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 #10

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Director, Mountain-Plains Consortium
North Dakota State University

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

a. What are the major goals of the program?

The overall 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-687** which can be found on the Mountain-Plains Consortium website.

b. What was accomplished under these goals?

i. Project Selection

One hundred fifty-four 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

Primary Focus	MPC's proposal targets the following FAST Act research and technology deployment objectives under the goal of Preserving the Existing Transportation System. Our research program 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.	11/30/2016	09/30/2023
Call for Proposals	Proposals are being solicited from each MPC university using guidelines developed by the MPC director.	12/1/2016	06/01/2022
Peer Review of Proposals	All project proposals are being subjected to external and internal peer review.	02/15/2017	07/01/2022
Selection of Projects	Projects are being selected from the proposals received which are peer reviewed by industry experts, academia, and stakeholders. Projects are awarded to the principal investigator and their respective University based on available funding.	11/30/2016	08/01/2022
Posting of Projects	Selected projects are being posted on the MPC website and added to the Research in Progress database as directed in the Grants and Deliverables document.	05/15/2017	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, **129 transportation and transportation-related courses** were offered this reporting period, for a **total of 1,126 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, **52 training sessions** were offered this reporting period for a **total of 617 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 **192 online training modules** that 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 PPPRs. 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 **98 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 **95 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 **198 students from the U.S. and countries around the world. This includes 6 post-Doc students, 93 doctoral students; 63 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.

Seventeen principal investigators, faculty, and administrators are participating in MPC projects at **Colorado State University**: Rebecca Atadero, Suren Chen, Yanlin Guo, John W. van de Lindt, Gaofeng Jia, Jeffrey Niemann, Joseph Scalia, Chris Bareither, Aditi Bhaskar, Thomas Bradley, Paul Heyliger, Peter A. Nelson, Karan Venayagamoorthy, and Mehmet E. Ozbek. In addition, fourty students are working on MPC research projects: Abdelrahman Abdallah, Wael Abdalrwaf, Avital Breverman, Wei-Hsiang Chen, Ben Irvin, Abdullah Asiri, David Trinko, Yangyang Wu, Kaisen Yao, Craig Staples, Brandon Perry, Min Li, Zana Taher, Katie Knight, Daniel Sanchez, Aaron Rabinowitz, Elizabeth Byron, Emma Adams, Cooper Bisset, Hope Carlson, Maddie Collins, Jack Derbique, London Kubicec, Elizabeth Lacey, Shelby Oke, Connor Strizich, David Thormosgood, Abby Wright, and Chao Jiang.

Seventeen 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, and Sharma Kshitij. In addition, twenty-eight students are working on MPC project: Yaobang Gong, Shantanu Awasthi, Bahar Azin, Tanner Isom, Zhao Zhang, Xinyi Yang, Hafiz Usman Ahmed, Ihsan Khan, Yun Zhou, Salman Ahmed, Keshab Thapa, H M Nasrullah Faisal, Neeraj Dhingra, Narendra Malalgoda, Yihao Ren, Morgan Jacobson, Bhavana Bhardwaj, Sajad Ebrahimi, Dawei Zhang, Ratna Yasoda, and Erik Johnson.

Nine 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, and Rouzbeh Ghabchi. In addition, twenty students 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, and Muhammad Jamil.

Ten 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, 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, Alayna Truong, Ricardo Gonzalez, Brady Heath, Wajdi Ammar, Aliasghar Hasani, Robert Fitzgerald, Mahdi Ghafoori, Nick Coppola, Ali Alatify, Wei Li, Tobby Lei, Yongechen Ji, Khang Nguyen, and Jun Wang.

Four 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, eight students are working on MPC research projects: Sree Sinha, Emma Porter, Kailey Painter, Catherin Bianci, Matthew Cole, and Jessica Mantia.

Thirteen 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, Zhuo Chen, Abbas Rashidi, and Xianfeng Terry Yang. In addition, thirty-seven students are working on MPC research projects: Zhuo Chen, Nima Haghighi, Zhiyan Yi, Dipendra Thapa, Ijan Dangol, Swastik Pohkrel, Duc Tran, Saisravan Maringanti, Qinzheng Wang, Yirrong Zhou, Chandler Cross, Emad Ghodrati, Henrik Burns, Nadereh Adham, Kaden Harris, Bahar Azin, Boe Erickson, Abdullah Mamum, Ali Hassandokht, Seth Miller, David Sacharny, Yinhu Wang, Victoria Binifarias, Ryan Burton, Suman Neupane, Remy Thigpen, Dylan Brown, Cyrus Safai, Sarah Stoplkai, and Zhao Zhang.

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 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, MD Shah Jamal, Harish Kalauni, Zorica Cvijovic, Benjamin Fosu-Saah, Md Nasim Khan, Sahima Nazneen, Zephaniah Connell, Lokendra Khatri, James Mock, and Anas Alrejjal.

Eleven principal investigators, faculty, and administrators are participating in MPC projects at **Utah State University** are: Ziqi Song, Patrick Singleton, James Bay, Abilash Kaminemi, John Rice, Nick Roberts, Andrew Sorensen, Michelle Mekker, and Marvin Halling. In addition, twenty-one students are working on MPC research projects: Ikwulono Unobe, Pouyan Saeidian, Brad Davis, Prasanna Humagain, Hossein Nasr-Esfahani, Suman Roy, Pilaiwan Vaikasi, Sailesh Acharya, Nick Langford, Niranjan Poudel, Zach Benson, Abdullah Al Sarfin, Yiming Zhang, Trevor Gardner, Nate Raine, Thad Hansen, Ahadul Islam, Md Rafiur Rahman.

ii. The following other collaborators have been identified and are working with our PI's on MPC projects that are outside of our consortium:
North Dakota State University: Kateri Hale, MHA Nation; Trooper Anthony Hoaby, Motor Carrier Assistance Program, ND Highway Patrol; Doug Hoopman, Motor Carrier Services; Barb Smith, MHA Nation; Jingnan Zhao, Rutgers
University of Colorado Denver: Nick Ferenchak, University of New Mexico; Yongcheng Ji, Northeast Forestry University
University of Utah: Jongsoo Choi, Land and Housing Corporation, Korea; Jamie Mackey, Utah Department of Transportation; Stan Peters, Castle Rock Consulting; Nico Sutmoller, Aerix Industries
University of Wyoming: 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

- The first all atomistic model of swelling clay tactoid subjected to mechanical loading is reported by our research group. The work is published in the Journal of Applied Clay Science. This is an important outcome of this project. (It should have been reported in the previous period)
- A new experimental technique to conduct nanoindentation experiments on wet clay samples has been developed and described in a submitted manuscript. A brief description is given below.
- Nanoindentation experiments capture the mechanical responses from micron-sized regions of samples and depths in the range of 10s or 100s of nanometers. The data from these experiments are important for accurately modeling the micro and nanomechanics of clays that can potentially be scaled up to model the macroscale mechanical response. Researchers have conducted nanoindentation experiments on dry clays; however, techniques for conducting nanoindentation experiments on wet clays have not been reported, likely because of the difficulties in conducting such experiments. In the technique that has been developed, the first step involved obtaining undisturbed clay samples at various levels of swelling. The samples were swollen to various magnitudes using a previously fabricated device by our group. Specially designed sample extraction devices were designed, and 3D printed to allow for undisturbed extraction of samples for nanoindentation experiments and macroscale Unconfined Compression test experiments. This was done to compare nanoindentation results with standard macroscale results. The samples were placed in the magnetic stage of the nanoindenter. A Berkovich diamond tip was used for indentation experiments. The nanoindentation experiments commenced immediately to avoid drying. Loading and unloading rate of 125 nm/second was used, and the indenter tip was cleaned with acetone after each indent. An average of 14 indents were made on each sample and statistical analysis was conducted on the data. Oliver and Pharr method was used for computing the elastic modulus and hardness values. Indentation depths were 500 nm and 1,000nm.
- On-line app (https://kmtgis.shinyapps.io/ak_plot/) development is finished. This on-line app allows safety improvement agencies to perform scenarios analysis for various contributors of crash and crash severity so that they have quantitative understanding on the marginal effects for crash frequency and severity based on the research results.
- We obtained input from several local government highway departments on the number of Local Road Safety Plan projects that have been completed and how many dollars from the Highway Safety Improvement Program have been used from FHWA.
- Transportation trainings, workshops and conferences for regional and national venues have been posted to UGPTI's Tribal Outreach website (https://www.ugpti.org/outreach/tribal/). In addition, emails have been sent to tribal transportation personnel pertaining to these trainings. Consistent dialogue and communications with tribal entities is maintained.

South Dakota State University

- A website was developed to disseminate the findings with researchers and the public. The website is frequently updated to show the project progress.
  https://sites.google.com/people.unr.edu/mostafa-tazarv/research/mechanically-spliced-columns

University of Colorado Denver

- A software tool was developed for CDOT bridge engineers' daily use to perform bridge deterioration forecasting. This software is a standalone and self-inclusive application that will predict future conditions using historical bridge performance data (i.e., NBI data) for one or more bridges, and retrain the prediction models based on bridge performance data (NBA), weather data (from NOAA), and traffic data.
- A database of paratransit trips in the Denver Region, with additional factors for land use at the TAZ level and weather factors.

University of Denver

- We have created and updated a web site describing our tools for measuring and managing safety culture: https://www.du.edu/ncit/safety.html

University of Utah

- A Matlab tool that will allow UDOT to update its routes for different parameter settings. The tool enables a user to load data for different cities in Utah, select the number of available snowplow trucks, and subsequently obtain efficient routes. To facilitate further use of the tool, the research team has prepared a manual and held one training session with UDOT employees.
- Several journal publications in the areas of transportation, materials, structures, and artificial intelligence, as well as presentations and conference proceedings demonstrate the significance of the research carried out during this period. Moreover, Matlab-based tools were developed to optimize operations such as snowplow truck routes.

University of Wyoming

- Feedback was received from WYDOT's Right-of-Way office about the expected cost ranges for the land acquisitions of the proposed locations. WYDOT officials recommended Zone 4 to be the most appropriate location for the proposed test track. Zone 4 is located on the eastbound segment of I-80 west to Cheyenne.
- A field demonstration using unmanned aerial systems (UAS) was conducted on Zone 4 of the potential locations. A drone was flown in Zone 4 to collect a photogrammetry data along an I-80 segment west to Cheyenne (MP: from 354.2 to 355.2). The photos were gathered considering a predefined surveying grid defined on an adjacent area of I-80 with a 500-foot-wide strip and over a mile long. The point cloud data were imported into Pix4D software to produce the 3D model of the surveyed location.
- The research interests on the main test track are being further investigated considering the size of pavement assets and related PMS parameters. The 2020 PMS dataset was received from WYDOT and is being analyzed to prioritize the research experiments currently urgent for WYDOT's sponsorship of the test track. Some criteria are considered to determine the size of pavement assets on the different categories, including type of pavement, pavement structure codes, type of treatments, among other factors.
- A workshop presentation was presented in the 2021 annual conference of the Rocky Mountain Asphalt User/Producer in Tucson, Arizona. The main objective of this presentation was to share the information about the proposed test track and invite all interested partners to contribute to the advancement of the testing facility by sponsoring research experiments on the test track. Some feedback was received either by the PIs or WYDOT sponsors about potential interests in these future efforts.

Utah State University

- Equipment for controlled heating and cooling tests for any construction materials has been designed and manufactured during this period.

4. Outcomes:

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

South Dakota State University

The 12 active projects at SDSU will have the following outcomes: increased understanding of ultimate and fatigue strength of transportation dynamic messaging signs, 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

systems, establishing the most comprehensive mechanically spliced precast column experimental database and validation of design methods, 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, and improved techniques using recycled Electrospun Polyethylene Terephthalate microfibers for characterization of the asphalt binders.

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 awareness of transportation agencies of landslide risks; (4) increased understanding of constructability and durability issues associated with embedded wireless charging systems in pavements; (5) improved traffic operations and improved adoption by transportation agencies related to autonomous vehicles; (6) improved adoption of electric buses; (7) improved understanding and possible adoption of fiber reinforced bridge decks; (8) increased safety of bicycles at roundabouts; (9) improved safety for pedestrians at intersections; (10) increased understanding of the post impact behavior of bridge pier couplers; (11) increased pool of educated transportation professionals and better trained transportation workforce; (12) improved durability of charging infrastructure for the future of electrified transportation in the US.

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.

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 University will have the following outcomes: (1) increased understanding of the limitations of lifecycle cost analysis, high efficiency UAS based inspection techniques, and how to make use of existing bridge inspection data and in-depth inspections for transportation infrastructures such as bridges and pavements; (2) increased knowledge about post-hazard traffic flow simulation techniques, risk mitigation, community resilience assessment methodology, how to plan EMS traffic and understanding of strategy of long-term restoration prioritization following natural hazards such as earthquakes, flooding and landslide; (3) improved understanding and awareness of transportation safety issues under adverse weather, and hazardous and complex traffic conditions, such as strong crosswinds and railroad trespassing traffic.

Especially, for outcome (1), we are pursuing new research that seeks to go beyond economic costs to consider societal impacts in decision making, developing advanced data analytics tools for extracting structural condition information from the images collected by UAV, and developing unique and valuable database of geotagged and labeled trios of visible, thermal, and fused images for training pothole detection algorithms.

For outcome (2), people have developed more advanced traffic flow simulation techniques on roads with obstructions, improved strategy to plan EMS traffic and bridge recovery prioritization following earthquakes to save more lives, conducted a case study illustrating utilization of the Federal Highway Administration's (FHWA) bridge scour equations with a two-dimensional hydraulic model, and modeled a landslide hazard with reduced vegetation under potential future climate scenarios, which reveals a large-scale shift in the areas subject to increased hazard.

For outcome (3), we have prepared preliminary guidance on appropriate level of CFD model sophistication required for obtaining wind loads (magnitude and distribution) on high-sided vehicles, developed simulation-based traffic safety risk assessment methodology, and aggregated current practices on railroad trespassing prevention and statistics.

North Dakota State University

The projects at North Dakota State University will lead to:

1) safety measures dedicated to AVs in a mixed-driver-environments;
2) molecular interactions-microstructure-property relationships detail for swelling clays that would lead to robust analysis;
3) cost effective, sensor-based improvement to railroad track inspection efficiency and safety countermeasure selection;
4) sensor-based WIM pavement design complement with AASHTOWare ME design;
5) subpopulation-based and individualized intervention in impaired driving and novice teen driver crash risk;
6) best practices approach for tribal communities and small local road departments to encourage safety integration into ongoing planning and investment decision processes;
7) personnel gained information allowing them greater understanding and knowledge on what is needed to pass CDL testing to contribute to the pool of CDL holders on our tribal nations.
8) greater workforce understanding and knowledge on what is needed to pass CDL testing to contribute to the pool of CDL holders among tribal nations
9) DOT adoption of AI-based methodology for state traffic estimates based on proposed AI-based methodology in vehicle trajectory reconstruction
10) broadened understanding about potential impacts of the scope of autonomous aircraft cargo logistics, prospects for adoption, deployment challenges, and the potential implications for planners and policymaking.
11) increased the body of knowledge and technical understanding of emerging drone technologies that can improve the effectiveness and reduce the cost of transportation infrastructure, such as asset inspections, and study how emerging cargo drone technologies could induce a mode shift away from surface transportation modes.
12) 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.

University of Colorado Denver

All projects are progressing very well over the last project period and with 2 journal papers and 3 conference presentations. This work is also significant 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) access to smartphone-based apps for assessment of fatigue and alertness in the operational environment; 2) an online measurement tool for the assessment of safety culture; 3) development of a training model and module to teach effective leadership techniques for developing and maintaining safety culture; 4) the discovery of the impact of USDOT policies on the health and safety of drivers during the pandemic; and 5) increase the skill and confidence of railroad employees for intervening with potentially suicidal persons and the public by increasing prevention interventions by railroad employees and increased public awareness.

1) The project “Validation of Smartphone Alertmeter Fatigue Assessment Device for Transportation Workers" (MPC-605) provided technology to assess fatigue and alertness of drivers before they are operating vehicles. Ultimately, the utilization of the device could lead to a reduction in accidents and injuries in the transportation system.
2) The “Safety Culture, Leadership & Fatigue” project (MPC-582) has been of interest to short line railroads 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 Leadership Training Model to Improve Safety Culture” (MPC-604) will aid leaders of transportation organizations in demonstrating the behaviors and best practices that will lead to the development of an effective safety culture characterized by reduced numbers of accidents and injuries.
4) The “Fatigue, Health and Driving Behavior During COVID" (MPC-646) and “Effects of Autonomous Vehicles" (MPC-552) projects will provide a greater understanding of how the USDOT policy and regulatory changes during the COVID-19 affected driver safety, health, and productivity. Recommendations for policy improvements will be made.
5) The “Trespasser and Suicide Prevention Training" (MPC-667) project will increase the skill and confidence of railroad employees for intervening with potentially suicidal persons and the public by increasing prevention interventions by railroad employees and increased public awareness. It is expected that the project will lead to an

increase in the identification of at-risk suicidal trespassing persons who will be identified, approached, and referred to appropriate sources of care and assistance.

University of Utah
The projects at the University of Utah will have the following outcomes: (1) Guidance to UDOT on long-range plans for the impact of automated vehicles on future vehicle-miles traveled; (2) Increased the body of knowledge in bridge seismic resilience so that using hybrid bridges will remain functional after a strong earthquake; (3) Increased the body of knowledge on policies and specifications regarding the design of pavement materials resulting in more cost-effective pavements; (4) Increased the body of knowledge regarding approach slab support systems near bridges to reduce differential settlement; (5) Guidance to UDOT regarding geosynthetics for soil improvement to change their specifications to use multiaxial geogrid within pavement systems for new roadways; (6) Increased the understanding of how mechanical tests can relate to the performance of balanced asphalt mix designs, resulting in the design of cost-effective pavements; (7) Increased the body of knowledge on how vehicle automation and connectivity can convey more data regarding the driving environment, thus improve driver decision-making by reducing the crash risks resulting from roadway geometries; (8) Increased the body of knowledge regarding 3D photogrammetry for asset management practices for highway assets and within public transportation agencies; (9) Increased the body of knowledge and provided UDOT better ways to ensure that bumps at the ends of bridges are minimized; (10) Increased understanding of microtransit to assist transit agencies with performance evaluation, regional transport strategies, and optimal vehicle dispatching; (11) Increased understanding of the performance of glass fiber reinforced polymer bars under earthquakes and in constructing bridges using durable materials for bridge construction in high seismic regions; (12) Increased the body of knowledge on road safety performance before and after the implementation of the new Variable Speed Limit system highway sign visibility; (13) Increased the body of knowledge regarding the flexibility index of asphalt mixtures to improve the design and cost-effectiveness of pavements; (14) Guidance to UDOT regarding design of pavement systems bearing on soft subgrades and identification of additional geogrid-like materials that are better than the standard biaxial geogrid; (15) Guidance to UDOT regarding energy impacts of large-scale drone delivery as well as viable airspace network policies for industry; (16) Improved the body of knowledge regarding efficient snowplow routes for Utah cities to reduce UDOT's operational costs; (17) Guidance regarding numerical models for analysis of footing-to-column connections for designing bridges in seismic regions; (18) Improved the body of knowledge regarding a new robust and accurate autonomous measurement method using vision-based techniques for airport operations categorized; (19) Improved the body of knowledge regarding a simulation model for city traffic used for traffic management and control to inform how coordinated ramp metering control is beneficial in reducing delays and improving road safety; (20) Improved the body of knowledge for the design of a retrofit method for composite action in bridge decks; (21) Development of new techniques to relate the material properties to structural performance of pavements and improve their longevity; (22) Improved understanding of factors that lead to how non-propagating modes in rails can be promoted using the electromechanical impedance method.

University of Wyoming
During this reporting period, in MPC 600, a device to identify passing zones on two-lane highways has been completed and based to WYDOT. WYDOT has already begun utilizing the new device to identify safe passing zones in the state.

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

North Dakota State University
The projects at North Dakota State University will lead to the adoption of new practices and/or potential commercialization in: (1) safety measures dedicated to AVs in a mixed-driver-environments; (2) molecular interactions-microstructure-property relationship details for swelling clays that would lead to robust analysis; (3) cost-effective, sensor-based improvement to railroad track inspection efficiency; (4) sensor based WIM pavement design complement with AASHTOWare ME design; (5) subpopulation-based and individualized intervention in novice teen driver crash risk; (6) best practices approach for tribal communities and small local road departments to encourage safety integration into ongoing planning and investment decision processes; (7) anticipate that DOT agencies will adopt the proposed AI-based methodology for state traffic estimates based on proposed AI-based methodology in vehicle trajectory reconstruction and look to ITS solutions in asset monitoring and management; (8) tools for local road agencies to prioritize their unpaved road networks in a performance-based approach to roadway investment with scare resource allocation; (9) knowledge foundation with electrified cargo drones for potential environmental and economic impacts in surface transportation

systems; (10) freight planning GIS foundation to assess investments, estimate corridor performance measures, and assess efficiency in food and container logistics; and (11) tribal nation workforce understanding and knowledge with system monitoring in maintenance in technical training assistance, such as large vehicle operations and testing to contribute to the pool of heavy equipment operators and CDL holders among tribal nations' members.

South Dakota State University
The 12 active projects at SDSU will have the following anticipated impacts: develop design methodology for transportation dynamic messaging signs using adhesively connected joints, promote sustainable bio-materials and agricultural byproducts for the production of bio-asphalt binders, promote sustainability in bridges using timber products, develop new precast column connections for accelerated bridge construction, 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, and develop a novel technique for recycling waste PET in asphalt mixes addressing an important environmental challenge.

University of Colorado Denver
Our FASTACT 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 are currently being integrated into NREL's Hive transportation network technique, which will help increase the efficiency of fleet route planning, ridesourcing, and ridesharing and be leveraged by many federal, state, and private agencies.

University of Utah
The projects at the University of Utah will have the following impacts: (1) Assist public agencies in understanding the impacts of shared autonomous vehicles on travel patterns to further consider the special needs of autonomous vehicle technology in long-range cost estimates and programming processes; (2) Adopt a test for evaluating the performance of asphalt mixtures that can reduce the number of low performing asphalt mixtures, resulting in significant cost savings; (3) Assist UDOT in implementing technologies that reduce differential settlement at bridge approaches which will improve safety and transport of people and goods on roadways; (4) Develop roadway systems that perform better and require less long-term maintenance than current practice; (5) Develop new bridge systems in high seismic regions that will be affected by strong earthquakes; (6) Provide better insights into how road geometric designs can affect connected autonomous vehicle safety performance and road safety; (7) Assist data collection using image-based 3D reconstruction; (8) Enhance the transferability of microtransit programs without additional cost and inform transit agencies on people's behavioral changes and the evolution of their travel patterns to guide operational strategy adjustments; (9) Improve understanding of the seismic performance of fiberglass reinforcement in bridge columns and whether it is an appropriate material for bridge columns in regions with strong earthquakes; (10) Evaluate the effectiveness of new Changeable Message Signs by performing a comprehensive before-and-after analysis using online-based algorithms with automatic operations; (11) Improve understanding of the performance of pavement systems constructed without and with geogrid reinforcement that perform better and require less long-term maintenance; (12) Assist in strategic deployment of drone centers and fleet size planning to assess different assumptions of the model and run "what-if" scenarios by generating animation of the optimized airspace network in Utah; (13) Improve efficiency of snowplowing operations via data and analytics; (14) Improve understanding of construction methods for cost-effective bridges in seismic regions using accelerated bridge construction methods; (15) Provide cost-effective and accurate data collection using automated image-based aircraft tracking and record-keeping for Utah airports; (16) Improve evaluation of a test capable of evaluating the potential performance of asphalt mixtures by using field cores; (17) Evaluate coordinated ramp metering strategies for Utah freeways to alleviate bottlenecks; (18) Improve assessment of travel conditions and identifying potential issues of road assets using videos from mobile phones; (19) Improve understanding through numerical simulation of strengthening techniques for bridge decks utilizing partial-depth precast panels to minimize cost and traffic delays for bridge deck repairs; (20) Improve the effectiveness of rail and transit systems by enabling condition-based maintenance rather than a time-based or age-based approach using an electromechanical impedance method.

University of Wyoming
MPC 600 resulted in a new device which will identify passing zones accurately. This device will result in reducing head-on crashes on two-lane highways. WYDOT has already started using this newly developed device.

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 AVs. Several of these projects provide the groundwork for the increased adoption of electrified vehicles as well as the adoption of autonomous transportation in the near future. The use of fiber reinforced concrete for bridge decks will improve durability and therefore make the transportation system 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
The projects at Colorado State University will have the following impacts: (1) the studies on inspecting and improving transportation infrastructures, such as bridges and pavements, may offer data analytics tools for quantifying, tracking, and localizing the changes of damages on bridges which are expected to be useful for the inspection industry and state DOTs. The developed automated tools for pavement pothole detection can be adopted by CDOT maintenance teams to facilitate fast and cost-effective road condition data collection and assessment; (2) the study on green stormwater infrastructure may help municipalities, which are implementing new or taking advantage of existing green stormwater infrastructure developed originally for other purposes, consider the benefits in reducing roadway flooding. The long-term restoration prioritization technique of damaged bridges following earthquakes may assist stakeholders to make better decisions on bridge repair; (3) traffic safety studies under adverse weather, work zones, and complex traffic scenarios will eventually provide substantial findings that will lead to adoption of best practices, such as travel advisories under extreme wind conditions, and develop real-time monitoring technology that could emerge from such concerted studies and industry collaboration. The study on rail trespassing will provide agencies in charge of designing, building, and maintaining railroad right of ways and crossings with information about how the public perceives various countermeasures. This will help these agencies prioritize and select countermeasures (i.e., signage, barriers) that appropriately match intended pedestrian behavior with actual pedestrian understanding and interpretation of the countermeasure.

North Dakota State University
The projects at NDSU may encourage new practices among state DOTs and stakeholders in use of ITS, such as drones, sensors, and AI processes in incident response, investment planning and asset monitoring. Policy decisions may be refined in traffic safety strategies to prevent alcohol impaired driving, improve novice driver early on-road experiences, and strengthen tribal communities' human capital capacity. Research in surface infrastructure decisions regarding freight corridor investment, unpaved road management, rail-highway grade crossing investments, and swelling clay predictions will contribute to longer-term system reliability and health with regard to resources invested.

South Dakota State University
The 12 active projects at SDSU will have the following expected impacts: lifting the ban imposed by transportation agencies on the use of adhesive joints for the construction of transportation dynamic messaging signs, 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, reducing bridge bent construction time and cost, 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, and development of a post-processing method for waste plastic to be used as asphalt materials.

University of Colorado Denver
MPC-616 will soon 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. No start-up companies have been initiated.

University of Denver
The research projects at the University of Denver will have the following expected impacts on the adoption of new practices and new technologies: 1) The Safety Culture measures has been adopted by at least one other transportation agency as a tool for measuring its effectiveness; 2) the ready availability of a portable smartphone-based app for measuring driver/operator 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. It is also anticipated that 3) the results of the research will also lead to the adoption of a new and more streamlined model for training and development leadership practices required for the development and maintenance of a Positive of Safety Culture and the leadership techniques needed to implement. 4) The adoption of new practices by providing training materials, operational checklists for use in identifying and screening at-risk for suicide trespassers, and for increasing the confidence and skill - essentially adopting new practices and procedures - of railroad employees for conducting interventions with trespassers at risk for suicide.

University of Utah
The projects at the University of Utah will have the following impacts on adoption of new practices: (1) Captured the effects of shared autonomous vehicles on travel behavior in Utah through modifying the regional travel demand model; (2) Adoption by highway agencies of mechanical testing of asphalt mixtures to evaluate their potential performance once placed in the field; (3) Mitigation of differential settlement at highway bridge approaches using the developed concrete technology, which will be ready for implementation by UDOT; (4) Development of better design and construction guidelines for geogrid-supported pavement systems, which should result in wider use of this technology within roadway systems; (5) The hybrid bridge bent technology will improve seismic performance of bridges and thus increase seismic resilience of the infrastructure; (6) One project will help identify the locations that should be installed with connected automated vehicle roadside equipment to improve traffic safety; (7) Development of a cost-effective method for applications in asset inventory including pedestrian access ramp inspection using photogrammetry; (8) Transfer of knowledge on how COVID-19 altered travel behavior; (9) Improved efficiency of snowplowing operations via data and analytics, which resulted in proposed routes that were implemented in practice in 12 cities in Utah.

University of Wyoming
MPC-540 resulted in developing a new software which will enable DOTs to select appropriate speed limits on downgrades. Selecting appropriate speed limits will result in reducing the number and severity of crashes. It is anticipated that WYDOT will fully implement the software at the conclusion of the study.

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

Colorado State University
The projects at Colorado State University will have the following impacts: (1) the studies on inspecting and improving transportation infrastructures such as bridges and pavements have developed new image computation and machine learning algorithms, which are effective for damage quantification, tracking and localization, and produce new knowledge on the use of machine learning techniques to automate tasks related to inspection and maintenance of road pavement; (2) the studies on transportation infrastructure and communities under natural hazards have greatly improved the body of scientific knowledge, such as developing new knowledge and methodology on assessing the mobility of EMS traffic. This knowledge will be developed with potential for improved intervention methods during the response and recovery stages following disasters such as earthquakes, and for the first time, learn how the probability of landslides undergoes a potential shift from south-facing to north-facing slopes under climate change scenarios; ; (3) for the studies on traffic safety under adverse weather and work zones, the following impacts are made: compared to the state of the art of simulation-based studies focusing on traffic safety under normal conditions, this project has provided a new simulation methodology to assess traffic safety risks of vehicles under adverse driving conditions and/or work zone conditions. The study will help toward improved safety assessment and development of guidelines for management of traffic movement under extreme meteorological conditions. It will also, in a larger context, provide guidance on policies for decision making that alleviates negative impacts such as high economic costs associated with vehicular accidents. For the rail

trespassing study, human behavior and perception related to safe and unsafe railroad right of way crossings will be identified.

South Dakota State University
The 12 active projects at SDSU will have the following expected impacts: generation of new data on fatigue and strength behavior of dynamic messaging signs, 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, generation of comprehensive test data on mechanically spliced precast bridge columns, better understanding of the critical shear stress and erosion rates in different clay soils and sand-clay mixtures, producing 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, and characterization of Electrospun PET Microfiber (EPM) used in asphalt binder.

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 of safety culture and fatigue management, which can have a direct impact on reducing accidents injuries and associated expenditures; 2) Contributing to the development of 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 of a smartphone-based assessment tool for detecting fatigue in vehicle driver/operators. Currently, there are very few ultra-brief measures of fatigue/vigilance that have been validated. 4) The research may have an impact on the recommended number of hours that can be driven during emergency situations. 5) It is anticipated that the study will also determine whether levels of fatigue, empathy, and amount of driving are related to driver safety. In addition, the study will examine driver behavior, mood, and personality characteristics in relation to self-reported frequency of traffic citations, accidents, and crashes. Also, there may be some recommendations for additional services needed to support this essential component of the freight transportation and supply industry. 6) The anticipated contribution validation of the eco-system model of community involvement and activity in the prevention of suicide. It is also anticipated that by demonstrating the effectiveness of the eco-system model of suicide prevention, railroads throughout the country will be able to expand their prevention methods.

University of Utah
The projects at the University of Utah will have the following impacts on the body of scientific knowledge: (1) Shared autonomous vehicles compete most effectively with auto and non-motorized modes; (2) Use of geogrid in pavement systems can result in economical design of pavement systems; (3) Development of asphalt mixtures that have satisfactory performance once placed in the field; (4) Developing new design of bridges in seismic regions using damper elements; (5) Improved modeling and simulation of connected autonomous vehicles for different road geometric designs; (6) Image-based 3D reconstruction is assessed for having a usable 3D model for inventory and inspection purposes; (7) Better understanding of the cyclic performance of bridge columns reinforced with fiberglass bars and spirals; (8) Developed Machine learning (ML) models, including Artificial Neural Network (ANN) and Support Vector Machine (SVM), are developed to model crash frequency and severity; (9) Development of rigorous mathematical models for optimal allocation of snowplow trucks given their stochastic failures (or driver no-shows); (10) Development of deep learning and convolutional neural networks to recognize the type of aircraft before applying text recognition algorithms to recognize the aircraft ID and design of a probabilistic framework to use imperfect text recognition and finalize identification accurately; (11) Adoption and improvement of two coordinated ramp metering control algorithms; (12) Development of machine learning algorithms to evaluate various transportation assets using deep learning methods to understand how

computer vision could be utilized in facilitating asset management practice; (13) Evaluation of roadside safety using computer vision and 2D images.

University of Wyoming
All projects conducted will have contributions to the body of knowledge, as examples: MPC 652 will result in procedures that will reduce shrinkage cracking in bridge decks. MPC 573 developed new interchanges designs not currently available in the literature. Such designs will work well at congested interchanges.

Utah State University
The projects at Utah State University will have the following impacts on the body of scientific knowledge: (1) produce an optimization framework to deploy dynamic charging lanes for PHETs in an electrified road freight transportation system; (2) new knowledge on public perception of CVs and data, particularly on security/privacy concerns, demographics, and acceptance/use of the technology; (3) help transit agencies optimize their planning of a fast-charging BEB system; (4) produce a better understanding of real-world data sizes collected by LiDAR on a hypothetical AV. This new knowledge is expected to spawn future research in the area of AV data expectations and management.

USU's research will affect the body of knowledge through publication and dissemination of the results in the scientific community. Research results and technical publications will help spread the results of this research nationally and internationally.

d. What is the impact on transportation workforce development?

Colorado State University
The projects at Colorado State University will have the following impacts:
(1) Many graduate students and undergraduate students will receive research training on all these projects.
(2) Some of the research findings will be incorporated into some courses, such as SYSE 534 Human Systems Integration – when teaching students about survey methods for capturing human perception and behavior; ENGR 580a5 Systems Data Lifecycle and Visualization – when teaching students how to visualize survey response data; and CIVE 508-Bridge Engineering – when incorporating transportation infrastructure safety and resilience research.

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) existing workforce contribution with improved tribal and local road manager 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.

University of Colorado Denver
The 15 current MPC projects and 7 completed MPC projects have been instrumental in providing opportunities for 24 students that 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 Wyoming
The projects at the University of Utah will have the following impacts regarding transportation workforce development: (1) With regard to automated vehicle projects, three graduate students have received research training and have written computer scripts in Cube Voyager and learned the theories in travel demand modeling; (2) For asphalt pavement related projects, one graduate student is now employed in the transportation field; (3) With respect to geotechnical related projects, three graduate students have received research training, they have performed numerical analysis and laboratory

evaluations using commercial software and learned about geotechnologies used in bridge construction; (4) With regard to a project focused on hybrid bridge bent systems, two students working on the project have graduated, one of whom is working full time; (5) With regard to connected vehicle technology, one graduate student is leading the research and one student is involved, and in addition, the research results have been integrated into the course CVEEN 5920 Smart City and Infrastructure; (6) For a project dealing with image-based 3D reconstruction of roadway assets, graduate students were involved in 3D model productions using computer vision software; (7) Several projects in the transportation, structures, geotechnical, and imaging areas have utilized graduate students to develop algorithms and software, as outlined in the PI responses.

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 because of 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?**

Colorado State University
The projects at Colorado State University will have the following impacts: (1) the studies on inspecting and improving transportation infrastructures will improve the effectiveness of the transportation system by promoting improved bridge condition, guide risk-informed and cost-effective maintenance and inspection decision making for better preservation of bridges, and help decrease the cost of pavement condition data collection and assessment, and improve safety of roads; (2) the studies on infrastructure and community resilience under various hazards have identified emerging green stormwater infrastructure technology with benefit in reducing roadway flooding, adopted the new EMS planning strategy to potentially save human lives, and provided insights from the landslide modeling which may allow managers to focus attention on areas at higher risk; and (3) the studies on traffic safety under adverse weather conditions & hazards, work zones, and complex traffic scenarios will help with protecting drivers and conducting site-specific traffic operation and management strategy by understanding potential crash risks, offer improved safety guidance to mitigate crash risks for high-profile vulnerable vehicles, and assess the effectiveness of various railroad trespassing countermeasures currently in use.

Especially, for impact (1), a new bridge inspection technique has been developed to allow more quantitative condition assessment (enabling identification of damage location, severity and type), which is superior to the existing practice. The developed tools for pavement pothole inspection will automate the data collection and damage identification.

For impact (2), the work on flood prevention using green stormwater infrastructure can be used to better manage stormwater on roadways and mitigate the resulting traffic disruptions. The landslide model will make the maintenance of existing transportation infrastructure more efficient, and future infrastructure planning can be made safer.

For impact (3), with improved understanding risk of crashes under strong winds, some crashes can be avoided in windy environments, which will lead to more efficient and safer traffic operations. The work on assessing railroad trespassing events can help reduce railroad trespassing events and related injuries/fatalities.

University of Denver
The research projects at the University of Denver will have the following expected impacts on the effectiveness of the transportation system in the following ways: 1) Provide leaders of transportation organizations with tools to measure safety culture and how to train for the "Improve Safety Culture" model, which is expected to lead to fewer crashes, accidents, and injuries, resulting in greater safety and reduced costs. 2) Provide transportation organization leaders with more tools for managing fatigue using mobile hand-held alertness measuring devices, integrated into existing mobile phones, which will significantly improve access to fatigue information and increase the ability to better manage fatigue, potentially saving lives and money. 3) Provide leaders of transportation organizations with recommendations on the most effective policies for maintaining driver health and safety operating during a pandemic. 4) Contribute to an anticipated reduction in trespasser fatalities and suicide on passenger and commuter rail operations.

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 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.

North Dakota State University
The projects at North Dakota State University will contribute to body of scientific knowledge in: (1) new models to improve AV safety and mobility of traffic in mixed-driver-environments; (2) multiscale computational framework for swelling clays to evaluate the mechanical response of swelling clay to external loading; (3) closed-form modeling and machine learning techniques for railroads to benefit/cost outcomes related to new technology deployment; (4) improved cut-off frequency and feature extraction knowledge to improve the accuracy of anomaly location detection with low-cost smartphone signaling in rail track monitoring; (5) improved WIM data quality understanding and use in pavement design and performance; and (6) advanced, AI-based, traffic prediction methods in real-time estimates.

South Dakota State University
Five PhD, 13 MS, and 2 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 Denver
The research projects at the University of Denver had the following expected impacts on the transportation workforce development by: 1) Provided three additional graduate students training and experience in the research process, including literature review, data collection and analysis using Excel and SPSS and report writing, and also understating the principles for the ethical conduct of field research; 2) Safety managers at two railroads were given information on how to improve their safety culture; 3) Managers at several trucking companies received information about how to manage fatigue levels as a result of this project. 4) Increased the skill and confidence of railroad employees in dealing with at-risk-of-suicide trespassers and the development of operational checklists for use in identifying and screening at-risk-of-suicide trespassers that will contribute to an improvement in transportation worker skill and competence.

University of Utah
The projects at the University of Utah will have the following impacts regarding transportation workforce development: (1) With regard to automated vehicle projects, three graduate students have received research training and have written computer scripts in Cube Voyager and learned the theories in travel demand modeling; (2) For asphalt pavement related projects, one graduate student is now employed in the transportation field; (3) With respect to geotechnical related projects, three graduate students have received research training, they have performed numerical analysis and laboratory evaluations using commercial software and learned about geotechnologies used in bridge construction; (4) With regard to a project focused on hybrid bridge bent systems, two students working on the project have graduated, one of whom is working full time; (5) With regard to connected vehicle technology, one graduate student is leading the research and one student is involved, and in addition, the research results have been integrated into the course CVEEN 5920 Smart City and Infrastructure; (6) For a project dealing with image-based 3D reconstruction of roadway assets, graduate students were involved in 3D model productions using computer vision software; (7) Several projects in the transportation, structures, geotechnical, and imaging areas have utilized graduate students to develop algorithms and software, as outlined in the PI responses.

6. Changes/Problems

North Dakota State University
A few changes/problems were noted by NDSU researchers: (1) development of all-atomistic models of clay aggregates that maintain the ability to incorporate the clay-clay interactions and clay-water interactions at the molecular scale which are significantly superior in predicting clay behavior; and (2) unanticipated state agency partner changes to project timing and crash event location details in terms of road segment details, particularly with events occurring on the local road segments that delayed and prohibited some project tasks in the teen and LRSP research, respectively.

South Dakota State University
Some changes have been reported in two projects due to material shortage or test setup limitations. However, all PIs have reported reasonable progress and with no significant delays.

Utah State University
Most of the changes, problems, or delays in project progress can be attributed to the continuing effects of the Covid pandemic. Some projects are delayed due to supply chain issues with equipment, access to labs, and diminished productivity of staff due to Covid. 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 on-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. Laboratory facilities, as well as travel and other "normal" activities, are beginning to return to pre-Covid status.

7. SPECIAL REPORTING REQUIREMENTS:

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