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

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Mountain-Plains Consortium, North Dakota State University
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North Dakota State University
Upper Great Plains Transportation Institute
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Semi-Annual Progress Report #11

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

a. What are the major goals of the program?

The overall 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 (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

One hundred sixty-eight research projects have been selected and 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 will then 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.	11/30/2016	09/30/2022
	Mod 1, Grant No. 69A3551747108 (Year 2)	10/01/2017	09/30/2022
	Mod 2, Grant No. 69A3551747108 (Year 3)	10/01/2018	09/30/2022
	Mod 3, Grant No. 69A3551747108 (Year 4)	10/01/2019	09/30/2022
	Mod 4, Grant No. 69A3551747108 (Year 5)	10/01/2020	09/30/2022
	Mod 5, Grant No. 69A3551747108 (Year 6)	10/01/2021	09/30/2023
Site Visit	A site visit to all MPC universities is being conducted annually by the MPC Director.	11/30/2016	09/30/2023
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	09/30/2023

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 and are organized by major subject area. In some cases, courses with the same titles were offered at more than one MPC university. Altogether, **144 transportation and transportation-related courses** were offered this reporting period, for a **total of 1,270 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, **63 training sessions** were offered this reporting period for a **total of 681 offered under this grant period.** Due to the page limits of this documents, we have listed all workforce development activities in Appendix C. The listing in Appendix C of workforce development activities illustrates the diversity of our workforce offerings for transportation professionals. In addition, we've had **114 online training modules** and **103 recorded sessions** that **1,812 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, and 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 12-18 months with dissemination of results 18-24 months from the start of the research. We continue to monitor very closely the progress of the work plans as reported for each project in the Semi-Annual Progress Reports (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 the timing of match funding, and 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 **202 students from the U.S. and countries around the world. This includes 7 post-doc students, 94 doctoral students; 65 master's students; and 36 undergraduate students.**

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

Fifteen principal investigators, faculty, and administrators are participating in MPC projects at **Colorado State University**: Rebecca Atadero, 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, forty-one 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, and Abby Wright.

Fifteen principal investigators, faculty, and administrators are participating in MPC projects at **North Dakota State University** are: Ying Huang, Pan Lu, Raj Bridgelall, Kelly Bengtson, Dinesh Katti, Kalpana Katti, Denver Tolliver, Kimberly Vachal, Joy Annette, 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, twenty-five students are working on MPC project: Yaobang Gong, Bahar Azin, Zhao Zhang, Xinyi Yang, Ihsan Khan, Yun Zhou, Salman Ahmed, Keshab Thapa, H M Nasrullah Faisal, Yihao Ren, Sajad Ebrahimi, Asad Ali, Taraneh Azkarzadeh, Gul Badin, Awuku Bright, 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** are: Junwon Seo, Nadim Wehbe, Guanghui Hua, Kyungnan Min, Christopher Schmit, Mostafa Tazarv, Francis Ting, Michael Pawlovich, Aritra Banerjee, and Rouzbeh Ghabchi. In addition, twenty-four stuudents are working in 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, and Muhammad Jamil.

Twelve principal investigators, faculty, and administrators are participating in MPC projects at the **University of Colorado Denver** are: Wesley Marshall, Bruce Janson, Moatassem Abdallah, Caroline Clevenger, Jimmy Kim, Meng Li, Carolyn McAndrews, Kevin Rens, Aditi Misra, Mehmet Ozbeck, Manish Shirgaokar, and Farnoush Banaei-Kashani. In addition, twenty-four students are working on MPC research projects: Ibrahim Bumadian, Mohamed Mesbah, Shahryar Monghasemi, Mallory Redmon, Shalini Mahanthege, Ali Alatify, Ricardo Gonzalez, Alayna Truong, Brady Heath, Wajdi Ammar, Aliasghar Hasani, Robert Fitzgerald, Mahdi Ghafoori, Nick Coppola, Wei Li, Tobby Lei, Yongechen Ji, Khang Nguyen, Carrie Tremblatt, Dervis Cemal Akcicek, Chris Cameron, Molly Wagner, Ryan Cheng, and Jun Wang.

Three principal investigator, faculty, and administrator are participating in MPC projects at the **University of Denver**: Patrick Sherry, Ruth Chu-Lien Chao, and Andi Puavat. In addition, ten students are working on MPC research projects: Sree Sinha, Emma Porter, Kailey Painter, Catherin Bianci, Matthew Cole, Sandra Bertram Grant, Megan Solberg, Desiree Martin, and Jessica Mantia.

Twelve principal investigators, faculty, and administrators are participating in MPC projects at the **University of Utah** are: Xiaoyue Cathy Liu, Chris P. Pantelides, Steven Bartlett, Evert Lawton, Pedro Romero, Tiffany Hortin, Mark Bryant, Nikola Markovic, Abbas Rashidi, Jianli Chen, Xuan Zhu, and Xianfeng Terry Yang. In addition, thirty-eight students are working on MPC research projects: Abdulla Mamun, Seth Miller, Pouria Mohammadi, David Sacharny, Dan

Seely, Duc Tran, Quinzheng Wang, Yinhu Wang, Keping Zhang, Zhao Zhang, Vitoria Binifarias, Dylan Brown, Henrik Burns, Ryan Burton, Chandler Cross, Tatiana de Camargo, Emad Ghodrati, Carlos Hermoza, Yaqi Huang, Adam Jones, Saisravan Maringanti, Suman Neupane, Swastik Pohdrel, Dipendra Thapa, Remy Thigpen, Dylan Briggs, Boe Erickson, Kaden Harris, Syrus Safai, and Sara Stropkai.

Fourteen principal investigators, faculty, and administrators are participating in MPC projects at the **University of Wyoming** are: Jennifer Tanner, Khaled Ksaibati, Ahmed Abdelaty, Shaun Wulff, Chengyi Zhang, Anas Alrejjal, Mohamed Ahmed, Ahmed Farid, Suresh Muknahallipatna, Milan Zlatkovic, Marwan Hafez, Kam Ng, Mahdi Rezapour, and Muhammad Tahmidual Haq. In addition, twenty-one students are working on MPC research projects: Sherif Gaweesh, Esraa Alomari, Vincent Ampadu, Arash Khodbakhsi, Shamel Perez Buenfil, Peng Liu, Nafis Masud, Opeyemi Oluwatuyi, John Higgins, Md Shafiqual Islam, Zorica Cvijovic, Benjamin Fosu-Saah, Md Nasim Khan, Sahima Nazneen, Zephaniah Connell, Imran Reza, Md Shah Jamal, Harish Kalauni, Lokendra Khatri, James Mock, and Anas Alrejjal.

Nine principal investigators, faculty, and administrators are participating in MPC projects at **Utah State University** are: Ziqi Song, Patrick Singleton, Abilash Kaminemi, Nick Roberts, Andrew Sorensen, Michelle Mekker, Shuna Ni, Keuhyun Park, and Marvin Halling. In addition, nineteen 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, Wentao Han, and Pengfei Xin.

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

Colorado State University–Abdelrahman Abdallah, Bridge Engineer, EXP

North Dakota State University–Barb Smith, MHA Nation; Kateri Hale, MHA Nation; Trooper Anthony Hoaby, Motor Carrier Assistance Program, ND Highway Patrol; Doug Hoopman, Motor Carrier Services; Steve Monlux, LVR Consultants

University of Colorado Denver–Nick Ferenchak, University of New Mexico

University of Denver–Chris Harrington, Keolis, Commuter Services; Marty Jimenez, Metrolink SCRRA; Jeff Moller, VP Safety, Association of American Railroads

University of Utah–Ye Chen, Virginia Commonwealth University; Ilya O. Ryzhov, University of Maryland; Kevin VanFrank, CME Consultant

University of Wyoming–Jennifer Goodrich, Wyoming Department of Transportation; Amirarsalan Mehrara Molan, University of Mississippi; Sarah Zlatkovic, Claremont Graduate University

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

i. During this period MPC faculty and investigators have published **84 peer-reviewed articles or papers** in scientific, technical, or professional journals. Since the beginning of this grant, **we have published 442** different peer-reviewed articles or papers.

b. Conference Papers can be found in Appendix D

i. This reporting period **we have published 25 conference papers and 194 total since the grant began**.

c. Presentations can be found in Appendix D

i. MPC faculty and investigators **have presented at 38 different** scientific, technical, or professional conference this period. In total, we have **had 247 presentations on MPC research**, results, and outcomes.

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

i. The MPC website is fully operational at: https://www.mountain-plains.org/

ii. The MPC Key Personnel can be found at: https://www.mountain-plains.org/personnel/

iii. Other **outputs** that are University specific:

North Dakota State University – MPC-548 – Katti, during the current period, simulations of the solvated clay tactoid model were conducted to evaluate the tensile and shear deformations of the solvated clay tactoid model for various water content levels. These models are formed by mineral structures stacked vertically in 10 sheets or more to create the fundamental building block of clays, the clay tactoid. For the dry tactoid aggregate model, we have started the

minimization and heating simulation for three different aggregate models for different orientations. Our goal is to develop predictive models and evaluate the mechanisms of particle breakdown, which has been observed in our experimental work. This particle breakdown in the clays controls many engineering properties that will be of interest to the geotechnical and transportation communities.

University of Colorado Denver – The NREL HIVE software platform was extended to include a version of our proposed solution for constraint-based route planning. The HIVE platform will be open sourced (time TBD), and this will provide open access for the public to our solutions among other solutions offered by the HIVE platform.
We developed two software tools for bridge deterioration forecasting and bridge subtyping to be used by CDOT bridge engineers bridge engineers.

University of Denver – We have created and updated a website describing our tools for measuring and managing safety culture: https://www.du.edu/ncit/safety.html
We have created training materials and checklists and training videos. A training guide for presenters and a Suicide Risk Assessment Checklist have been posted on the website. The checklist can be used by frontline railroad employees to guide their assessment of the risks posed by a trespasser and also practical intervention steps to be followed when making an intervention. This checklist is also distributed to participants in training programs.
https://www.du.edu/ncit/prevention/prevent_checklist

University of Wyoming – A user-friendly GSRS software was established incorporating roadway geometry and horizontal curvature for both the Continuous Slope and Separate Downgrade method. Also, the user manual to enable regular users with minimal computer skills to manipulate the software was developed. Two research papers based on this software were prepared and published in two journals. Experiments to validate the GSRS model for trucks equipped with only drum brakes were documented and the output was used to publish a research paper in order to disseminate the results to a wider audience of transportation professionals and researchers.

Utah State University – This dataset includes the results of a survey about bicyclists' preferences and perceptions about roundabouts. Conducted in fall 2020, around 600 US adults who bicycle at least occasionally completed a survey about their transportation and bicycling behaviors, preferences for bicycling at roundabouts with different designs, perceptions of comfort and safety at roundabouts, and personal characteristics. Survey data were used to identify roundabout designs that bicyclists prefer and feel more comfortable using when bicycling at roundabouts. The data are publicly accessible via Zenodo (https://doi.org/10.5281/zenodo.5107737).
We tested a vehicle fire on a polymer concrete bridge overlay, resulting in vehicle fire test data (temperature and heat flux) and pre-fire and post-fire performance data of polymer concrete (e.g., delamination, abrasion resistance, chloride resistance, and water penetration). Those data will be published in the project report, journal, and conference papers and will be shared in a public data repository at DigitalCommons@USU.

4. Outcomes:

i. **Significant** outcomes by selected members of the consortium universities during this rating period are as follows:

University of Colorado Denver

This period included a significant number of papers and presentations at a wide variety of outlets.

Utah State University

As campus director at USU, I would note the work done this past period of Professor Andrew Sorensen and his PhD student Israi Abu Shanab. The reference is given below and is important as it bridges some usual bridge repair techniques and air emissions.

In Press: Abu Shanab, Israi, and Andrew D. Sorensen. "Air Emission Pollutants of Different Partial Depth Concrete Bridge Deck Repair Techniques: A Comparative Study." Journal of Structural Integrity and Maintenance, June 2022.

ii. **Summary of outcomes** resulting from each university's MPC projects during this reporting period. These will also include anticipated or expected outcomes for each university.

Colorado State University

The projects at Colorado State Universities will have the following outcomes:
(1) Enhanced understanding and techniques of inspection and monitoring of transportation infrastructures. Although existing NDE can provide an enhanced understanding of bridge conditions, it can still be difficult to justify the additional costs associated with the technology and to consider the impact of infrastructure deterioration. By using lifecycle analysis, studies will demonstrate NDE is a cost-effective choice. New techniques are developed to effectively capture the deterioration nature over time. An example is non-homogenous Markov deterioration models that can better predict bridge conditions and capture the impact of various important factors (explanatory variables). In addition, new imaging methods

can help in rapid assessment of damage and deterioration of existing structures. We also have developed the capability to move from image to a full structural analysis based on the current state of the structure.
(2) Increased understanding of transportation system performance against various natural hazards and incidents, such as earthquakes, landslides, floods, and crashes. Toward this goal, various new analytical, simulation and experimental methods are developed. For example, studies improve understanding of where landslides are more likely to occur, both under current and potential future climate scenarios. Importantly, the potential impact of geographic shifts in vegetation covers due to climate change on the relative stability of hillslopes. Various disruption scenarios under different hazards and incidents will help further simulate the impact on transportation systems. For flood hazards, studies have increased our understanding of the extent of nonlinearity in the response of Colorado Front Range River basins and the contribution of this nonlinearity in scour estimations.
(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. A new solution of improving network mobility and resilience through advanced signal control techniques was proposed. In addition, an improved understanding of effective and non-effective mitigation methods of railroad right-of-way crossings from the perspective of real users was achieved. The crash modeling of high-profile moving vehicles under strong crosswinds based on computational fluid dynamics 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. Furthermore, some suggestions on safety and preventive measures may lower the associated safety risks.

North Dakota State University
The projects at North Dakota State University will lead to safety measures dedicated to AVs in mixed-driver environments; molecular interactions-microstructure-property relationships detail for swelling clays that would lead to robust analysis; cost effective, sensor-based improvements to railroad track inspection efficiency and safety countermeasure selection; sensor-based WIM pavement design complemented with AASHTOWare ME design; subpopulation-based and individualized intervention in impaired driving and novice teen driver crash risk; and a best practices approach for tribal communities and small local road departments to encourage safety integration into ongoing planning and investment decision processes.
Additional outcomes include gained information that gives personnel a greater understanding and knowledge on what is needed to pass CDL testing to contribute to the pool of CDL holders on our tribal nations; greater workforce understanding and knowledge on what is needed to pass CDL testing to contribute to the pool of CDL holders among tribal nations; DOT adoption of AI-based methodology for traffic state estimates based on proposed AI-based methodology in vehicle trajectory reconstruction; 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. We showed that an increase the body of knowledge and technical understanding of emerging drone technologies 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. Finally, we enhanced freight planning ability with development of a GIS road and railroad network of the multistate corridor that can be used in scenario and planning research applications.

South Dakota State University
The 14 active projects at SDSU will have the following outcomes: improved understanding of the benefits of using cellulose nano-fibers in asphalt mixes; increased knowledge of structural performance of cross laminated timber (CLT) girders and CLT bridge system; better understanding of the structure of turbulent flow and induced bed shear stress around eroding soils; improved understanding of the effectiveness of steel byproducts for bacteria removal from stormwater runoff; better understanding of the effects of deicing agents on durability of the asphalt mixes; adoption of sealants that delay deterioration of bridge decks; development of an appropriate methodology for traffic safety network screening; updated testing methodologies for in-situ acceptance of the compacted granular bases; 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; better understanding of the potential effects of climate change on pavement infrastructure; improved understanding of the velocity distribution and bed shear stress in free-surface flows at a sudden change in bed roughness; improved understanding of over-embrittlement of asphalt mixes as a result of using reclaimed asphalt pavement by application of new rejuvenators; and improved understanding of the treatment efficiencies of stormwater filters using steel byproducts under field conditions.

University of Colorado Denver
These projects all progressed very well over the last project period; in total there were 10 journal papers, 14 conference papers, and 13 conference presentations. This work is also significantly impacting the students working on these projects in terms of providing an opportunity for research and the various research-related skill development.

University of Denver
The research projects at the University of Denver will have the following expected outcomes: (1) The validation of a smartphone AlertMeter 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 will hopefully lead to a reduction in drowsy driving and fatigue and an increase in alertness and vigilance. Ultimately, utilization of the device could lead to a reduction in accidents and injuries in the transportation system; (2) The identification of linkages between safety culture, leadership, and fatigue in transportation operations and how best practices are effective in reducing accidents 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 leaders of transportation organizations in demonstrating the behaviors and best practices that will lead to developing an effective safety culture characterized by reduced numbers of accidents and injuries. Previous research has not specified to either safety organizations or transportation. Consequently, there is still a need to develop a standard model or approach to developing a safety culture within the transportation industry; (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. There will also be increased 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, along with identification of behavioral and psychological risk factors associated with being involved in trespasser fatalities and railroad suicides.

University of Utah
In the area of asphalt pavements we will have the following outcomes: (1) an increased understanding of the effect of recycled materials in the performance of asphalt mixtures and the ability to predict their expected performance allowing for optimization of resources; (2) an evaluation of the variability in the IDEAL CT tests, which will result in quantification of what can be expected from the IDEAL CT test so it can adopted as a specification; (3) an increased understanding of the implications of adopting the flexibility index test as part of quality control and quality acceptance specifications; (4) an understanding of how pavement materials change once placed in the field after a few years of service, thus providing significant insight into the aging process; (5) demonstrate the feasibility of using single point tests to predict the dynamic modulus of the material that is needed for the mechanistic-empirical pavement design process.

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.

In the structures area we will have the following outcomes: (1) adopt a new method of constructing self-centering bridges in seismic regions using buckling restrained braces, which are replaceable after an earthquake; (2) use light, durable and corrosion-free fiberglass materials in the construction of bridge columns of bridges built in seismic regions that will last for at least the design life of the bridge; (3) increase the body of knowledge for modeling bridge columns with intentional debonding for improved seismic performance of bridges so this technique can be adopted into design practice for cast-in-place construction and accelerated bridge construction in seismic regions; (4) enable DOTs to develop a design method for the retrofit of bridge decks with delamination issues and thus prolong the life of bridge decks constructed with partial depth deck panels; (5) improve knowledge of a comprehensive management system for culverts and storm drains in Utah; machine learning algorithms, including support vector regression (SVR) and random forest regression (RFR), as well as the risk-based prioritizing approach, were used in the proposed method for determining culvert deterioration curves and inspection frequency.

In the transportation area we will have the following outcomes: (1) increased understanding of traffic safety performance under different connected vehicle penetration rates and increased knowledge of CV impact to traffic safety under various

geometric road conditions; (2) increased body of knowledge for the feasibility of photogrammetry as an alternative approach to laser scanning in collecting roadway assets information that will eventually provide transportation agencies with a cost-effective tool to reconstruct virtual 3D models of the transportation assets distributed across roadways; (3) increased body of knowledge on the impact of regulatory hybrid changeable message signs on traffic safety under different freeway geometric designs, which have decreased crash severity mostly during inclement weather when using the amber legend for signs; (4) increased efficiency of snowplow routes that UDOT has implemented in practice; (5) improved understanding regarding that the bottleneck method can reduce freeway mainline time by using sensitivity analysis to examine different levels of improvement for freeway mainstream operation; (6) enabled 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; this enables traffic engineers to address the most common safety concerns around state roadways; (7) introduce a prototype algorithm based on mobile-phone-based artificial intelligence to identify guardrails and barriers for road asset management.

In the air transport area we will have the following outcomes: (1) introduce a statewide airspace network, delivery schedule, and truck/drone fleet mix, which provides the state of Utah with more clarity about the energy impacts of large-scale drone delivery, as well as a viable airspace network; (2) provide identification of the airport-level aircraft operations and fleet mix information that can be used as a tool to identify each individual aircraft operating at non-towered general aviation airports to improve safety and security; this is done by developing computer vision algorithms and implementing an intelligent camera system at five non-towered general aviation airports.

In the rail transport area, we will have the following outcomes: (1) improved understanding of factors that lead to how non-propagating modes in rails can be promoted using the electromechanical impedance method; this will enable introduction of non-propagating modes in rails for non-destructive evaluation purposes.

University of Wyoming
The following items were accomplished in this reporting period: (1) The body of knowledge was supplemented with multiple papers generated from multiple studies. (2) A new device was developed for identifying passing/no passing zones on two-lane highways. The second generation of that device is being developed. (3) A new study was initiated to reduce snowplow-related crashes. It is anticipated that the developed warning system will reduce frequency and severity of crashes.

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 of bicycles at 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 electrified transportation in the United States.
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 on the effectiveness of the transportation system?

Colorado State University

The projects at Colorado State Universities will have the following impacts:

(1) The series of studies on infrastructure monitoring, damage detection, and deterioration modeling will have significant impacts. Firstly, increasing the use of NDE in appropriate situations helps support a state of good repair as bridge managers have better data to use for decision making. Secondly, the proposed automating assessment tools can allow the data being possibly collected without an actual site visit, and a rapid determination can be obtained as to the current strength, stiffness, and usage for damaged transportation systems. Thirdly, a portable sensing technique for measuring displacement will be developed, which does not require the instrumentation of the structure or interruption of traffic. As a result, it is 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) The series of studies on transportation system safety and resilience under various hazards and incidents will have following impacts. Firstly, 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. The developed model calculates relative stability across the landscape, identifying potential hot spots for landslide hazards in the road network. Secondly, the new disruption modeling techniques under hazards were developed; these can provide more accurate prediction of possible damages and disruptions to transportation infrastructures during hazards and can potentially save many lives that otherwise might be lost because of hazards and incidents such as tree failure and crashes. Thirdly, by developing a better understanding of the scour of bridge piers and abutments by river flows, studies can help improve scour calculations and thus can potentially reduce the number of bridge failures due to scour of piers and/or abutments. Fewer bridge failures and more cost-effective designs would lead to a more robust and effective transportation system. Lastly, by studying impacts on transportation infrastructures from various hazards, the Material Point Method (MPM) is adopted for application in transportation research because of its unique strength; however, it was not nearly as widely used as the finite element method (FEM). Therefore, by promoting this technique and training students in its development and application, we are increasing the visibility and usefulness of this methodology in the transportation community.

(3) The studies on traffic safety under adverse driving environments and railways will have the following impacts. Firstly, the findings of traffic safety risk assessment of vehicles under adverse driving environments and under work zone conditions can help develop risk-informed traffic operations and management strategies, such as advisory driving speeds and critical weather conditions to close traffic on roads and bridges out of safety concerns. Traditionally, traffic management under adverse weather was mainly conducted under generic criteria or experience. Secondly, the proposed new network modeling methods will combine flow-based traffic performance simulation and graph-based network modeling techniques to offer more comprehensive and accurate coverage of traffic network performance under hazards and incidents. With the improved understanding of network performance evolvement over incidents, more effective intervention techniques can be developed to have more efficient and safer traffic. Thirdly, to reduce railway trespassing crashes, a list of mitigation methods is compiled with documented evidence for their effectiveness. The study will then generate a measure for how people interpret and how they would intend to respond to these mitigation methods. Lastly, this study will identify gaps in people's knowledge about safe and permissible behaviors near railroad rights-of-way. As such, it is expected that these results will help inform jurisdictions of effective methods to implement near railroad rights-of-way to discourage unsafe crossings and ultimately improve safety.

North Dakota State University

The projects at North Dakota State University will have the following roadway related 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 assisted pavement design planning for traffic impacts on pavement condition and greater awareness of WIM data quality issues; (3) Future transportation professionals trained on machine learning algorithms and at-grade crossing safety performance evaluation 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 such as convolution neural network, linear discriminant analysis, K-nearest neighbors, classification and regression trees, and naïve Bayes classifier and their performance

comparations, especially considering an extremely imbalanced dataset; (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 teen drivers in parental engagement in driver safety during novice driving experiences. The tribal liaison completed the Alive @ 25 instructor coursework for certification and now must complete classroom work. The Alive @ 25 program will provide tribal teens with insight to greater responsibility while driving by focusing on their behavior, judgment and decision-making while driving and by providing tools for making positive choices. The tribal liaison continues to participate in tribal conferences and TRB committees. Engaging in other associations and activities provides an opportunity to increase tribal awareness to transportation issues. She has also provided trainings to indigenous workers, which helps to promote safety in transportation. The tribal liaison leads the Tribal Sign Warrior program, which encourages our youth to be aware of safety and the importance that road signs provide to themselves, their families, and communities. The 2021 calendar will be highlighted by tribalsafety.org as an innovative engagement program for tribal traffic safety. In a related local rural crash risk area, a best practice core was identified for local road stakeholders, including an identification method, timing, and funding sources. Rural road local crash GIS layer validation for the NDDOT ESRI layer is used in the USDOT for all public roads reporting HPMS annual road segment file submissions. A documentation process was developed to update and validate local rural road systems and segments, including ownership and surface type, based on information from GRIT (local road managers), NDDOT, and other data repositories. Also, impacts of railroad research resulted in increased knowledge and technical understanding to improve application and cost effectiveness in implementing smartphone-based sensors to monitor rail track surface conditions.
NDSU projects also focused on enabling rail rolling stock within the Internet-of-things (IOT) as relevant in connected vehicle technology and big data processing. The collaborative COVID-19 traffic investigation proposed a new streaming learning model to significantly improve physics regularized Gaussian process training time, thus reducing the computational complexity while maintaining reliable and accurate prediction performance.

South Dakota State University
The 14 active projects at SDSU will have the following anticipated impacts: promote sustainable bio-materials and agricultural byproducts for the production of bio-asphalt binders; promote sustainability in bridges using timber products; improve laboratory techniques for measuring the critical shear stress in cohesive soils to better predict bridge scour; develop a new filtration technology for stormwater runoff using steel byproducts; improve the selection process of deicing agents; recommend guidelines on bridge deck sealant applications; develop a network screening method for improved safety remediation measures; reduce the possibility of insufficient field soil compaction; develop a new stormwater filtration technology using drinking water treatment residual coated woodchips; develop a novel technique for recycling waste PET in asphalt mixes, which addresses an important environmental challenge; minimize repair and rehabilitation of pavement with expansive and unsaturated soil substrates, including climate change effects; enhance prediction of sediment erosion and scour; promote sustainability of pavement using reclaimed asphalt pavement; and improve the management and quality of stormwater.

University of Colorado Denver
Our FAST ACT MPC projects are helping lay the foundation for improving the built environment and extending the longevity of the existing infrastructure. We also seek to help make our roads safer and more efficient, and thus far, the results are helping do so. For instance, the results of MPC-585 is currently being integrated into NREL's Hive transportation network technique, which will help increase the efficiency of fleet route planning and considerably reduce the carbon footprint of such services. This is also expected to significantly reduce travel time for customers and drivers of the ride sourcing, ridesharing, and fleet services, which will enhance efficiency and cost effectiveness.

University of Denver
The research projects at the University of Denver will have the following expected outcomes: (1) The validation of a smartphone AlertMeter 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 will hopefully lead to a reduction in drowsy driving and fatigue and an increase in alertness and vigilance. Ultimately, utilization of the device could lead to a reduction in accidents and injuries in the transportation system; (2) The identification of linkages between safety culture, leadership, and fatigue in transportation operations and how best practices are effective in reducing accidents 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 leaders of transportation organizations in demonstrating the behaviors and best practices that will lead to developing an effective safety culture

characterized by reduced numbers of accidents and injuries. Previous research has not specified to either safety organizations or transportation. Consequently, there is still a need to develop a standard model or approach to developing a safety culture within the transportation industry; (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. There will also be increased 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, along with identification of behavioral and psychological risk factors associated with being involved in trespasser fatalities and railroad suicides.

University of Utah

The asphalt pavement projects will have the following impacts: (1) allow transportation agencies to select asphalt mixtures for optimal performance, thus significantly reducing maintenance costs; (2) highway agencies will be able to develop thresholds or specifications that take into account the idiosyncrasies of the IDEAL-CT test, thus get better predictions for pavement cracking to achieve a balanced asphalt mix design; (3) ability to use the flexibility index test in the selection of paving materials, thus allowing the optimization of materials with potential for cost savings; (4) develop an understanding of how field conditions affect asphalt mixture material properties and thus its performance in the field; (5) improve ability to relate quality control tests used during material production to pavement structural design requirements. The geotechnical projects will have the following impacts: (1) lightweight cellular concrete technology (LWCC) will be ready for implementation by the Utah DOT; the first phase of this implementation will be a "demonstration" project where LWCC will be installed and monitored; (2) the 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) a 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) a significant reduction of settlement/heave of approach embankments for bridges should mitigate problems with bumps at the ends of newly constructed bridges. The structural projects will have the following impacts: (1) using buckling restrained braces with post-tensioning in the bridge columns of a new bridge enables its use immediately after a large earthquake, thus greatly improving seismic resilience; the only structural elements that need to be replaced are the buckling restrained braces; (2) bridge designers can use fiberglass materials to design and built columns that are corrosion-resistant and have excellent structural performance during strong earthquakes; (3) development of an analysis and design method using intentional debonding for constructing bridges using accelerated construction methods in seismic regions will have excellent seismic performance in a large earthquake; (4) the cost-effective retrofit methods developed for partial-depth panel bridge decks with delamination problems will reduce the need for bridge deck replacement; (5) reduce Utah DOT funds for culvert inspections and reactive maintenance and instead focus more on proactive maintenance, resulting in a higher-quality culvert network and a safer transportation system. The transportation projects will have the following impacts: (1) improve the safety benefits of connected automated vehicles (CAV) under various driving conditions; (2) help transportation agencies choose the right tool when adopting laser scanning or photogrammetry technologies for collecting roadway asset information; (3) decreased crash severity with hybrid changeable message signs during inclement weather, such as icy roads, using the amber legend for signs; (4) increased efficiency of Utah DOT's snow removal operations; the new routes are 5% more efficient in terms of vehicle-miles, 15% more efficient in terms of turnaround times, and 13% more efficient in terms of deadhead miles; (5) identify current freeway bottlenecks in Utah and select the site that may benefit from coordinated ramp metering techniques; conduct experimental investigations to answer the question: "To achieve a certain freeway congestion level, how many additional delays will be created to those ramps?" (6) a computer-vision-based system for the safety ranking of rural roadways has been developed which has high accuracy in detecting the safety parameters on the roadside and improves safety planning by providing a cost-effective and simultaneously accurate safety ranking system; (7) demo videos are developed to assist UDOT in managing road assets, including striping, traffic signing, and identification of litters, in a timely and efficient manner; this helps improve road asset conditions and the effectiveness of the transportation system. The air transport projects will have the following impacts: (1) a drone air delivery network has been created by lifting the virtual highway network into the sky; the tool can further inform the UDOT Division of Aeronautics to develop policies and negotiate with industry stakeholders; (2) extend and improve the knowledge of aviation planners by providing a cost-effective and accurate data collection tool by developing computer vision algorithms and implementing an intelligent camera system; this greatly impacts the public and private sectors. 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.

University of Wyoming
MPC-540 resulted in a new software, which will enable engineers select appropriate speed limits on downgrade sections that include horizontal/vertical curves. This software will be made available for WYDOT as well as other DOTs in the near future.
MPC-686 will develop a collision warning and collision avoidance system for WYDOT snowplows. The system will result in reducing snowplow-related crashes, which have been on the increase in recent years. The actual testing of the system will take place during the winter of 2022/2023.
MPC-631 will enhance crash data reporting to highway safety partners in Wyoming by utilizing big data analysis and survey techniques. The main outcome of this study was to understand the data needs of WYDOT's safety partners and agencies, identify gaps in crash reporting, and recommend appropriate guidelines to present traffic safety data.

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 through investigating and altering traveler behavior. Several of these projects will 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 much more effective.

b. What is the impact or expected impact on the adoption of new practices, or instances where your university's MPC research outcomes have led to the initiation of a start-up company?

Colorado State University
(1) The studies on infrastructure inspection, monitoring, and deterioration modeling are expected to have significant impacts on new practices and technology transfer. Firstly, the studies may help support the more frequent and systematic use of the data collected from NDE inspections. When there is a clear use for these data, NDE will be more commonly used. Secondly, the studies with new NDE techniques will provide new methods to replace highly expensive physical inspections with an evaluation that is almost fully automated, and to track these as a function of time even if there is no finite trauma event on the system so that maintenance schedules and repair can be directed where they are needed most. Thirdly, the UAV-based technology can provide three-component displacement measurement, which can potentially be used to facilitate modal/load testing in practice. Lastly, adoption of the developed deterioration models can lead to more accurate prediction of bridge condition deterioration, which can help improve the safety of bridges and also guide more cost-effective maintenance and inspection decision making.
(2) The studies on safety and resilience of transportation systems under various hazards will have following impacts: Firstly, the probabilistic modeling and connection between landslide hazards and landscape characteristics, such as aspect, slope, and vegetation cover, may provide insight to public agencies that will help to identify areas of higher risk of slope failure. Secondly, there is currently no appropriate model which can predict complex disruptions caused by hazards such as tree failures or crashes 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 hazardous weather. Thirdly, for the flood hazard study, the results are expected to be used as a reference case study for those performing bridge scour analysis. By demonstrating how Colorado Dam Safety's new hydrologic modeling guidelines can be used for bridge scour applications, the study is expected to facilitate the use of those procedures for scour analysis by practicing engineers. Lastly, by developing the Material Point Method (MPM) numerical tool, it is expected that more entities and individuals will become familiar with MPM, and possibly use this technology over the long term to study impacts on infrastructures from hazards.
(3) The studies on traffic safety under adverse environments and railways will have the following impacts. Firstly, the existing DOT traffic operation does not have a consistent and science-based approach to quantify crash risks. The proposed technology of reliability-based traffic safety assessment tools under adverse driving conditions may have some potential to be adopted in future DOT practices. Secondly, 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. Thirdly, for railway trespassing events, the knowledge gathered regarding effective and non-effective mitigation methods of such events with a focus on signage will lead to jurisdictions implementing improved methods to reduce unsafe railroad right-of-way crossings, particularly from pedestrians. Lastly, for the high-profile vehicle crash study, the prediction of wind fields in itself is quite complex due to the turbulent nature of wind. Combining that complex wind field with a high-profile body leads to a rich flow that is challenging to predict. This project is

expected to lead to some new research projects that will lead to substantial findings, which will lead to adoption of best practices such as travel advisories under extreme wind conditions. We also can foresee how real-time monitoring technology could emerge from such efforts in conjunction with industry collaboration.

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 affect the engineering properties of clays significantly, this work provides a new characterization technique that can be used in geotechnical engineering practice. Sensor and drone related investigations are also underway with a state of good repair focus. We produced a new optical sensor interrogator, which 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 for industries to adopt drone-based inspection technologies based on the research findings. Network management during crises supports TIM agencies' adoption of our prediction model developed in a collaboration between NDSU and stakeholders, considering the pandemic's impact and changes in traffic patterns, and to make a detour/divert operation decision when a traffic incident occurs while considering those changed traffic patterns. Related specifically 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. The impact is on new drivers with their CDLs and how more CDL holders can help roadways and other areas of need in Indian Country. Recent activities include building knowledge for tribal governments, BIA, and NDDOT to better understand the gaps in transportation to help tribes gain greater food access that will, in many cases, have a CMV aspect. Work with crash factors and locations will enable decision-makers to make better informed resource and policy decisions related to highway-rail grade crossings, rail monitoring, teen drivers, and impaired driving prevention.

South Dakota State University

The 14 active projects at SDSU will have the following expected impacts: promoting the use of sustainable bio-materials and agricultural byproducts for production of bio-asphalt binders; developing new sustainable alternatives to structurally deficient bridges on local roads; predicting soil critical shear stress and erosion rates in cohesive soils; reducing the bacteria contamination caused by stormwater runoff; implementing pavement condition-specific deicing materials; reducing rapid deterioration of bridge deck sealants; codifying a methodology for traffic safety network screening; developing a quick and efficient practice for evaluation of the field compaction quality; developing a new filtration technology for stormwater treatment; developing a post-processing method for waste plastic to be used as asphalt materials; creating effective and resilient design of embankments and pavements on sulfate-rich expansive soil, improving the estimation accuracy of bed shear stress, thus improving estimation of soil erosion rates, developing new recycling practices using sustainable recycling agents, and application of E. coli removal using steel byproduct filtration for stormwater treatment.

University of Colorado Denver

MPC-616 is starting to be adopted and used by the Colorado Department of Transportation for daily operation in bridge monitoring. MPC-612 is also close to the point where state DOTs can adopt it as a new practice in reporting roadway conditions at low cost. The new data will also support state DOTs in allocating budgets to improve roadway performance and increase the overall performance of the transportation network. Commutrics (www.commutrics.com) is a start-up company that evolved out of MPC-553 and MPC-584 with PI Moatassem Abdallah serving as CEO, CO-PI Caroline Clevenger serving as head of strategy and operation, and PhD student Shahryar Monghasemi working on engineering and development.

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 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

of the risks of trespassing on or near railroads. Finally, there may be a reduction in trespass fatalities associated with intentional self-harm. In addition, it is anticipated that there will be 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 have the following impacts regarding adoption of new practices: (1) it will allow transportation agencies to incorporate performance related tests into their materials specification, thus ensuring longer lasting roads; (2) the IDEAL-CT test for pavement cracking will be included by the Utah DOT in their specifications; this will greatly improve the durability of pavements and reduce the need for maintenance, resulting in significant savings; (3) the adoption of new performance related tests into DOT material specifications will eliminate or reduce the placement of poor performing materials; (4) field testing of asphalt mixture cores will change the manner in which material specifications are set based on the known changes that occur in the field; (5) simplify the structural design of pavements by relating the required inputs to single point tests. The geotechnical projects will have the following impacts regarding adoption of new practices: (1) assist Utah DOT project personnel in implementing technologies that will reduce differential settlement at bridge approaches, which will improve the safety and transport of people and goods on roadways; (2) wider use of geogrid-supported pavement systems within roadway systems as designed by all pavement designers; (3) material and construction specifications for approach embankments for bridges will be revised by Utah DOT and other public agencies; (4) better methods of design and analysis of both unreinforced and geogrid-reinforced pavement systems within the State of Utah and surrounding states. The structural projects will have the following impacts regarding adoption of new practices: (1) enable DOTs in seismic regions to adopt hybrid bridge piers with buckling restrained braces and post-tensioned precast concrete columns, thus creating seismically resilient bridges; (2) DOTs will adopt new fiberglass materials to prolong the life of bridges in terms of resistance to corrosion without compromising their seismic performance; (3) enable bridge designers to adopt accelerated bridge construction with intentional debonding of rebar in seismic regions; (4) allow DOTs to adopt retrofit methods for partial depth precast concrete panels and prolong the life of bridge decks; (5) enable Utah DOT to save resources and money during inspection and maintenance programs by adopting machine learning algorithms to facilitate the process of automatically predicting and identifying culverts in bad condition. The transportation projects will have the following impacts regarding adoption of new practices: (1) analyze the potential safety benefits of operating connected and automated vehicles (CAV) under different road geometric conditions so as to help identify the locations where CAV roadside equipment should be installed; (2) by using photogrammetry technology, inspectors can have access to 3D models of pedestrian access ramps to conduct necessary measurements without actual presence of the surveyor in the field; (3) assist Utah DOT in evaluating the benefits of using the amber legend for changeable message signs from both operational and safety perspectives; (4) provided Utah DOT with a routing tool using data analytics that will allow them to update their snowplowing routes; (5) provided guidance to Utah DOT on the deployment plan development for coordinated ramp metering (RM) systems in Utah, which will integrate several upstream RM to alleviate one or several downstream bottlenecks; (6) a GIS shapefile was developed that enables Utah DOT traffic engineers to quickly monitor the safety conditions of rural roadways; (7) developed and tested an artificial intelligence algorithm on state highways and demonstrated its use to support timely transportation asset management; the prototype algorithm was also developed to identify guardrails. The air transport projects will have the following impacts regarding adoption of new practices: (1) the developed tool on drone centers and fleet size planning for drone delivery in Utah is critical for air mobility simulation and modeling; the viability of considering large-scale environmental impacts of advanced air mobility on specific communities by using micro-simulation technology was demonstrated; (2) aviation planners will adopt the automated image-based aircraft tracking and record-keeping technology, especially to prepare master plans for airports with increased traffic; this information helps managers to better prepare their airports in terms of services such as fuel, aircraft maintenance, required hangars, and aviation operators. The rail transport project will have the following impacts regarding the adoption of new practices: (1) ultrasonic non-propagating modes will assist in inspection and nondestructive evaluation, which has the potential for expanding to rail and transit networks.

University of Wyoming

The software developed for identifying speed limits on downgrades (MPC-540) will be made available free to all interested users in the transportation community. That software will enable agencies to identify appropriate speed limits based on grades as well as both vertical and horizontal alignments.

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 that will change the way electricity is delivered into vehicles; (2) effective strategies for travel demand management surrounding episodic air pollution events. 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) A series of new models and techniques in terms of new infrastructure monitoring 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 proposed UAV-based technique provides all three components of the displacement and is more advanced compared with the existing UAV-based dynamic response measurement techniques, which only measure one or two components of displacement.
(2) Improved knowledge and several advanced modeling techniques are 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 and/or work zone conditions. The railway safety study will identify human perceptions of safe railroad right-of-way crossings and interpretation of current signage. These results will also provide insight on how these perceptions and behaviors differ across various demographics. For high-profile vehicle safety under crosswinds, the study offers some insights that will help toward improved safety assessment and development of guidelines for management of traffic movement under adverse and extreme meteorological conditions.

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.

South Dakota State University
The 14 active projects at SDSU will have the following expected impacts: added knowledge in the field of biomaterials and the use of environmentally friendly and renewable fuel resources; generation of new test data on timber bridges; better understanding of the critical shear stress and erosion rates in different clay soils and sand-clay mixtures; production of new knowledge on bacteria adsorption by steel byproducts and the long-term bacteria removal from stormwater; addition of new knowledge on the effects of chemicals used in deicing agents on asphalt; added knowledge on the effectiveness of various concrete bridge deck sealants for preventing water and chloride infiltration; expanding the knowledge on traffic safety screening methodologies; expanding the knowledge on soil compaction testing methodologies; producing new data on nutrient removal by water treatment residual coated woodchips; characterization of electrospun PET microfiber (EPM) used in asphalt binder; highlighting the impacts of climate change on the transportation infrastructure in this region with sulfate-rich expansive soil substrates; 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; generation of a new experimental database on asphalt binders and mixes using asphalt recycling agents; and producing new knowledge on the performance of a pilot scale filter in field treatment conditions.

University of Colorado Denver
Given our extensive publishing and presentation efforts, our 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. As we continue with these projects, we expect that these results will have broader, multi-disciplinary impacts within the business community, the bridge construction industry, and with Vision Zero cities.

University of Denver
The research projects at the University of Denver will have the following expected impacts on the body of scientific knowledge by: (1) Increasing our understanding of the role safety culture has in fatigue management, which can have a direct impact on reducing accidents, injuries, and associated expenditures; (2) Contributing a standardized model for the training of 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. Currently, there are very few ultra-brief measures of fatigue/vigilance that have been validated. The current project validated the accuracy of a tool that is able to assess vigilance within two minutes (other assessments can take up to 30 minutes); (4) Increasing our understanding of how-to best train people to deal with trespassers and those at risk for suicide by railroad. This research will also impact the scientific body of knowledge by increasing the understanding of secondary trauma or post-traumatic stress symptomatology and sequalae associated with the repeated exposure to railroad trespass fatalities or railroad trespasser suicides.

University of Utah
The asphalt pavement projects will have the following impacts regarding the body of scientific knowledge: (1) new knowledge on the relation between use of recycled asphalt materials, material testing, field performance, and the cost of recycled materials over the life cycle of the pavement; (2) increased the existing body of scientific knowledge on a test that predicts intermediate-temperature cracking of pavements; (3) increased understanding of flexibility parameters and how they relate to pavement performance and the practical use of an index in the material specifications; (4) new knowledge of how the environment affects asphalt materials by testing of field cores, which can be used to adjust current specifications; (5) demonstrated the feasibility of using a simple test to predict the dynamic modulus of asphalt materials.

The geotechnical projects will have the following impacts regarding the body of scientific knowledge: (1) determine the fundamental material behavior of lightweight cellular concrete under static and cyclic loading at varying amounts of saturation to better plan, design, and construct embankments in bridge approach areas; (2) improve the base of knowledge with respect to the economical design of pavement systems; (3) our understanding of the loading and wetting stress-strain characteristics of various types of soil will be greatly enhanced; (4) improvement in knowledge within the civil engineering field with respect to the design and analysis of pavement systems, both without and with geogrid reinforcement.

The structural projects will have the following impacts regarding the body of scientific knowledge: (1) increased knowledge on the appropriate selection design of the buckling restrained brace yield strength for a self-centering bridge pier with post-tensioning for improved seismic performance; (2) increased knowledge on the use of fiberglass spirals and fiberglass vertical bars in reinforced concrete columns of bridge piers with and without post-tensioning for seismic regions; (3) increased our understanding on the effect of debonding of column steel bars in the footing for bridges in seismic regions and the numerical models for seismic analysis in actual bridges; (4) the use of various retrofit methods for connecting two delaminated components of a concrete partial depth bridge deck through experiments and numerical analysis has increased the body of knowledge; (5) better understanding of machine learning techniques and their application in transportation asset management, such as culverts. The air transport projects will have the following impacts regarding the body of scientific knowledge: (1) improved understanding of a web-based platform that takes inputs from the statewide road network, regarding the total number of (drone-deliverable) packages per day and the energy and cost per vehicle, and produces a statewide airspace network, delivery schedule, and truck/drone fleet mix; the platform evaluates the impact of the truck/drone fleet mix model to determine whether this hybrid approach is more cost and energy efficient compared with the current truck-only delivery model; (2) better understanding of intelligent cameras and machine vision techniques used for a two-step aircraft identification method to increase reliability. The rail transport project will have the following impact regarding the body of scientific knowledge: new knowledge on ultrasonic non-propagating modes in rails and how they can be used for inspection, which contributes to better inspection and maintenance practices.

University of Wyoming
The results from the GSRS study resulted in a major update for the algorithm used for selecting speed limits on downgrades. That algorithm was developed more than 40 years earlier and it really needed the update due to the changes in the design of trucks as well as pavement. MPC-599 developed new and improved vehicle communication protocols and created signal control programs for special signal operations with the goal of improving operations and safety at signalized intersections. It will advance the control strategies related to speed harmonization, queue warning, and preemption/priority, especially on facilities with high truck traffic percentages and high-ridership transit routes.

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 directly at improving our living environment and therefore will directly impact the way studies are conducted in the future.

d. What is the impact on transportation workforce development?

Colorado State University
The projects at Colorado State Universities will have the following impacts in terms of body of transportation workforce development:
(1) A number of graduate student and undergraduate students have received research training through these projects.
(2) Some collected data and survey methods have provided content for use in three courses at CSU: an undergraduate data analytics class, a graduate level human factors class, and a graduate level data visualization class.

North Dakota State University
The projects at North Dakota State University will impact transportation workforce development with: (1) 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) greater existing workforce contributions with improved tribal and local road management access to pragmatic and relevant safety investment data and tools; (5) 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; and (7) graduate student experience with GIS modeling, including TransCAD© and TransModeler© software applications.

South Dakota State University
Five PhD, 17 MS, and two 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 13 current MPC projects and 9 completed MPC projects have been instrumental in providing opportunities for 24 students who are all developing new skills as well as gaining experience with research methods, paper writing, and presenting. These projects have also provided them with the opportunity to attend conferences and interact with and share our work with other researchers and the broader transportation community. Students are also learning state-of-the-art techniques that they can bring directly to the workforce.

University of Denver
The research projects at the University of Denver had the following expected impacts on the transportation workforce development by: (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 impact regarding transportation workforce development: provided opportunities for research and teaching in transportation related disciplines; the graduate students that were part of this project will eventually join the workforce. The geotechnical projects will have the following impacts regarding

transportation workforce development: (1) provided support for graduate student researchers who study geo-technologies applied to transportation systems; the methodologies and results of the research are being used in course materials; (2) provided exposure to many aspects of the transportation field to several students who have worked on project; many practitioners and students will be exposed to the outcomes of this research and the importance of transportation systems to our everyday lives. The structural projects will have the following impacts regarding transportation workforce development: (1) providing support for graduate student researchers who study bridge projects regarding improved design and performance of seismic resilient bridges, several of whom have entered the work force and some that are soon to enter the workforce after graduation; (2) employers were leaders in delivering services ranging from data collection to outcome verification in the majority of the tasks in this project; 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 regarding transportation workforce development: (1) the students built simulation networks and used Python to control the simulation parameters in real time; research results are integrated into the course CVEEN 5920 Smart City and Infrastructure; (2) graduate students were involved in 3D model productions using computer vision software packages and improved their skills needed for relevant jobs in transportation agencies; disseminated educational materials will be useful for both skilled and novice engineers when implementing stationary, mobile, or UAV photogrammetry; (3) helped UDOT employees better understand how advanced optimization algorithms can help improve efficiency of their operations; the university team learned about important practical aspects of the problem that are not discussed in scientific literature; (4) the project has involved a technical committee involving more than 10 UDOT engineers; the project also involved graduate students in data collection as well as algorithm development and validation; this improves knowledge of both practitioners and students working in the transportation field; (5) employers took the lead in providing services that range from data collection to results verification; graduate students were involved in model development software packages, and undergraduate students were mostly involved with data labeling. The air transport projects will have the following impacts regarding transportation workforce development: (1) one doctoral student has received research training during this project by writing computer scripts using Python and developed the proposed web-based platform; the methodologies and results of the research will be implemented in materials for the course on transportation planning; (2) the absence of the necessary materials in the current curriculum has raised concern among aviation practitioners for not having professional workforce candidates while recruiting the new workforce; graduate students studied the literature concerning airport-level operations and increased their knowledge and the opportunity to find decent and well-paid jobs in the aviation industry.

University of Wyoming
The findings of all UW projects have been communicated with WYDOT engineers to facilitate implementation. The software developed in MPC 540 have been shared and tested by WYDOT for potential implementation.
The findings of the concrete shrinkage study will be shared with WYDOT so that they have good knowledge of how to control shrinkage cracking. All findings will also be integrated in the various classes taught at UW to help future engineers develop a good understanding of how highway safety can be enhanced and how service lives of infrastructures can be extended.

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.

e. Based on the above responses, please 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.
The 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 and driver groups such as highway-rail crossings and young drivers. Work with tribal communities remains a focus with NDSU, work underway will contribute with workforce development, data-driven transportation system studies, and capacity-building among transportation network managers.

University of Denver
As a result of MPC research on the AlertMeter (MPC-605), it has been adopted for use on a regular basis to determine fitness for duty of a group of commercial drivers.

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. 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. The structural projects will improve seismic resilience of new bridges by using replaceable elements such as buckling restrained braces and fiberglass materials that are corrosion-resistant 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, 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. Another impact is that transportation agencies can choose the right tool when adopting laser scanning or photogrammetry technologies for collecting roadway asset information. In addition, a computer-vision-based system for the safety ranking of rural roadways, which has high accuracy in detecting the safety parameters on the roadside, has been developed. The air transport projects will inform the Utah DOT Division of Aeronautics to develop policies and negotiate with industry stakeholders and improve the knowledge of aviation planners by providing a cost-effective and accurate data collection tool by developing computer vision algorithms and implementing an intelligent camera system. 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.

6. Changes/Problems

South Dakota State University
The PI of two active projects (MPC-576 and 626), Dr. Seo, passed away in Sept. 2022. These projects are delayed. For MPC-576, a copy of the final report submitted to the project cosponsor was obtained and submitted to MPC for review and possible approval. SDSU is working to find a solution for MPC-626.
Some changes have been reported in five projects due to material shortages, test setup limitations, and/or global supply chain issues. However, all PIs have reported a reasonable progress and with no significant delays.

University of Denver
Due to COVID restrictions, demonstration activity has been delayed. Investigators have been unable to meet with all participants to conduct a training event. In addition, due to sensitivity of some issues, some resistance to participation has been encountered. Efforts are ongoing to gather additional data and to conduct virtual training and demonstration events.

Utah State University
Research productivity is moving forward, but there are still lingering effects from COVID-19.
Some projects are delayed due to supply chain issues with equipment, access to labs, and diminished staff productivity. Things are improving considerably during this current reporting period, and we expect these improvements to continue. Projects utilizing laboratory facilities have been slowed due to limitations on the use of campus laboratories. Many graduate students, particularly international students, have been unable to enter the US, which has had an impact on the number of students available to work on projects. Also, several researchers have reported that the dissemination of research results has been affected due to travel restrictions. In some cases, conferences and workshops have been canceled, delayed, or switched to a virtual format. Almost all events are now back on the calendar, but the effects are lasting longer than most expected. Laboratory facilities, as well as travel and other "normal" activities, are returning to pre-COVID status.

7. SPECIAL REPORTING REQUIREMENTS:

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