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

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Mountain-Plains Consortium, North Dakota State University
Denver Tolliver, Director
denver.tolliver@ndsu.edu
(701)231-7190

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North Dakota State University
Upper Great Plains Transportation Institute
NDSU Dept. 2880, P.O. Box 6050, Fargo, ND 58108-6050

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Semi-Annual Progress Report #13

Denver D. Tolliver

Director, Mountain-Plains Consortium
North Dakota State University

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 Event	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
	No cost extension granted	09/30/2023	09/30/2024
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, **160 transportation and transportation-related courses** were offered this reporting period, for a **total of 1,594 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 770 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 **103 online training modules** and **102 recorded sessions** that **2,721 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 SAPRs. 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 **86 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
Joseph Podolsky, Materials and Road Research, Minnesota DOT
University of Colorado Denver
Chengbo Ai, University of Massachusetts, Amherst
University of Utah
Cody Copperman, Utah Department of Transportation
Jeff Williams, Utah Department of Transportation
University of Wyoming
Joel Meena, Wyoming DOT
Greg Milburn, Wyoming DOT

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 **68 peer-reviewed articles or papers** in scientific, technical, or professional journals. Since the beginning of this grant, **we have published 567** different peer-reviewed articles or papers.

B. Conference papers can be found in Appendix D

This reporting period **we have published 22 conference papers and 230 total since the grant began**.

C. Presentations can be found in Appendix D

MPC faculty and investigators **have presented at 28 different** scientific, technical, or professional conference this period. In total, we have **had 327 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
In collaboration with the College of Engineering and the CSU Drone Center, we have proposed and received approval for a new class, ENGR 480: Engineering with Drones, to be taught by the PI of this study and Christopher Robertson in spring of 2024. The new drone course is one of very few in the state or region that will train engineers to use UAS for engineering and transportation projects.

South Dakota State University
Methodologies for clustering crashes and examining crash distributions, including the use of radial methods (similar 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; subsequently, these methodologies are not finalized but may be adjusted based on our development of the outputs, thus they are pending. As mentioned in the plan for the next reporting period, we discovered a problem regarding crash case assignment and therefore needed to revise that. This delayed our prior efforts somewhat but we are recovering. The resulting clustering and preliminary crash distributions are currently undergoing analysis to test validity and determine statistical clustering. These methods will be disseminated both 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 (offered in fall 2022).

A new course, CEE 792 Slope Stability and Earthen Structures, was introduced where the curriculum includes the effects of climate change on embankments and a design project on these concepts (offered in spring 2023).

A new course, CEE 792 Soil Behavior, was introduced where the curriculum includes the reasons for the adverse effects of using cement as a stabilizer for sulfate-rich expansive soils (offered in fall 2023).

An old 17-feet long, 8-inch wide, and 17-inch deep open-channel flume that had not been used since 2002 has been refurbished and re-commissioned in this project. The refurbishment included installing a new water reservoir and two centrifugal pumps to increase the flow capacity, an electro-magnetic flow meter for accurate measurement of flow discharge, a globe valve for precision control of flow rate, and redesigning the flume inlet and outlet to improve entrance conditions. The infrastructure building project has restored a valuable piece of permanent equipment for transportation research and education at South Dakota State University.

University of Colorado Denver
Dataset of five construction workers' physiological data, including HR, breathing rate, acceleration of torso movements, and torso posture during a bridge rehabilitation project (available upon request).

University of Utah
We have produced additional laboratory testing results on the material and pavement properties of lightweight cellular concrete (LWCC). This information will be used for the potential implementation of LWCC in pavement systems as a base and subbase material. The Utah Department of Transportation is researching the potential use of LWCC underneath pavements and approach slabs to reduce the differential settlement (i.e., bump at the bridge) that occurs at bridge crossings.

4. Outcomes

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

Colorado State University

The projects at Colorado State University will have the following outcomes:
(1) Enhanced techniques of transportation infrastructures inspection and monitoring. Existing NDE can provide good understanding of bridge conditions but with additional high costs. The proposed method emphasizes conducting inspections only when there is a high level of uncertainty about a bridge condition and using nondestructive evaluation methods that can provide useful information based on the phase of the bridge's service life. A life-cycle cost comparison shows that inspection cost savings can be realized with the proposed method, especially when user costs are considered.
(2) Increased understanding of transportation system performance against natural hazards, such as earthquakes, landslides, and crashes. Several new analytical, simulation and experimental methods are developed. For example, the study provided new insights on predicting hazardous mass movements by using and testing a probabilistic model for landslide initiation. This model was shown to outperform a deterministic model, so adoption of this approach may lead to improved capability of predicting where infrastructure is at risk of landslide hazards. In addition, various disruption scenarios under different hazards and incidents will help further simulate the impact on transportation systems.
(3) Improved understanding and prevention measures to improve traffic safety. For example, under adverse driving environments, studies have increased the body of knowledge about how to assess traffic safety risk during hazards and disruptions by considering local road and network performance. This study on intersection traffic control has increased the understanding of network performance at intersections during extreme events. A new solution for improving network mobility and resilience through advanced signal control techniques has been developed. In addition, an improved understanding of effective and non-effective mitigation methods of railroad right-of-way crossing from the perspective of real users was achieved. Furthermore, high-profile moving vehicle crashes under strong crosswinds was modeled based on computational fluid dynamics, which can lead to some tentative guidance on best practices for using computational fluid dynamics (CFD) models for simulating the complex flow pattern and predicting wind loads on vehicles.

North Dakota State University

The projects at North Dakota State University will lead to:
1) safety measures dedicated to AVs in mixed-driver-environments;
2) molecular interaction-microstructure-property relationships detail for swelling clays that would lead to robust analysis;
3) cost-effective, sensor-based improvement to railroad track inspection efficiency and safety countermeasure selection;
4) sensor-based WIM pavement design that complements AASHTOWare ME design;
5) subpopulation-based and individualized intervention in impaired driving and novice teen driver crash risk;
6) best practices approach for tribal communities and small local road departments to encourage safety integration into ongoing planning and investment decision processes;
7) personnel gained information allowing them greater understanding and knowledge on what is needed to pass CDL testing to contribute to the pool of CDL holders on our tribal nations;
8) greater workforce understanding and knowledge on what is needed to pass CDL testing to contribute to the pool of CDL holders among tribal nations;
9) DOT adoption of AI-based methodology for state traffic estimates based on a proposed AI-based methodology in vehicle trajectory reconstruction;
10) broadened understanding about potential impacts of the scope of autonomous aircraft cargo logistics, prospects for adoption, deployment challenges, and the potential implications for planners and policymaking;
11) increased body of knowledge and technical understanding of emerging drone technologies, which can improve the effectiveness and reduce the cost of transportation infrastructure, such as asset inspections of how emerging cargo drone technologies could induce a mode shift away from surface transportation modes;
12) enhanced freight planning ability with the development of a GIS road and railroad network of the multistate corridor that can be used in scenario and planning research applications;
13) greater understanding of food security among the Native American tribes in North Dakota through research that allows us to compare the results of North Dakota Native American food insecurity with national results.

South Dakota State University

The 13 active projects at SDSU will have the following outcomes: (1) improved understanding of the benefits of using cellulose nano-fibers in asphalt mixes; (2) better understanding of the structure of turbulent flow and induced bed shear

stress around eroding soils; (3) improved understanding of the effectiveness of steel byproducts for bacteria removal from stormwater runoff; (4) better understanding of the effects of deicing agents on durability of the asphalt mixes; (5) adoption of sealants that delay deterioration of bridge decks; (6) development of an appropriate methodology for traffic safety network screening; (7) update testing methodologies for in-situ acceptance of the compacted granular bases; (8) improved understanding of the effectiveness of nutrient removal from stormwater runoff using woodchips, improved techniques using recycled electrospun polyethylene terephthalate microfibers for characterization of the asphalt binders; (9) better understanding of the potential effects of climate change on pavement infrastructure; (10) improved understanding of the velocity distribution and bed shear stress in free-surface flows at a sudden change in bed roughness; (11) improved understanding of over-embrittlement of asphalt mix as a result of using reclaimed asphalt pavement by application of new rejuvenators; and (12) improved understanding of the treatment efficiencies of stormwater filters using steel byproducts under field conditions.

University of Colorado Denver

All of these projects made significant progress during the last project period, resulting in the publication of 11 journal papers (with two in review), two conference papers (with four in review), and six conference presentations. Moreover, the students working on these projects benefited greatly from the opportunity to engage in research and develop various research-related skills.

University of Denver

The projects at the University of Denver will have the following outcomes:
1) The validation of Smartphone Alert Meter Fatigue Assessment Device for Transportation Workers, which will provide validating data for a new device and technology that can be readily deployed in the operational environment to assess fatigue and alertness of operators and drivers before operating vehicles. The technology should lead to a reduction in drowsy driving and fatigue and an increase in alertness and vigilance. Ultimately, the utilization of the device could lead to a reduction in crashes and injuries in the transportation system.
2) The identification of linkages between Safety Culture, Leadership & Fatigue in Transportation Operations and how best practices are effective in reducing crashes and injuries in various transportation/transit organizations. An online safety culture assessment has been posted on our web site.
3) The Development of a Safety Leadership Training Model to Improve Safety Culture will aid transportation organization leaders in demonstrating the behaviors and best practices that will lead to the development of an effective safety culture characterized by reduced numbers of accidents and injuries. Previous research has not been specified to either safety organizations or transportation. Consequently, there is still a perceived need to develop a standard model or approach to creating a safety culture within the transportation industry.
4) An 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, an increase in public awareness and understanding of the risks of trespassing on or near railroads. Finally, there may be a reduction in trespass fatalities associated with intentional self-harm. The identification of behavioral and psychological risk factors associated with being involved in trespasser fatalities and railroad suicides.
5) Increased data on drivers working during COVID and a greater understanding of the impacts that the pandemic had on their physical, psychological, and economic health and on driver safety.
6) The various projects have increased the number of trained transportation professionals.

University of Utah

In the area of asphalt pavements we will have the following outcomes: (1) it was determined that there is a relation between the results from single point tests, specifically the IDEAL CT and the dynamic modulus of the material; such knowledge will allow for incorporation of mix design into pavement structural design; (2) the body of knowledge was increased from theory validated by two asphalt mixtures to validation from nine different asphalt mixtures that are more representative of the region.

In the geotechnical area we will have the following outcomes: (1) making design and construction recommendations pertaining to the implementation of lightweight cellular concrete as an approach slab support system near bridges to reduce differential settlement; (2) change specifications to preclude the use of native materials in fills supporting roadway pavement systems that do not meet current requirements for granular borrow; (3) allow the use of multiaxial geogrid as an alternative to currently allowed biaxial geogrid within the pavement systems for new roadways; (4) provide great insight into the expected magnitude of settlement or heave that will occur from strains within the embankment for each of the 10 selected materials; (5) provide state DOTs with enhanced methods to predict the settlement or heave of approach

embankments, thereby allowing them better ways to ensure that bumps at the ends of bridges are minimized; (6) changes to the software used to design pavement systems' bearing on soft subgrades.

In the structures area we will have the following outcomes: (1) use light, durable, and corrosion-free fiberglass materials in constructing bridge columns of bridges built using accelerated construction methods in seismic regions that will last for at least the design life of the bridge; (2) enable DOTs to develop a design method including numerical simulations for the retrofit of bridge decks with delamination issues and thus prolong the life of bridge decks constructed with partial depth deck panels; (3) improve knowledge of a comprehensive management system for culverts and storm drains in Utah; this is beneficial since machine learning algorithms for determining culvert deterioration curves and inspection frequency were used, and this allows UDOT to inspect and manage its culverts more efficiently.

In the transportation area we will have the following outcomes: (1) enable transportation agencies to quickly screen local road networks for "problematic locations" of road segments and prioritize projects to improve safety levels and provide detailed information about safety rankings at each road segment; clear zones, guardrails, side slopes, and rigid obstacles are the main safety factors; this enables traffic engineers to address the most common safety concerns around state roadways; (2) introduce a prototype algorithm based on mobile-phone-based artificial intelligence to identify guardrails and barriers for road asset management, mainly for pavement marking issue identification; the algorithm realizes an accuracy of 90% for identification of pavement marking issues; we have also evaluated the algorithm performance under different driving speeds and illuminance levels; (3) estimate the queue length and queuing time estimation using video processing; this study will enable transportation agencies to quickly determine vehicle class, total time spent, and the number of vehicles per lane at any instant of time and adjust the ramp meter signaling strategy accordingly; (4) improve the understanding of slippery road conditions and connected vehicle safety; (5) develop a city-scale agent-based simulation to produce daily travel profiles using time-inhomogeneous Markov chain, and a location mapping technique using publicly available data.

In the air transport area, we will have the following outcomes: (1) introduce a statewide microsimulation framework that outputs a statewide airspace network, delivery schedule, and truck/drone fleet mix for a given set of parameters for deployment of drone centers and fleet size planning for drone delivery in Utah.

In the rail transport area, we will have the following outcomes: (1) introduction of non-propagating modes in rails for non-destructive evaluation purposes; the project has produced a better understanding of wave propagation and nondestructive evaluation for rail track structures and has also improved inspection technology for rail track structures.

University of Wyoming
The projects at University of Wyoming will have the following outcomes: (1) Increase the body of knowledge. (2) Develop a new technology to identify passing zones on two-lane highways. That new technology will enhance safety on two-lane highways, and it will make it easier and more accurate for transportation professionals to determine passing zones. (3) Increase the number of certified transportation professionals for highway testing. Every year, the Wyoming LTAP certifies over 300 materials testers to ensure the quality of materials used in paving projects. (4) Implement online certification program for flaggers to enhance work zone safety statewide. Between 500 and 700 individuals from WYDOT and the construction industry get certified annually.

Utah State University
The projects at Utah State University will have the following outcomes: (1) improved planning for the deployment of charging infrastructure for electric vehicles; (2) increased knowledge of travel behavior leading to reductions in air pollution in the state of Utah; (3) increased understanding of constructability and durability issues associated with embedded wireless charging systems in pavements; (4) improved traffic operations and improved adoption by transportation agencies related to autonomous vehicles; (5) improved adoption of electric buses; (6) improved understanding and possible adoption of fiber reinforced bridge decks; (7) increased safety and cyclist perceptions of roundabouts; (8) improved safety for pedestrians at intersections; (9) increased understanding of the post impact behavior of bridge pier couplers; (10) increased pool of educated transportation professionals and better trained transportation workforce; (11) improved durability of charging infrastructure for the future of U.S. electrified transportation; (12) calibrating ground response analyses beneath an instrumented bridge using the I-15 borehole array and ground motions from the Magna earthquake; (13) an improved understanding of crash data; (14) improved repair times for bridge decks in need of deck replacements; and (15) improvements in the fire behavior of polymer coated bridge decks.

These outcomes are coming and will continue to come as a result of the well-planned research projects. These projects consistently utilize students and, in some cases, outside companies and agencies, to perform the studies. In all cases, the students develop a deeper understanding of the complexities and challenges facing current transportation professionals. Additionally, the Utah LTAP Center provides training to many in the current workforce.

5. Impacts

A. What is the impact or expected impact on the effectiveness of the transportation system during this rating period.

Colorado State University

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 have significant impacts. First, increasing the use of NDE helps support a state of good repair as bridge managers have better data to use for decision making. Second, the studies will help improve bridge management practices. This study contributes to the ongoing conversation about how to improve bridge inspection planning to improve efficiency and how to incorporate NDE to provide enhanced information. Third, a portable sensing technique for measuring displacement, which does not require the instrumentation of the structure or interruption of traffic, will be developed. It is therefore more convenient and cost-effective as compared with the current techniques. Finally, 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 preservation of bridges.

(2) Several studies on transportation system safety and resilience under various hazards and incidents will have the following impacts. First, the landslide hazard study can greatly improve transportation management agencies' ability to plan for and respond to rainfall-triggered landslides. The developed model calculates relative stability across the landscape, identifying potential hot spots for landslide hazards in the road network. Second, the new disruption modeling techniques under hazards that were developed can provide a more realistic prediction of possible impact on transportation infrastructures from various hazards. Potentially more lives may be saved from hazards and incidents such as tree failure. Finally, to study impacts on transportation infrastructures from various hazards, the newly developed predictive tools, which better represent the potential movement and forces of the material that surrounds highways and bridges, would be greatly beneficial from both a design and analysis perspective. This work is expected to add to the library of computational tools engineers have to predict behavior and design novel methods for slowing or directing high-velocity vehicles.

(3) The studies on traffic safety under adverse driving environments and railways will have following impacts. First, the developed tools will automate the data collection and damage identification of potholes and help decrease the cost of road condition data collection and assessment. They will also help improve road safety because road damage such as potholes can be promptly identified using the developed tool so that repairs can be made quickly; therefore, reduced damage to cars and fewer potential crashes results in improved road safety. Second, the long-term recovery planning method will potentially optimize limited resources to maximize the recovery process based on resilience assessment. The quantitative measures will offer resilience-based indicators of various optimization processes for recovery planning such as bridge repairs. Third, to reduce railway trespassing crashes, the study aims to identify gaps in intended messaging and interpreted messaging of railroad signage for pedestrians. Thus, it is anticipated that increased pedestrian safety (i.e., fewer deaths and injury) will occur with improved sign design and implementation.

North Dakota State University

The roadway-related projects at North Dakota State University will have the following impacts: (1) An 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) An improved knowledge on how environmental effects on WIM data-assisted 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 evaluation while contributing knowledge regarding highway-rail grade crossing safety and countermeasure effectiveness. (4) An improved algorithm to enhance understanding of the mixed environment for human factors and autonomous vehicle/smart infrastructure environment. (5) Reduced crash risk for Native Nations through training and utilization of traffic safety planning tools and countermeasure implementation and prevent teen driver crashes with parental engagement in driver

safety during novice driving experiences. (8) Enabling rail rolling stock within the Internet-of-Things 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 physics regularized Gaussian process training time, thus reducing the computational complexity while maintain reliable and accurate prediction performance. (10) Insight for addressing food security inequities as they relate to Native Nations transportation issues.

South Dakota State University
The 13 active projects at SDSU will have the following anticipated impacts: (1) promote sustainable bio-materials 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 improved safety remediation measures; (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 addressing 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; and (13) improve the management and quality of stormwater.

University of Colorado Denver
The 13 projects outlined encompass a wide spectrum of transportation system facets, including enhancements in route planning for ride sourcing, ridesharing, and fleet services, research into cost-effective sensing devices for monitoring roadway pavement conditions, advancements in the precision of bridge deterioration forecast models, innovative approaches to assess ADA compliance in pedestrian infrastructure, and more. Collectively, these projects aim to bolster the efficiency of transportation services, decrease their environmental impact, and enhance the safety, accessibility, and cost-efficiency of transportation infrastructure. Anticipated outcomes from these projects include the development of a more skilled workforce, safety improvements, and cost savings for transportation agencies.

University of Denver
The research projects at the University of Denver will have the following expected impacts: 1) Provide leaders of transportation organizations with information about how to reduce costly accidents and injuries and improve safety culture and operational fatigue levels and reduce accidents and injuries. 2) Provide transportation organization leaders with a Safety Leadership Training Model to Improve Safety Culture in order to refine and improve how to develop safety culture, which will lead to fewer crashes and injuries, 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. Also, improved 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 as a result of increased knowledge and greater understanding 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.

University of Utah
The asphalt pavement projects will have the following impacts: (1) will lead to relating different aspects of pavement design, allowing for long-term cost analysis; (2) a simple relation will be developed between the asphalt mixture design and the structural design of pavements; such a process will allow for better optimization of materials and the possibility of life-cycle analysis.

The geotechnical projects will have the following impacts: (1) lightweight cellular concrete technology (LWCC) will be ready for implementation by the UDOT; the first phase of this implementation will be a "demonstration" project where LWCC will be installed and monitored; (2) improved understanding of the significant influence of native subgrade materials and fill materials on the performance of pavement systems constructed on soft subgrades should result in roadway systems that will perform better and require less maintenance; (3) better understanding of the performance of

pavement systems constructed on soft subgrades, both without and with geogrid reinforcement, should result in roadway systems that will perform better and require less long-term maintenance; (4) significant reduction of settlement/heave of approach embankments for bridges, thereby mitigating problems with bumps at the ends of newly constructed bridges.

The structural projects will have the following impacts: (1) bridge designers can use fiberglass materials to design and built columns that do not corrode and have excellent structural performance during strong earthquakes; (2) cost-effective strengthening methods developed for partial-depth panel bridge decks with delamination problems will reduce the need for bridge deck replacement; (3) reduction in UDOT funds needed for culvert inspections; implementation of strategies developed in this research will result in a more resilient culvert network, thereby enhancing the Utah transportation system's safety and effectiveness.

The transportation projects will have the following impacts: (1) extend and improve the knowledge of safety planners by providing a cost-effective and simultaneously accurate safety ranking system using automated image and video analysis; this will greatly impact the public and private sectors by decreasing the number of accidents and reducing the consumption of federal taxes; (2) develop an applicable artificial intelligence algorithm to auto-detect pavement marking issues for highway maintenance; the auto-identified pavement marking technique can be directly utilized to prioritize pavement marking repair work orders and evaluate quality of paint from different suppliers; (3) improve effectiveness of the connected infrastructure with infrared thermography; (4) use queue length and queuing time estimation in highway on-ramps to design a signal timing that would help the traffic management team maintain traffic flow in the mainline; this ensures that no vehicle on the ramp will face more delays than the standard threshold; (5) utilize a high-fidelity city-scale road network, which incorporates drivers' non-work-based activities and applies real-world electric vehicle distribution to develop and validate a charging demand estimation model.

The air transport projects will have the following impact: (1) develop a simulation platform that enables 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.

The rail transport project will have the following impact: (1) sensing technology will promote local resonances, including zero-group velocity modes and cutoff frequency resonances, to detect and monitor the growth of rail internal defects; between regular rail inspections, the technology can support more informed decision-making and improve the effectiveness of inspection for rail safety.

University of Wyoming
The GSRS study results, which should help reduce crashes on downgrade segments, have been passed to WYDOT for potential implementation. Software was developed to assist traffic engineers in determining speed limits on complex segments, which include multiple grades and horizontal curves. Selecting the appropriate speed limit is essential for reducing crashes, which have been increasing on downgrade segments.

The newly developed device for establishing passing zones on two-lane highways has been adopted by WYDOT and is currently being used by other local agencies in the state. The implementation of this device will enhance the safety of two-lane highways and will result in reducing some of the head-on/sideswipe crashes due to more accurately determining passing/no passing zones. Duplicates of the developed device can be built and/or obtained by other DOTs for potential implementation in other states.

Utah State University
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 thru investigating and altering traveler behavior; (5) equitable deployment of both plug-in charging stations and wireless charging lanes; (6) potential reduction of required seismic design forces; and (7) improved preparation for traveling in areas of wildfires and winter inversions. 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 adoption of new practices and cases where a technology or process has been commercialized.

Colorado State University

The projects at Colorado State University will have the following impacts:
(1) The studies on infrastructure inspection, monitoring, and deterioration modeling are expected to have significant impacts on new practices and technology transfer. First, the changes in bridge inspection planning can make the more routine use of NDE affordable and could help improve the adoption of NDE into bridge inspections. Second, adoption of the developed deterioration models can lead to more accurate prediction of bridge condition deterioration, which can help improve bridge safety and also guide more cost-effective maintenance and inspection decision-making. Because the developed deterioration models account for the difference in condition—environment and deterioration rate of different bridges—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.
(2) The studies on safety and resilience of transportation systems under various hazards will have the following impacts: First, probabilistic modeling of landslide initiation allows us to quantify potential landslide risk across the landscape, given uncertain input data. Our study suggests that vegetation changes due to climate change could result in major shifts in the people and infrastructure susceptible to landslides in the Colorado Front Range. Second, there was no appropriate model which can predict complex disruptions caused by tree failures under hazardous weather (e.g., wind). The proposed technology may be adopted in new practices of traffic management during hazards by city management and traffic departments to predict potential impact from windstorms, save potential costs caused by traffic congestion, and improve traffic safety under disruptions. Finally, current analysis tools are limited and are not ideal for many problems. By developing and advancing MPM models and actually using them to study the design of new systems, the consequences of natural hazards (e.g., rockfall) or human error (an out-of-control truck on an interstate highway) can be better understood and possibly controlled.
(3) The studies on traffic safety under adverse environments and railways will have the following impacts. First, the methods of vehicle powertrain optimization under predictive powertrain control will be used by automotive original equipment manufacturers to improve their algorithms for local vehicle control and coordinated control with TMS. Second, the proposed new intersection signal control scheme may be adopted by departments of transportation (like CDOT or City of Fort Collins) to deal with congestion during snowstorms or other adverse weather. Third, for railway trespassing events, the knowledge published from this study can be used by rail authorities and DOTs to improve sign effectiveness. Specifically, the results point toward signs that actual users perceive as less effective or more effective regarding whether it is safe and permissible to cross railroad tracks. Given the relatively high number of train-pedestrian collisions, this research can highlight areas of improvement for signs to convey their intended message such that pedestrians correctly understand the messaging. Currently, there is a gap in the literature comparing intended sign messaging with perceived sign messaging. Finally, for the high-profile vehicle crash study, the flow dynamics of a turbulent wind field encountering a high-profile vehicle is both a challenging and exciting problem. In this study, we took a first cut at understanding this problem. We expect the project will lead to new research project(s) that will lead to substantial findings, which will inform best practices such as travel advisories under extreme wind conditions.

North Dakota State University

One of the critical outcomes of this work at NDSU has been developing techniques to conduct nanoindentation on wet and dry clays. Experiments at this length scale on wet clays have not been previously reported. Since these experiments probe the length scale (micrometer to nanometers), which has been shown to significantly affect the engineering properties of clays, this work provides a new characterization technique that can be used in geotechnical engineering practice.

Sensor and drone related investigations are also underway with the state of good repair focus. This work produced a new optical sensor interrogator that is capable of collecting data from 24 sensors simultaneously for an enhanced weigh-in-motion (WIM) perspective; and data collected on concrete roads is expected to estimate vehicle weight with high accuracy. Drone investigations promote the likelihood that industries will adopt drone-based inspection technologies based on the research findings.

Network management during a crisis supports TIM agencies' adoption of our prediction model. Considering pandemic impact and change in traffic patterns, greater foresight is beneficial to effectively detour/divert traffic. This impact was evident when a traffic disruption occurs in an environment like the pandemic which was associated with prolonged traffic pattern changes.

Specifically related to tribal communities, NDSU supported efforts related to driver shortages and CDL training equity. Trainings held in collaboration with MHA Nation and NDLTAP created awareness of what transportation trainings can accomplish in areas of need, such as tribal lands. This impacts new drivers with their CDL and how more CDL holders can help improve roadways and other areas of need in those areas. Recent activities are building knowledge that helps tribal governments, BIA, and NDDOT better understand transportation gaps, which can result in tribes having better food access that in many cases will have a CMV aspect.

Working with crash factors and locations will enable decision-makers make better informed resource and policy decisions related to highway-rail grade crossings, rail monitoring, teen drivers, and impaired driving prevention.

Native Nations' work with traffic safety and food security is aimed to understand and address inequities in transportation resource allocation, workforce development, and transportation investments.

South Dakota State University
The 13 active projects at SDSU will have the following expected impacts: (1) promoting the use of sustainable bio-materials and agricultural byproducts for production of bio-asphalt binders; (2) predicting soil critical shear stress and erosion rates in cohesive soils; (3) reducing the bacteria contamination caused by stormwater runoff; (4) implementing pavement condition-specific deicing materials; (5) reducing rapid deterioration of bridge deck sealants; (6) codifying a methodology for traffic safety network screening; (7) developing a quick and efficient practice for evaluation of the field compaction quality; (8) developing a new filtration technology for stormwater treatment; (9) developing a post-processing method for waste plastic to be used as asphalt materials; (10) effective and resilient design of embankments and pavements on sulfate-rich expansive soil; (11) improving the estimation accuracy of bed shear stress, thus improving estimation of soil erosion rates; (12) developing new recycling practices using sustainable recycling agents; and (13) application of E. coli removal using steel byproduct filtration for stormwater treatment.

University of Colorado Denver
The MPC research projects collectively emphasize the adoption of new practices and technologies across various domains of transportation and infrastructure. MPC-585 introduces innovative methodologies for route planning, which can be leveraged by federal, state, and private agencies to enhance transportation network efficiency and environmental impact. MPC-612 focuses on low-cost sensing devices for reporting roadway conditions, enabling state departments of transportation (DOTs) to adopt cost-effective practices and improve overall network performance. While MPC-613 primarily addresses engineering aspects, it hints at potential future adoption of composite-based repair techniques. MPC-616 offers software tools and models for bridge management, aiming for adoption by CDOT and other agencies, and even considers commercialization. MPC-649 explores deep learning models for construction worker safety, potentially leading to new technologies and practices. MPC-675 seeks to revolutionize timber bridge rating methodologies, with expected adoption by state DOTs. MPC-676 provides models to optimize asset maintenance, reducing operational costs for state DOTs and exploring commercialization. Although MPC-677 identifies inefficiencies, it aims to prompt changes in operations and policies in paratransit services. MPC-678 addresses ADA compliance and sidewalk infrastructure data, aiming to help cities create data-driven ADA transition plans and enhance asset management practices. These projects collectively contribute to the advancement and adoption of new practices and technologies in their respective fields.

University of Denver
The research projects at the University of Denver will have the following expected impacts on adoption of new practices and new technologies: 1) The measurement of safety culture with a standard survey measurement instrument has been adopted by at least one other transportation agency as a tool for measuring its effectiveness. 2) The adoption of a new standardized approach to training and development of safety culture. 3) The increased marketability and availability of a new and more portable and accessible device for measuring fatigue and alertness in the workplace that produces accurate measurements and valid results comparable to those that have previously only been obtained with larger, non-mobile static devices. 4) The development of training materials that can be used with railroad personnel in dealing with trespassers and others who might be at risk for intentional death using a railroad, or suicide by rail. In addition, these materials could be used in marketing campaigns by Operation Life Saver to increase public awareness and understanding the risks of trespassing on or near railroads. A large transportation services company purchased the device during this reporting period. 5) Adoption of new practices, new training programs, preventative training, and other measures taken to ensure that psychological harm does not befall railroad or other transportation employees exposed to repeated encounters with railroad trespass fatalities and/or railroad suicide fatalities.

University of Utah
The asphalt pavement projects will result in a pavement design process that will be used by different highway agencies; such a process can potentially result in significant savings.

The geotechnical projects will assist DOT project personnel in implementing technologies that will reduce differential settlement at bridge approaches and improve material and construction specifications for approach embankments for bridges; this will improve the safety and transport of people and goods on roadways. In addition, better design and construction guidelines for both unreinforced and geogrid-supported pavement systems will result in wider use of this technology within roadway systems as designed by all pavement designers.

The structural projects will improve seismic resilience of new bridges by using fiberglass materials that do not corrode and have excellent structural performance during strong earthquakes. Another impact is that research will reduce expensive culvert inspections and reactive maintenance and instead focus on proactive maintenance using tools that optimize resource allocation and financial expenditures, resulting in a higher-quality culvert network and a safer transportation system.

The transportation projects will improve the safety benefits of connected automated vehicles under various driving conditions; UDOT and other public agencies will use the technology and algorithm to assess the benefits of winter roadway safety access; the proposed technology provides a non-invasive sensing technology for slippery roadway conditions assessment. UDOT is interested in further testing and applying mobile phone-based artificial intelligence development for maintenance asset management. In addition, a computer-vision-based system for the safety ranking of rural roadways has been developed; it has high accuracy in detecting safety parameters on the roadside; it is anticipated that safety planners will adopt the developed technology for the safety evaluation of any rural roadway. In another project, we implemented our methodological pipeline regarding electric vehicle demand estimation into the Salt Lake City metropolitan area to showcase its effectiveness; a series of validations were conducted to justify the robustness of simulation results.

The air transport projects will develop advanced air mobility in the state of Utah regarding drone centers and fleet size planning for drone delivery. This type of tool is critical for research in this area as it incorporates the latest software and infrastructure development techniques available.

The rail transport project will improve the effectiveness of rail and transit systems by enabling condition-based maintenance rather than a time-based or age-based approach; the knowledge, sensing technology, and data will be used to evaluate the feasibility of an autonomous monitoring system with the Utah Transit Authority. Utah Transit Authority would prefer a more detailed demonstration and order-of-magnitude cost analysis on implementation.

University of Wyoming
The newly developed device for passing zones has been implemented in Wyoming. Although it will not be commercialized, it can be utilized by other DOTs nationwide.

Utah State University
The projects at Utah State University will have the following impacts on the adoption of new practices and process commercialization: (1) the use of electrified infrastructure to change the way electricity is delivered into vehicles; (2) effective strategies for travel demand management surrounding episodic air pollution events; (3) adoption of proposed partial depth bridge deck replacements that will speed up and simplify bridge repairs.

Governments and organizations can utilize these behavior change strategies for dealing with the negative impacts of air pollution.

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

Colorado State University
(1) Several new models and techniques in terms of infrastructure monitoring and NDE techniques with cost effectiveness and bridge deterioration have been developed. These new models and techniques are not available in current bridge management practices. For example, the proposed UA V-based technique provides all three components of the

displacement and is more advanced compared with the existing UA V-based dynamic response measurement techniques, which only measure one or two components of displacement.
(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, a probabilistic Monte Carlo modeling of landslide initiation is developed to accurately reflect observed slope failures and highlight the importance of hillslope vegetation on slope stability. The flood hazard project implemented advanced hydrologic modeling methods to incorporate that effect. The resulting flows were then used in hydraulic models and scour calculations.
(3) For traffic safety studies, some new methodologies have been developed and some new knowledge and insights have been made. For example, a more realistic risk-based simulation methodology, which has not been conducted before, was proposed to assess traffic safety risks of vehicles under adverse driving conditions. The railway safety project identified the perceived effectiveness of various shapes, colors, and wordage of signs to convey safety information to pedestrians.

North Dakota State University
NDSU'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.

NDSU's safety and economic competitiveness work has 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.

Increased understanding of drone capabilities such as freight delivery, asset monitoring, and driverless vehicle function in rural and tribal environments is anticipated. The use of AI in data collection and processing is featured in several projects. The contribution will be primarily in efficiently gathering data, processing information streams, and producing AI-assisted decision support related to rural transportation environments and issues.

South Dakota State University
The 13 active projects at SDSU 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) better understanding of the critical shear stress and erosion rates in different clay soils and sand-clay mixtures; (3) production of new knowledge 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) expansion of knowledge on traffic safety screening methodologies; (7) expansion of knowledge on soil compaction testing methodologies; (8) production of new data on nutrient removal by water treatment residual coated woodchips; (9) characterization of electrospun PET microfiber (EPM) used in asphalt binder; (10) highlighting the impacts of climate change on the transportation infrastructure in this region with sulfate-rich expansive soil substrates; (11) 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; (12) generation of new experimental database on asphalt binders and mixes using asphalt recycling agents; and (13) production of new knowledge on the performance of a pilot scale filter in field treatment conditions.

University of Colorado Denver
The MPC research projects collectively make significant contributions to the body of scientific knowledge across various domains. MPC-585 introduces innovative data-driven route planning techniques with potential applications in transportation systems research. MPC-612 advances knowledge by creating a new dataset and model for low-cost sensor-based roadway condition assessment. MPC-613, while engineering-focused, incorporates scientific principles, enhancing the technical depth of the study. MPC-614 represents a pioneering effort in systematically documenting transportation issues faced by people with disabilities. MPC-616 introduces deep learning methodologies for bridge management, likely inspiring similar approaches in the field. MPC-647 emphasizes a systems-level approach to understanding left-turning vehicle-pedestrian crashes, contributing to a deeper comprehension of the issue. MPC-649 analyzes physiological factors affecting construction workers, expanding knowledge on worker health and safety. MPC-650 pioneers' physics-based deep learning for bridge management, potentially inspiring similar research endeavors. MPC-675 employs computational modeling to generate meaningful data for timber bridge engineering research. MPC-676 contributes by developing models

for cost-effective building and bridge maintenance interventions. MPC-677 deepens understanding of paratransit inefficiency and disability-related issues in transportation services. MPC-678 aims to fill gaps in sidewalk infrastructure data and ADA compliance knowledge, potentially enabling more expansive and higher-quality research in this field. Together, these projects enrich the scientific understanding of their respective areas and may inspire further exploration in related domains.

University of Denver
The projects at the University of Denver will have the following outcomes: 1) Increasing our understanding of safety culture's role in fatigue management, which can have a direct impact on reducing accidents, injuries, and associated expenditures. 2) Contributing a standardized model for training leaders intending to implement and develop a safety culture in transportation organizations, which will provide a basis for testing the most effective approaches for undertaking organizational change. 3) Contributing 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 to increase our understanding of how-to best train people to deal with trespassers and those at risk for suicide by railroad. 5) Increasing the understanding of secondary trauma or post-traumatic stress symptomatology and sequelae associated with the repeated exposure to railroad trespass fatalities or railroad trespasser suicides.

University of Utah
The asphalt pavement projects will allow transportation agencies to select asphalt mixtures for optimal performance and develop appropriate specifications, thus significantly reducing maintenance costs. Relations between different modes of testing, both theoretical and through experimentation, have been developed. The relationship between parameters obtained during the IDEAL CT tests can now be used to develop dynamic modulus master curves for asphalt mixtures. This advancement in the body of knowledge can be used to benefit the design and maintenance of the infrastructure.

The geotechnical projects will improve understanding of the significant influence of native subgrade materials, geogrid reinforcement, and fill materials on the performance of pavement systems constructed on soft subgrades, and result in roadway systems that will perform better and require less maintenance. Moreover, the fundamental material behavior of lightweight cellular concrete under static and cyclic loading at varying amounts of saturation will be determined; this will be used to better plan, design, and construct embankments in bridge approach areas.

The structural projects will improve seismic resilience of new bridges by increasing the body of knowledge regarding the seismic performance of concrete columns reinforced with glass fiber reinforced polymer spirals. A method for strengthening partial depth prestressed concrete panels for bridge decks has been developed; the numerical models for the original deck and the strengthened deck improved the body of knowledge in determining the performance of similar bridge decks. Research improved the body of knowledge by using a risk-based approach for maintaining culverts by analyzing deterioration curves and life-cycle analyses based on real data rather than expert opinion.

The transportation projects advance existing artificial intelligence algorithms to support automated infrastructure management, especially for pavement marking issue identification; the customized algorithm shows robustness in pavement marking assessment under different practical situations. In another project, new knowledge on connected infrastructure and vehicle and infrared thermography is expected to contribute to better winter roadway safety management practices. In addition, a computer-vision-based system for the safety ranking of rural roadways, which has high accuracy in detecting safety parameters on the roadside, has been developed; this is one of the first studies that attempted to evaluate the conditions of roadside safety using computer vision and two-dimensional images. Another project showed that decentralized design can effectively augment electric vehicle drivers' accessibility to the nearest charging stations; atypical activities could also impact public charging demand.

The air transport project allows UDOT to assess different assumptions of the model and run "what-if" scenarios by generating animation of the optimized airspace network; the platform provides the state with more clarity about the energy impacts of large-scale drone delivery as well as a viable airspace network. The tool can further inform the UDOT Division of Aeronautics to develop policies and negotiate with industry stakeholders.

The rail transport project will improve the effectiveness of rail and transit systems by enabling condition-based maintenance rather than a time-based or age-based approach; the project has produced a better understanding of wave propagation and nondestructive evaluation for rail track structures, which allowed us to perform a more frequent and more accurate inspection of rail track structures.

University of Wyoming
All the projects completed or in the process of getting completed have enhanced the body of knowledge. Several papers have been presented and published in journals as a result of the various research activities.

The University of Wyoming projects resulted in ready-to-implement products. Multiple papers have been published in reputable journals describing the developed technologies in order to assist other DOTs and researchers in implementing the recommendations of these studies. Examples are shown in previous responses.

Utah State University
The projects at Utah State University will have the following impacts on the body of scientific knowledge: (1) Many of the projects at USU have as their goal to determine ways to improve the transportation system and the environment. Much of the work is directed at improving our living environment. (2) The project 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 the ground motions and dynamic response that was recorded by the Magna earthquake, this will be a unique and invaluable resource for seismic site response and soil-structure interaction studies. (3) The knowledge gained about the performance of the polymer under high temperatures will add to the body of scientific knowledge and provide an infrastructure-based alternative solution to promote autonomous driving.

C. What is the impact on transportation workforce development?

Colorado State University
The projects at Colorado State University will have the following impacts in terms of transportation workforce development: (1) A number of postdoctoral fellows, graduate, and undergraduate students have received research training through these projects. (2) A new course, ENGR 480: Engineering with Drones, will be taught by one MPC PI of this study and Christopher Robertson in spring of 2024. The new drone course is one of very few in the state or region that will train engineers to use UAS for engineering and transportation projects.

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. The safety-related research will enable decision-makers and practitioners to make more informed decisions in times of crisis as well as with high-risk sites and driver groups such as highway-rail crossings and young drivers. Work with tribal communities remains a focus with NDSU as projects underway will contribute to longer-term goals for increasing roadway asset management capabilities and reducing serious crash incidence. Tribal transportation research gave valuable insight into the gaps between federal transportation program contract requirements and tribal transportation workforce capacity for financial management, reporting, and performance. This insight can be used to deliver a valuable user-informed workforce development program.

South Dakota State University
Seven Ph.D., 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.

University of Colorado Denver
The MPC projects mentioned above have played a crucial role in offering students hands-on experience and valuable training within the transportation field. These projects have effectively educated and prepared students in various domains, including system-optimal route planning, low-cost sensing devices, multi-hazard loadings, bridge management, and life-cycle-cost optimization. Students engaged in these initiatives have gained proficiency in cutting-edge data-driven techniques and have become well-versed in the critical challenges of transportation infrastructure management, which will undoubtedly benefit their future careers. Furthermore, the project outcomes have generated valuable educational materials that can be incorporated into relevant courses, facilitating the dissemination of knowledge and training to a broader audience.

University of Denver
The projects at the University of Denver will have the following outcomes: 1) Four graduate students received training and experience in the research process, including literature review, data collection, and analysis using Excel and 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.

University of Utah
The asphalt pavement projects will have the following impacts: Two graduate students were funded as part of this work and one of them has recently joined the transportation workforce.

The geotechnical projects will have the following impacts: This research is providing support for graduate student researchers who study geotechnologies applied to transportation systems; the methodologies and results of the research are being used in course materials. Moreover, the research has provided exposure to many aspects of the transportation field to five graduate students who have worked on the geotechnical projects. As this research gets disseminated through workshops and publications and incorporated into coursework, many practitioners and students will be exposed to the outcomes and the importance of transportation systems.

The structural projects will have the following impacts: This research has provided support to three graduate students, who plan to join the workforce at completion of their studies. Moreover, the outcomes of this research will be used in the future for courses on bridge design. In another project, graduate students focused on model development software packages, while undergraduate students focused on data labeling. Additionally, the distributed educational materials will be very helpful for both experienced and inexperienced engineers while conducting culvert or storm drain inspections.

The transportation projects will have the following impacts: Several graduate students were involved in model development software packages, and undergraduate students with data labeling; this increases their knowledge and the opportunity to find quality and well-paid jobs in the transportation industry. Moreover, the disseminated educational materials will be significantly useful for both skilled and novice engineers. In another project, two graduate students were involved in automated infrastructure management research; this project prepares graduate students with comprehensive and practical experiences in developing artificial intelligence algorithms from data collection/processing to algorithm training and validation. In another project, three graduate students received research training during the project and wrote computer scripts in Python; the project information was also used for teaching the Transportation Planning course. In another project, a graduate student received research training during the project and wrote computer scripts using MATLAB and Python and learned the theory and methods of computer vision.

The air transport projects will have the following impacts: One graduate student received research training during the project in scientific computing; the student has the opportunity to solve a transportation problem with the computational skillset.

The rail transport project will have the following impacts: Two graduate students have received research training during the project; they wrote computer scripts using MATLAB and learned the theory and methods of wave propagation.

University of Wyoming
The findings from the projects completed at University of Wyoming have been presented to transportation professionals to facilitate implementation. For example, the prototype 2 of the passing zone study was presented to many engineers from WYDOT's traffic branch. In addition, the findings of the GSRS study were presented during the reporting period to WYDOT (RAC).

Students at the University of Wyoming benefited greatly from the MPC research. Some of the students were hired to assist with the research program, which was greatly beneficial for them in getting hands-on experience. All students working on the research projects were able to secure jobs immediately after graduation. In addition, the findings of some of the research studies are being discussed in the classroom to help shape the knowledge of future transportation engineers.

Utah State University
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 numbers of people involved in these events is presented in the section on workforce development.

D. Address any significant impacts.

North Dakota State University
Incremental transformations with transportation data collection, processing, and decision-making will continue to create, access, and utilize the most efficient decision-support research and tools while appropriately recognizing cultural and environmental parameters to address inequality and road user vulnerability.

University of Denver
Over 537 individuals have read the technical report describing the validation of the Alert Meter. There are several citations of instrument documentation in the literature. Most recently, we have heard that a private transportation company has purchased the Alert Meter for use in its day-to-day operations.

6. Changes/Problems
None at the current time.

7. Special Reporting Requirements
A. T2 Performance Measures and Targets are listed in Appendix E.