reduced freight transportation costs. (3) Increased durability of electrified infrastructure. (4) Improved transportation agency decision making regarding data collection and management from EVs, and improved air quality through investigating and altering traveler behavior. Several of these projects provide the groundwork for the increased adoption of electrified vehicles as well as the adoption of autonomous transportation in the near future. The use of fiber reinforced concrete for bridge decks will improve durability and therefore make the transportation system more effective.

B. What is the impact or expected impact of your university's MPC research on the body of scientific knowledge?

The projects at **Colorado State University** will have the following impacts in terms of body of scientific knowledge: (1) Several new infrastructure monitoring models and techniques and NDE techniques with cost effectiveness and bridge deterioration have been developed. These models and techniques are not available in current bridge management and practices. For example, the results of the new bridge deterioration model will produce new and more advanced models for modeling bridge deterioration. These models can provide more accurate deterioration and condition prediction for individual bridges, rather than assuming the same deterioration rate for different bridges as done in existing deterioration models. The new models will contribute to better management and preservation of bridges. In addition, the project on loophole detection will produce new knowledge on the use of machine learning techniques to automate tasks related to inspection and maintenance of road transportation networks. The novel contribution lies in the development of a robust machine learning algorithm that can leverage both regular RGB images and thermal images to establish robust and accurate damage identification. This improves upon existing algorithms that mainly use regular RGB images, which suffer from low accuracy when lighting conditions are not good (e.g., cloudy or dark).

(2) Improved knowledge and several advanced modeling techniques have been developed to model transportation system safety and resilience under various hazards and disruptions. For example, the study on landslide hazards will provide a better understanding of how climate change and topographic effects influence the risk of landslides in mountainous terrain. In addition, the study on disruptions following multiple hazards has produced a better understanding of mechanisms and risks of disruptions such as tree failures and crashes under various hazards and possible debris caused by such failures.

(3) For traffic safety studies, some new methodologies have been developed and some new knowledge and insights have been made. For example, the study on railway trespassing will yield a better understanding of how signage messaging strategies (sentiment, text, shape, color) influence human perception of the information. In addition, the study on high-profile vehicle safety risk due to wind will help improve safety assessment and development of guidelines for management of traffic movement under adverse and extreme meteorological conditions. At a broader level, it will also provide guidance on policies for decision making to mitigate negative impacts of vehicle crashes due to wind effects.

North Dakota State University's state of good repair research outcomes thus far indicate that interactions between clays and fluids control mechanical properties and need to be incorporated in the analysis and design of transportation systems built on swelling clays. Newly developed experimental techniques that target swelling clays will help better characterize swelling clays. In addition, new findings regarding sensor technology and drone use will enhance asset monitoring and planning activities.

Safety and economic competitiveness work by NDSU have produced a better understanding of the effect of considering both crash frequency and crash severity on the risk assessment or ranking of at-grade crossings applying detailed spatial analysis. Freight modeling methods employed advance freight modeling techniques above assignment of observed flows, allowing researchers to forecast impacts into the future. In addition, linking freight flows to specific segments allows for further research into the impacts of changes in modal shares on existing infrastructure.

The 13 active projects at **South Dakota State University** will have the following expected impacts:
(1) Added knowledge in the field of biomaterials and the use of environmentally friendly and renewable fuel resources. (2) A better understanding of the critical shear stress and erosion rates in different clay soils and sand-clay mixtures. (3) New knowledge produced on bacteria adsorption by steel byproducts and the long-term bacteria removal from stormwater. (4) Addition of new knowledge on the effects of chemicals used in deicing agents on asphalt. (5) Added knowledge on the effectiveness of various concrete bridge deck sealants for preventing water and chloride infiltration. (6) Expanded knowledge on traffic safety screening methodologies. (7) Expanded knowledge on soil compaction testing methodologies, producing new data on nutrient removal by water treatment residual coated woodchips. (8) Characterization of Electrospun PET microfiber (EPM) used in asphalt binder. (9) Highlighting the impacts of climate change on the transportation infrastructure in this region with sulfate-rich expansive soil substrates. (10) Generation of new experimental data on flow velocity profile and bed shear stress at smooth-to-rough and rough-to-smooth bed transitions in subcritical and supercritical flows. (11) generation of a new experimental database on asphalt binders and mixes using asphalt recycling agents. (12) New knowledge on the performance of a pilot scale filter in field treatment conditions.

The projects at the **University of Colorado Denver** will have the following impacts:
With extensive publishing and presentation efforts, the funded MPC projects are successfully adding to the scientific body of knowledge on several fronts, including road safety, travel behavior, smart cities, and advanced infrastructure composites. While continuing with these projects, these results are expected to have broader, multi-disciplinary impacts within the business community, the bridge construction industry, and with Vision Zero cities.

More specifically, MPC-585 introduces a novel "data-driven system-optimal" approach for route planning in transportation systems, which could be applied to other similar problems. MPC-612 contributes to the knowledge of low-cost sensing devices by creating a new dataset and developing a new model to assess roadway conditions. MPC-613 develops advanced modeling approaches to understand the behavior of composite-strengthened concrete bridge members under multi-hazard loadings, contributing to the advancement of scientific knowledge. MPC-614 documents the experiences of people with disabilities in navigating transportation infrastructure, which enhances understanding of existing limitations. MPC-616 and MPC-650 introduce deep learning methodologies for bridge management, which could inspire further research in this area. MPC-647 takes a systems-level approach to understanding left-turning vehicle-pedestrian crashes, while MPC-649 assesses the physical demands of transportation construction workers to prevent excessive cardiovascular overload. MPC-675 advances the body of scientific knowledge in the area of bridge modeling by conducting three-dimensional finite element analysis, while MPC-676 develops a model to identify upgrade and maintenance interventions to minimize life-cycle cost. MPC-677 examines the efficacy of alternative modes of transportation for persons with disabilities, and MPC-678 aims to improve the understanding of sidewalk infrastructure data and ADA accessibility, leading to larger and better research studies.

The research projects at the **University of Denver** will have the following expected impacts on the body of scientific knowledge:
(1) Increased understanding on the role of safety culture in fatigue management, which can have a direct impact on reducing crash injuries and associated expenditures. (2) Contributed a standardized model for the training of leaders intending to implement and develop a safety culture in a transportation organization, which will provide a basis for testing the most effective approaches for undertaking organizational change. (3) Contributed to the concurrent and predictive validity and accuracy of a mobile-based assessment tool for detecting fatigue in vehicle operators. (4) The impact on the scientific body of knowledge will be an increased understanding of how to best train people to deal with trespassers and those at risk for suicide by railroad. (5) Increased understanding of secondary trauma or post-traumatic stress symptomatology and sequelae associated with the repeated exposure to railroad trespass fatalities or railroad trespasser suicides.

In the material, geotechnical and structural areas, the **University of Utah** will have the following impacts:
(1) Laboratory testing on lightweight cellular concrete (LWCC) being used to determine its fundamental material behavior under static and cyclic loading at varying amounts of saturation. (2) An improved knowledge in the civil engineering field with respect to economical design of pavement systems using geogrids. (3) A better understanding of the tests and methodologies used to evaluate asphalt mixtures at intermediate temperatures. (4) A greatly enhanced understanding of the loading and wetting stress-strain characteristics of various types of soil. (5) An improved body of knowledge by understanding the seismic behavior of bridge columns reinforced with glass fiber reinforced bars and spirals; this applies to both conventional bridge columns and columns with post-tensioning. (6) Significant improvement in the body of knowledge regarding design and analysis of pavement systems, with and without geogrid reinforcement. (7) An enhanced body of scientific knowledge on how to model and strengthen bridge decks and description of retrofit and rehabilitation methods. (8) A better understanding of the behavior of asphalt materials that are used in pavement construction; since each test provides a specific characteristic of the material, the relation between them allows for a more comprehensive description of how the material will behave when used in the field. (9) New knowledge on ultrasonic non-propagating modes in rails and how that can be used for inspection. (10) Increased knowledge on numerical modeling for hybrid bridge bents for conventional bridges and bridge bents with buckling restrained braces as energy dissipators for bridges constructed in high seismic regions; in addition, it will increase the body of knowledge for modeling glass fiber reinforced concrete columns as well as post-tensioned columns. (11) Developed a relation between multiple tests based on analysis of their mechanical response; this knowledge will allow for further developments of pavement material characterization.

In the cyber-infrastructure and transportation area, the **University of Utah** will have the following impacts:
(1) Enable researchers, planners, and practitioners to record and update assumptions about the distribution of vertiports, traffic, population, and other requirements that may affect the operation of the transportation network. (2) Develop customized AI algorithms based on deep learning methods to advance the understanding of AI applications and facilitate automated transportation asset management. (3) Advancement in the understanding and application of computer vision techniques in evaluating the safety of transportation networks. (4) Provide a risk-based approach for maintaining culverts by analyzing deterioration curves and life-cycle analyses. (5) Electric vehicle assignment and public charging decision modeling are specified in post-simulation analyses using socioeconomic and demographic information to produce high-resolution public charging demand. (6) Infrared technology will produce new knowledge on winter safety for connected vehicles. (7) A novel and efficient approach that uses computer vision and video-based processing model that provides a complete framework to extract data, analyze it, and provide the signal phase suggestion to the traffic management team.

The **University of Wyoming** projects will have the following impacts:
MPC-540 resulted in developing advanced techniques to identify speed limits on downgrades. The developed techniques will be utilized for decades to come. MPC-633 identified the needs for establishing a rod track in the freeze-dry region of the U.S. The surveys conducted and the papers generated from this study will be utilized by future researchers.

The projects at **Utah State University** will have the following impacts on the body of scientific knowledge:
Many of the projects at USU have the goal of determining ways to improve the transportation system and the environment. Much of the work is directed at improving our living environment. The project that is profiling the sub-surface soil beneath an I-15 structure will be used to generate the only known large-scale, 3D shear wave velocity model beneath an instrumented bridge in the U.S. When combined with ground motions and dynamic response recorded by the Magna earthquake, this will be a unique and invaluable resource for seismic site response and soil-structure interaction studies.

C. What is the impact on transportation workforce development?

The projects at **Colorado State University** will impact transportation workforce development as follows:
(1) A number of graduate student and undergraduate students have received research training through these projects. (2) Some collected data and methods have provided content for education. For example, the project on high-profile vehicles under wind conditions has provided support to train a graduate (MS) student who is funded to work on an interdisciplinary project that involves the use of computational fluid dynamics (CFD) and vehicle mechanics to inform traffic safety. The findings of this fundamental study pertaining to fluid-vehicle interactions will be leveraged in the future to challenge and excite students in both the PI graduate courses in CFD (Venayagamoorthy) and Traffic Engineering (Chen).

The projects at **North Dakota State University** will impact transportation workforce development as follows:
(1) A new workforce trained in AV, smart infrastructure, and mixed-driver environment safety. (2) Course development and new workforce training in swelling clay research experiments. (3) New workforce development with graduate student training in machine learning models in traffic safety analysis, traffic forecasting techniques, and project efficacy techniques. (4) An existing workforce contribution with improved tribal and local road manager access to pragmatic and relevant safety investment data and tools. (5) An increased awareness of individualized driver improvement countermeasures and their integration as data-driven approaches among traffic safety workforce professionals. (6) Support to tribal communities in heavy equipment and CMV driver workforce attraction, development, and retention. (7) Graduate student experience with GIS modeling, including Trans CAD© and Trans Modeler© software applications.

The **South Dakota State University** impacts on workforce development will include the following:
Six PhD, 18 MS, and three undergraduate students have been trained through transportation-related research activities planned in the SDSU projects. The students have been encouraged to work in transportation agencies or private firms working on transportation projects.

The **University of Colorado Denver**'s impact on workforce development include the following:
The MPC projects listed above have been instrumental in providing students with practical experience and training in the field of transportation. These projects have trained and educated students in areas such as system-optimal route planning, low-cost sensing devices, multi-hazard loadings, bridge management, and life-cycle cost optimization. The students involved in these projects have been equipped with advanced data-driven techniques and become familiar with important challenges in managing transportation infrastructure, which will be beneficial in their careers. The outcomes of these projects have also generated new materials that can be used in teaching relevant courses, thus spreading knowledge and training to a wider audience.

The research projects at the **University of Denver** had the following expected impacts on the transportation workforce:
(1) Four graduate students received training and experience in the research process, including literature review, data collection, analysis using Excel, SPSS, and report writing. (2) Safety managers at two railroads were given information on how to improve their safety culture. (3) Presentations on the preliminary aspects of the safety culture training model have provided useful information to safety managers in planning their next organizational safety culture program. (4) Managers at several trucking companies received information about how to manage fatigue levels as a result of this project.

The **University of Utah** will have the following impacts on transportation workforce development:
(1) The ongoing projects provided an opportunity for 16 Ph.D., 13 M.Sc., and four undergraduate students to perform research in transportation and related disciplines. In addition, the research grants enabled some of the students to become teaching assistants at some point in their studies, and this is beneficial. (2) The ongoing projects have enabled the university to retain students involved in transportation research; at least some of the students come from unrepresented groups. (3) The seminars provided and conferences sponsored from the projects enabled the development and dissemination of educational materials, which provided exposure to transportation and engineering technology to practitioners, young people, and members of the public. (4) Many of the graduate students involved in the sponsored research will eventually find jobs in the transportation or related industries.

The **University of Wyoming** conducted 20 workshops for workforce development. Most of these workshops involved issuing certifications required for transportation professionals.

The projects at **Utah State University** will have the following impacts on transportation workforce development:
(1) Inform the many students involved in performing the research. (2) Influence many undergraduates to study transportation as a career due to the exposure to so many interesting projects. USU's projects are having a broad impact on students as well as those who learn about the projects. Additionally, the transportation workforce is impacted by the many short courses and training modules provided by Utah's LTAP center located at USU. The number of people involved in these events is presented in the section on workforce development.

D. Address any significant impacts.

North Dakota State University: New experimental techniques developed that target swelling clays will help better characterize swelling clays. In addition, new findings regarding sensor technology and drone use will enhance asset monitoring and planning activities. Safety-related research will enable decision makers and practitioners to make more informed decisions in times of crises as well as with high-risk sites, such as highway-rail crossings, and driver groups, such as young drivers. Work with tribal communities remains a focus with NDSU. Work underway will contribute to tribal transportation research and give valuable insight into the gaps between federal transportation program contract requirements and tribal transportation workforce capacity for financial management, reporting, and performance that can be used to deliver a valuable user-informed workforce development program.

University of Denver: Over 500 individuals have read the technical report describing the validation of the Alert Meter, which has been commercially adopted by a private trucking firm. Several citations of the instrument documentation are in the literature.

Utah State University: Work in electrified transportation spans many disciplines of transportation. Many researchers are working in this area, including from the perspective of system optimization, infrastructure durability, and the sub-surface characterization of the soil.

6. Changes/Problems

South Dakota State University: The PI of two active projects (MPC-576 and 626), Dr. Seo, passed away in September 2022. For MPC-576, a copy of the final report submitted to the project cosponsor was obtained and submitted to MPC. Dr. Ghabchi has agreed to continue MPC-626 as the new PI. Some changes have been reported in four projects due to material shortages, test setup limitations, and/or global supply chain issues. However, all PIs have reported reasonable progress and with no significant delays.

University of Denver: Initial problems due to delays as a result of COVID and delays due to union negotiations have been overcome. Data collection in all but one project is nearly complete.

7. Special Reporting Requirements:

A. T2 Performance Measures and Targets are listed in Appendix E.