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 #9

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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-678** which can be found on the Mountain-Plains Consortium website.

b. What was accomplished under these goals?

i. Project Selection

One hundred forty-five 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	09/30/2023
	Mod 1, Grant No. 69A3551747108 (Year 2)	10/01/2017	09/30/2023
	Mod 2, Grant No. 69A3551747108 (Year 3)	10/01/2018	09/30/2023
	Mod 3, Grant No. 69A3551747108 (Year 4)	10/01/2019	09/30/2023
	Mod 4, Grant No. 69A3551747108 (Year 5) (Apr20)	10/01/2020	09/30/2023
	Mod 5, Grant No. 69A3551747108 (Year 6) (UG21)	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.	05/15/2017	07/01/2022
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	07/01/2022
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, **141 transportation and transportation-related courses** were offered this reporting period, for a **total of 997 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, **64 training sessions** were offered this reporting period for a **total of 565 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 **195 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 **85 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 **84 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 **160 students from the U.S. and countries around the world. This includes 4 post-Doc students, 76 doctoral students; 62 master's students; and 24 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.

Fourteen 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, twenty-nine students are working on MPC research projects: Abdallah Abdelrahman, 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.

Eleven 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-one 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, nineteen 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, Gunnar Kern, 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,Ghazal Batouli, Robert Fitzgerald, Mahdi Ghafoori, Nick Coppola, Yaneev Golomber, Ryanne Ototivo, Ali Alatify, Wei Li, Tobby Lei, Sohil Vaidya, Yongechen Ji, Selvakumar Jayaraman, 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, Andi Puavat, and Jesse Owen. In addition, seven students are working on MPC research projects: Sree Sinha, Emma Porter, Kailey Painter, Catherin Bianci, Matthew Cole, Jessica Solano, 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, Zhuo Chen, Abbas Rashidi, and Xianfeng Terry Yang. In addition, thirty-four students are working on MPC research projects: Zhuo Chen, Nima Haghighi, Zhiyan Yi, Dipendra Thapa, Ijan Dangol, Faramarz Safazadeh, Abu Sufian, 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, Carlos Herdoza, Adam Jones, Ryan Burton, Suman Neupane, Remy Thigpen, Dylan Brow, Cyrus Safai, Sarah Stoplkai, and Zhao Zhang.

Sixteen principal investigators, faculty, and administrators are participating in MPC projects at the **University of Wyoming** are: Jennifer Tanner, Khaled Ksaibati, Promothes Saha, Ahmed Abdelaty, Shaun Wulff, Chengyi Zhang, Anas Alrejjal, Mohamed Ahmed, Ahmed Farid, Suresh Muknahallipatna, Milan Zlatkovic, Marwan Hafez, Kam Ng, Mahdi Rezapour, Muhammad Tahmidual Haq, and Amirarsalan Mehrara Molan. In addition, twenty-three students are working on MPC research projects: Sherif Gaweesh, Esraa Alomari, Vincent Ampadu, Osama Nasri Abu Daoud, Waleed Aleadelat, Omar M. Albatayneh, Arash Khoda, Megh KC, Shamel Perez, 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.

Nine 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, eighteen 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: Lu Gao, University of Houston; Jingnan Zhao, Ruters, Postdoc Researcher; Aaron Wang, High School Research Assistant
University of Denver: Noel Beck, Keolis Commuter Services, VRE; Patti Gillette, Colorado Motor Carriers Association; Chris Harrington, Keolis Commuter Services, MBTA; Chris Harrington, Keolis Commuter Services; MBTA Manuel Machado, Keolis Commuter Services, VRE
University of Utah: Shawn Larson, Utah Department of Transportation; Stan Peters, Castle Rock Consulting; Nico Sutmoller, Aerix Industries
University of Wyoming: Sarah Zlatkovic, Claremont Graduate University
Utah State University: Alec Biehl, Oak Ridge National Laboratory

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 358** different peer-reviewed articles or papers.

b. Conference Papers can be found in Appendix D
i. This reporting period **we have published 41 conference papers and 169 total since the grant began**.

c. Presentations can be found in Appendix D
i. MPC faculty and investigators **have presented at 34 different** scientific, technical, or professional conference this period. In total, we have **had 209 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 project hosted two high school teachers during the summer 2021 from June to August 2021 for 6 weeks working on this project to get trained on smart cities. They also developed a high-school short course according to the research experiences they had with this project. These two teachers are listed as below:
    - Joshua Rogers, Davis High, Fargo, ND, 06/15-07/31/2021
    - Martha Nelson, North High, Fargo, ND, 06/15-07/31/2021
- Imbedded Sensor installed at MnRoad facilities, R. Bridgelall.
- Draft paper: Zhou, Y., S. Awasthi, I. Khan, and K. Vachal. "Reducing Reoffense in First-Time DUI Cases, A Machine Learning Approach," to be published.

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

- We have developed a series of new deep learning-based models for bridge subtyping (aka, bridge family generation). A bridge subtyping model can be used to automatically identify bridge-groups/families that behave similarly in terms of deterioration performance or carry similar structural characteristics. These families are in turn used for developing more accurate bridge deterioration models that are customized for each bridge family. We are in the process of preparing a publication to disseminate our results from comparative evaluation of the models.

University of Denver

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

University of Utah

- A new method for creating a hybrid bridge bent is to use stretch length anchors as the energy dissipaters and post-tensioned columns for self-centering the bridge bent in seismic events. The new method has been shared with engineers from FHWA. The method has been determined to be promising and is currently being considered for adoption by FHWA with some additional research.

- We have prepared 9 reports presenting current and proposed routes for 9 cities in Utah. For each report, we also prepared several YouTube animations compering current and proposed routes. Example animations for one city (Logan), are provided here:
    - https://www.youtube.com/watch?v=BhgK-38UUiY
    - https://www.youtube.com/watch?v=dOhfWiPWsZo

- We prepared and submitted a proposal for ACRP (airport cooperative research program) student design competition and won the first-place award in this nationwide competition. Link to the competition website: https://vsgc.odu.edu/acrpdesigncompetition/2021-competition-winners-3/

University of Wyoming

- A new design framework is proposed to design speed limits on horizontal curves for trucks in terms of the main threats on curves, skidding and rollover events. The proposed framework will assist Wyoming's roadway agencies in imposing more appropriate speed limits for trucks on hazardous sections based on the weather conditions.
- The first prototype was provided to WYDOT. After testing, several modifications were done to avoid the interference of the WYDOT CB radio with the device.
- The accelerated pavement testing (APT) was reviewed as a multi-purpose testing facility considering both pavement and non-pavement research activities. A comprehensive literature search was conducted to demonstrate how testing facilities can be involved in both pavement and non-pavement research initiatives. As part of the review, a text data mining was also conducted to investigate the current trends of APT research along the three APT conference proceedings (4th, 5th, and 6th conferences) in 2012, 2016, and 2020, respectively.
- A conceptual design was proposed for the testing facility in Wyoming considering recommendations derived from MnROAD, NCAT, and FDOT testing facilitates. Two alternatives were initiated for the facility including the test track and onsite facilities. The first alternative considers a full onsite layout with staff permanently assigned for testing facility research operations and management. It was found that the total area of the facility is estimated as 120 acres. The second alternative assumes remotely administrations from WYDOT office. In this case, the onsite facilities will be limited to only storage buildings and roadside data cabinets. It was found that the estimated area will be reduced to 80 acres.
- The appropriate location of the proposed road track facility in Wyoming was investigated along I-80 segments between Laramie and Cheyenne. The spatial data of traffic, safety, geometry, and environment were integrated to define the most suitable locations on I-80 so that the proposed locations would display lower crash rates, representative traffic loading and suitable geometric characteristics. A multi-criteria decision analysis was conducted using Geographic Information System (GIS) and the results propose four different zones to possibly construct the road track facility.
- Harish Kalauni and Nafis Masud will receive the Best Student Paper Award-runner up from the Deep Foundation Institute in October 2021.

Utah State University

- The data set linked below is from MPC-603 (Investigating Bicyclist Safety Perceptions and Behaviors at Roundabouts). It contains survey data as well as information about the analysis of stated preferences. Future releases will contain information about the analysis of perceived comfort and stated behaviors. https://doi.org/10.5281/zenodo.51077384

4. Outcomes:

i. **Significant** outcomes by university:

University of Denver: The results of the validation of the Alert Meter study continue to be sought after and shared with industry leaders. In addition, additional interest in the role of safety culture in the prevention of accidents and injuries also appears to be of continued interest.

University of Utah: One project was completed on hybrid bridge bents for seismic regions. Conference presentations and a journal paper have been presented and published; in addition, a proposal was submitted to Federal Highway Administration to optimize the parameters and provide further recommendations on the system developed. Ongoing transportation-related research has resulted in YouTube animations of current and proposed snowplow routes. A proposal for the Airport Cooperative Research Program won the first-place award in the student design competition.

Utah State University: The publication of the following paper by USU associated authors is a significant publication because of how it lays a framework or foundation for the future higher adoption electrified transportation system.

Published: Jansuwan, Sarawut, Zhaocai Liu, Ziqi Song, and Anthony Chen. "An Evaluation Framework of Automated Electric Transportation System." Transportation Research Part E: Logistics and Transportation Review, 148(102265), 2021. DOI: 10.1016/j.tre.2021.102265.

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) To develop advanced bridge inspection and robust automated pothole detection techniques and to update bridge inspection planning process to align with new FHWA guidance.
(2) Increased understanding of the new methodology to simulate the travel speed and travel time for roadways with disruptions and improved resilience-based recovery of the transportation network through new decision-making framework for scheduling and green infrastructure storm water management.
(3) Integrated technologies and advanced techniques to assess swelling potential of expansive soil and effectiveness of treatment technologies and the probabilistic landslide modeling to understand potential slope failure risks.
(4) Increased understanding of the crash mechanism of high-profile moving vehicles under strong crosswinds and the risk of vehicles in hazardous driving conditions.

The bridge inspection techniques will be improved by providing low-cost and high efficiency UAS based inspection techniques and advanced data analytics tools for extracting structural condition information from the images. A unique and valuable database of geotagged and labeled trios of visible, thermal, and fused images is developed for training pothole detection algorithms. Automated tools for pothole detection, pothole mapping and updating for use by state DOTs and highway maintenance team.

Resilience-based studies have increased the body of knowledge of traffic performance, how EMS traffic can be improved by the new modeling techniques, a bilevel decision-making framework for the resilience-based recovery scheduling of the transportation network in a mixed traffic environment with connected and autonomous vehicles (CAVs) and human-driven vehicles (HDVs), and the effect of green infrastructure on roadway flooding.

The probabilistic landslide modeling performed during this period has increased our understanding of which parts of the landscape are most susceptible to potential slope failures.

Improved understanding of the crash risk of high-profile vehicle under wind project is expected to achieve through preliminary insights and guidance in appropriate level of CFD modeling required to get estimates of wind loads (magnitude and direction) on vehicles; preliminary modeling of SVC occurrence based on wind loads from CFD, and suggestions on safety preventive measures which may lower the associated risks.

North Dakota State University

The projects at North Dakota State University will have the following impacts: roadway related impacts include (1) increased reliability for swelling clay predictive models; (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; (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; and (6) in a related local rural crash risk area, a best practice core identified for the local road stakeholders including identification method, timing and funding sources; along with railroad research impacts in (7) increased knowledge and technical understanding to improve application and cost effectiveness in implementing smartphone-based sensors to monitor rail track surface condition; (8) enabling rail rolling stock within the Internet-of-things (IOT) as relevant in connected vehicle technology and big data processing.

South Dakota State University
The 11 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 system, 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, update testing methodologies for in-situ acceptance of the compacted granular bases, and improved understanding of the effectiveness of nutrient removal from stormwater runoff using woodchips.

University of Colorado Denver
These projects all progressed very well over the last project period and with 18 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 app 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 and; 4) the discovery of the impact of USDOT policies on the health and safety of drivers during the pandemic.
1) The project "Validation of Smartphone Alert meter 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.

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 the area of bridge resilience so that using the two hybrid systems developed (Stretch Length Anchors or Buckling Restrained Braces) 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 on the effectiveness of Lightweight Cellular Concrete as an approach slab support system 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) Increase the body of knowledge of how mechanical tests (specifically the IDEAL CT test) can relate to the performance of balanced asphalt mix designs thus 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 and thus improve driver decision-making by reducing the crash risks resulting from roadway geometries; (8) Increased the body of knowledge regarding an alternative method (Photogrammetry) for asset management practices for highway assets and within public transportation agencies; (9) Increased the body of knowledge regarding the expected magnitude of settlement or heave that will occur from strains within the embankment and provide UDOT better ways to ensure that bumps at the ends of bridges are minimized; (10) Increased understanding of the unique spatiotemporal patterns of micro transit which will help 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 simulated seismic excitation which will help UDOT construct bridges using durable materials for accelerated 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, by collecting traffic flow information, speed limit records, weather index data, and crash rates; (13) Increased the body of knowledge regarding the flexibility index of asphalt mixtures to improve the design and cost-effectiveness of pavement materials; (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 stakeholders; (16) Improved the body of knowledge regarding efficient snowplow routes for nine cities in Utah in terms of total vehicle miles traveled and lower turnaround times that will reduce UDOT's operational costs; (17) Guidance regarding numerical models for analysis of footing-to-column connections that can be used to design bridges in high seismic regions using accelerated bridge construction methods; (18) Improved the body of knowledge regarding a new robust and accurate autonomous measurement method using vision-based techniques for airport operations categorized as departure, landing, and touch-and-go operations; (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.

University of Wyoming

(1) Increases the level of knowledge in multiple areas related to transportation.
(2) Publishing a significant number of papers as part of our technology transfer.
(3) Develop a new device which will help in establishing passing/no passing zone. Such device will enhance safety and increase the efficiency in establishing passing/no passing zones.

Utah State University

The projects at Utah State University (USU) will have the following outcomes: (1) an optimization framework for planning and modeling of electrified infrastructure; (2) an analysis of the preferences for roundabout attributes among bicyclists; (3) improved material and structural designs for use of electronics in dynamic power transfer applications within pavement; (4) an increased understanding of the structural behavior of grouted couplers in bridge piers; and (5) an analysis of traveler behavior and traveler responses to perceived changes in air quality.

The above listed outcomes will come as a result of several targeted projects that are described individually by the individual researchers. Namely, transportation system studies related to planning of an electrified system will result in the important distinctions between the existing US transportation system and the not-too-distant-future electrified infrastructure transportation system. The outcome of improved pavement designs will be realized because of collaborative work with the ASPIRE ERC located at USU which focuses on electrified transportation systems and pre-pilot exhibition projects which investigate alternative designs for future adoption for highway applications.

5. Impacts:

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

Colorado State University

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

(1) Cost-effective bridge and pothole inspection will save cost, allow for improved accuracy and new findings.
(2) The new traffic flow simulation technology, resilience-based modeling techniques will increase the simulation accuracy, reduce congestion and potential flooding and save cost.
(3) The knowledge about swelling soil and landslide risk will help utilize and protect soil and infrastructures.
(4) The vehicles in adverse driving conditions including strong crosswinds can become safer with the increased knowledge of associated risk.

A portable sensing technique for measuring displacement. This technique does not require the instrumentation of the structure, or interruption of traffic, thus is more convenient and cost-effective. The cost-effective bridge inspection method will save inspection costs up to 40%. The new inspection technique also allows more quantitative condition assessment (enabling identification of damage location, severity, and type), which is superior to the existing practice. The developed pothole inspection tools will automate the data collection and damage identification and will help decrease the cost of road condition data collection and assessment and will help improve safety of roads.

The developed traffic time and network simulation technique can increase travel time simulation accuracy which will contribute to improved evacuation and traffic planning. The new resilience-based scheduling technique can reduce congestion and restore traffic more effectively following earthquakes. Current practices mostly implement gray stormwater infrastructure for reducing roadway flooding. This work shows that the emerging and increasingly implemented green stormwater infrastructure (bioretention was used as an example type of green stormwater infrastructure in this project) can also have a benefit in reducing roadway flooding.

The integrated technologies and advanced techniques can better assess swelling potential of expansive soil and effectiveness of treatment technologies. The study at CSU has demonstrated a potential shift in areas susceptible to landslides under changing climate scenarios. That has potential impacts on management and planning of transportation systems, as areas may become more (or less) vulnerable to landslide hazard over time, and knowledge of these hazards may influence the decision-making process.

The findings of traffic safety risk assessment of vehicles under adverse driving environment and under work zone conditions can help developing science-based traffic operation and management strategy, such as advisory driving speeds and critical weather conditions to close the traffic on roads and bridges out of safety concerns. Traditionally traffic management under adverse weather were mainly conducted under generic criteria or experience. The study of crash risk under crosswinds pertains to improved safety guidance to mitigate crash risks for high profile vulnerable vehicles.

North Dakota State University

The projects at North Dakota State University will have the following impacts: roadway related impacts include (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 extreme imbalanced data set.; (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 course work for certification and now must complete classroom work. The Alive @ 25 program will provide tribal teens and insight to greater responsibility while driving, focuses on their behavior, judgment and decisions making while driving and provide tools for making positive choices. The tribal liaison continues to participation in tribal conferences, TRB committees and engaging in other association and activities provide an opportunity to engage and increase tribal awareness to transportation issues. She has also provided trainings to indigenous workers helps to promote safety in transportation. The tribal liaison lead the Tribal Sign Warrior program encourages our youth to be aware of the 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.; and (6) in a related local rural crash risk area, a best practice core identified for the local road stakeholders including identification method, timing, and funding sources. Rural road local crash GIS layer validation for the NDDOT ESRI layer used in the USDOT all public roads reporting HPMS annual road segment file submission. Process and documentation to update and validation local rural road systems and segment, including ownership and surface type, based on information from GRIT (local road managers), the NDDOT and other data repositories.; along with railroad research impacts in (7) increased knowledge and technical understanding to improve application and cost effectiveness in implementing smartphone-based sensors to monitor rail track surface condition; (8) enabling rail rolling stock within the Internet-of-things (IOT) as relevant in connected vehicle technology and big data processing; and (9) the collaborative COVID-19 traffic investigation proposed a new streaming learning model to significantly improve Physics Regularized Gaussian Process training time thus reduce the computational complexity while maintain reliable and accurate prediction performance.

South Dakota State University
The 11 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 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, guidelines on bridge deck sealant applications, develop a network screening method for an improved safety remediation measures, reduce the possibility of insufficient field soil compaction, and develop a new stormwater filtration technology using drinking water treatment residual coated woodchips.

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 will be integrated into NREL's Hive transportation network technique, which will help increase the efficiency of fleet route planning, ride sourcing, and ridesharing.

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 to Improve Safety Culture that is expected to lead to fewer crashes, accidents and injuries resulting in greater safety and reduced costs. 2) Provide leaders of transportation organizations with a more tools for managing fatigue using mobile hand-held alertness measuring device, 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 of policies for maintaining driver health and safety operating during a pandemic.

University of Utah
The projects at the University of Utah will have the following impacts: (1) The transportation planning community will have greater confidence in vehicle-miles traveled forecasts incorporating specific assumptions about automated vehicle market penetration; (2) Research on replaceable stretch length anchors or buckling restrained braces combined with post-tensioned columns has resulted in seismically resilient bridges; implementation of such bridges will significantly decrease traffic closure times and reduce financial impacts for recovering communities after an earthquake; (3) Research on asphalt pavements will have a significant impact by allowing pavement designers to select materials that are better suited for their specific transportation system; elimination of poor materials will result in cost-effective designs that increase the longevity of the transportation system with 10% potential savings; (4) The technology screening and selection process developed for mitigation of differential settlements at bridge approaches will result in technologies that will reduce differential settlements and this will improve the safety and transport of people and goods on roadways; (5) The improved understanding of the influence of native subgrade and fill materials on the performance of pavement systems constructed on soft subgrades will result in roadway systems that perform better and require less long-term maintenance than current practice; (6) Research using extensive simulation studies under various geometrical design conditions has resulted in better understanding of how connected automated vehicles can improve road safety; (7) A new cost-effective approach for collecting spatial data of the as-is condition of infrastructure assets has been performed using four data collection methods: mobile photogrammetry, mobile light detection and ranging, unmanned aerial vehicle photogrammetry, and unmanned aerial vehicle light detection and ranging; in addition, pedestrian access ramps were modeled in a stationary-terrestrial setting using photogrammetry and light detection and ranging; for city routes and detours close-range mobile photogrammetry is a feasible and low-cost approach but for state highway inventory a combination of mobile light detection and ranging and mobile photogrammetry should be used to lower costs; (8) Research on loading and wetting-induced settlement of bridge approaches will result in a significant reduction settlement/heave of approach embankments for bridges, thereby mitigating problems with bumps at the ends of newly constructed bridges; (9) Research on impact of mobility as a service mode for transit access shows that by understanding the patterns and possible causal factors for micro transit network development one can enhance the transferability of micro transit programs without additional cost; spatiotemporal structures of micro transit usage reveal that the usage is uneven; the two-peak temporal pattern demonstrates many variations resulting from first mile/last mile trips; by comparing results between pre- and post-COVID

periods, it is possible to inform transit agencies on behavioral changes and evolution of travel patterns to guide operational strategy; (10) Research on bridge columns built using glass fiber reinforced polymer longitudinal bars and spirals shows that bridges constructed using these materials will not only be durable but also will to some extend be seismically resilient because of the elastic self-centering properties of the glass fiber reinforced polymer bars; this will reduce replacement costs due to the combined effects of corrosion and earthquakes; (11) Research on hybrid changeable message signs will improve the knowledge of public agencies in understanding how the visibility of transportation signage such as speed limit signs could impact driver behavior and road safety performance; (12) Better understanding of the performance of pavement systems constructed on soft subgrades, both without and with geogrid reinforcement, will result in roadway systems that will perform better and require less long-term maintenance; (13) Research exploring delivery options with drones instead of trucks appears to be promising in terms of reducing cost, saving fuel, and reducing carbon emissions; a statewide policy regarding drone delivery is being researched that will assist public agencies to take a holistic view on the regional impact of drone delivery to improve environmental sustainability and competitiveness; (14) Research has shown that improvement of snowplow routes for nine cities has resulted in reduction of vehicle-miles traveled and turnaround times to clear the snow; there was a 10% reduction in total vehicle-miles traveled, which reduces the cost of winter maintenance, and a 20% reduction in turnaround times, which provides a higher level of service to taxpayers; (15) Research has resulted in a numerical model of footing-to-column connections which will facilitate the design of bridges in seismic regions; bridge designers will be able to implement accelerated bridge construction in seismic regions more efficiently by being able to better predict the performance of such footing-to-column connections for a variety of possible designs; (16) Research on automated image-based aircraft tracking has developed a vision-based method that is effective regarding both accuracy and cost; it overcomes the challenges that exist in detecting aircraft operations at non-towered airports, which account for more than 97% of the airports in the US, and addresses the issues and drawbacks inherent in existing operation counting methods; accurate measurement of aircraft operations will result in fair allocation of national funds across the country and accurate preparation of airport master plans; environmental studies will benefit from having an accurate tool to estimate aviation fleet mix information for pollution and noise emission; (17) Research on coordinated ramp metering strategies for freeways will provide more case studies, based on the field-collected data, to better evaluate and understand the freeway performance under the ramp metering control; with better understanding, travelers will have a safer, faster and more comfortable travel experience.

University of Wyoming
MPC 631 will help in providing safety partners with appropriate information so that they can come up with plans to enhance safety around the state.
MPC 600 resulted in an actual device to establish passing/no passing zones.
MPC541 will help counties in managing gravel roads more efficiently.
MPC 655 will provide DOTs with better understanding of motorcycle related crashes so that countermeasures can be developed to reduce the number and the severity of such crashes.
MPC 574 will result in selecting better speed limits in mountainous areas. Selecting more appropriate speed limits will result in less crashes.

Utah State University
The projects at Utah State University will have the following impacts on the effectiveness of the transportation system: (1) a more efficient traffic throughput; (2) a more satisfied bicycling traveling public; (3) a more durable pavement for longer lasting and less expensive highways; (4) a system that is safer and more reliable for the roadway users; and (5) a more informed traveler that will contribute to a less pollution generating system by individual choices.
The above listed impacts will occur because of the focus of each of these projects toward answering these significant questions.

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 bridge and pavement inspection techniques bear potential to be adopted by industry and state agencies.
(2) Disruption models and traffic performance and resilience modeling techniques may potentially be adopted by city management and transportation departments.
(3) The developed landslide runout model may eventually be applied to risk assessments evaluating landslide hazard.

(4) Traffic safety studies on vulnerable vehicles may be adopted by DOT.
The developed bridge inspection data analytics tools for quantifying, tracking, and localizing the changes of damage are expected to be useful for inspection industry and state DOTs. The developed pavement pothole automated tools can be adopted by CDOT maintenance teams to facilitate fast and cost-effective road condition data collection and assessment.

There is no appropriate model which can predict tree failure under hazardous weather (e.g., wind) and the impact on road debris based on advanced modeling. The proposed technology may be adopted in new practices of tree debris modeling by city management and traffic departments to predict potential impact from hazardous weather. There is no appropriate traffic recovery strategy for urban communities following natural hazards. The proposed recovery planning technology may be adopted in new recovery practices by city management. The results from the green stormwater infrastructure work are relevant to stormwater drainage municipal entities and was disseminated through an invited seminar at the Salazar Center (Salazar Center for North American Conservation Webinar panelist on Water Management, Community, and Urban Resilience discussing "How effective is green stormwater infrastructure for urban streams and streets?", Virtual, 12 August. http://salazarcenter.colostate.edu/events/urban-flooding-webinar/) and an article in the Colorado Water magazine.

The results on the landslide risk study show that within our study area, topographic controls provide plausible initial estimates of runout endpoints and an improvement over similarly simplistic methods such as the angle of reach. The potential of using critical slope combined with slope persistence to capture topographic controls to predict runout endpoints is a promising opportunity for landslide hazard mapping at large spatial extents.

Existing DOT traffic operation does not have a consistent and science-based approach to quantify crash risks of vulnerable vehicles in various adverse conditions. The proposed technology may have some potential to be adopted in future DOT practices. Crash risk of high-profile vehicles under windy conditions is quite challenging/complex given the degrees of freedom involved in assessing wind loads on vehicles under hazardous conditions. We anticipate that this work will be a first step in this regard and will lead to further research endeavors that 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 concerted research studies and industry collaboration.

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 relationships detail 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 DOT agencies will adopt the proposed AI-based methodology for traffic state estimates based on proposed with AI-based methodology in vehicle trajectory reconstruction.

South Dakota State University
The 11 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, and development of a new filtration technology for stormwater treatment.

University of Colorado Denver
With respect to completed project MPC-579, we met with representatives from America Walks and PAPREN (the Physical Activity Policy Research and Evaluation Network, which is sponsored by the CDC) to share our research insights on sidewalk infrastructure data collection. We expect the progress we made with this project in terms of turning remotely sensed impervious data into usable sidewalk metrics will lead to cities adopting new practices.

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.

University of Utah
The projects at the University of Utah will have the following impacts on adoption of new practices: (1) Research on exploratory modeling and analysis for automated vehicles will inform long range transportation plans of regional transportation agencies; automated vehicles will integrate into the vehicle fleet over time and not accounting for them will certainly underestimate future vehicle-miles traveled; (2) The results of research on resilient bridge bents with replaceable stretch length anchors or buckling restrained braces for accelerated bridge construction in seismic regions are being examined by the Federal Highway Administration for future implementation; adoption of this new system will result in significantly shorter recovery times of the transportation network after an earthquake; (3) Research on field performance on asphalt pavements will result in the adoption of a mechanics-based test to select and design balanced asphalt mixtures; highway agencies will likely include the test methods from this work in their specification, first as a trial-method and then as a standard specification for the design of pavement materials; (4) Research on mitigation of differential settlement at highway bridge approaches using lightweight cellular concrete technology will soon be ready for implementation by highway agencies; the first phase of this implementation will be a "demonstration" project where lightweight cellular concrete will be installed and monitored; (5) Development of better design and construction guidelines for geogrid-supported pavement systems should result in wider use of this technology within roadway systems by private and public sector pavement designers; (6) Research on the impact of connected automated vehicle technology on traffic safety under different highway geometric designs could provide a comprehensive study on the correlation between connected automated vehicle safety and road geometric designs which can help transportation agencies identify the potential high crash spots; (7) Asset management and maintenance of pedestrian access ramps through remote virtual inspection is a reliable and accurate practice of inspection, and is recommended and encouraged by a research study using photogrammetry technology; (8) Based on research for loading and wetting-induced settlement of bridge approach embankment materials, it is expected that material and construction specifications for approach embankments for bridges will be revised by public agencies; (9) Research focused on the underlying travel patterns associated with micro transit and their changes during the pandemic will help transit agencies understand the decline in micro transit ridership and the relationship between a public health crisis and micro transit demand; (10) Results of research for constructing bridges in seismic regions with glass fiber reinforced polymer bars and spirals will be transferred to transportation agencies and the Federal Highway Administration; such bridges are durable and seismically resilient as opposed to bridges constructed with mild steel reinforcement which would have to be repaired or replaced because of corrosion and residual deformation issues; (11) Average speed and speed variation on the I-80 corridor have been reduced after implementation of new changeable message signs; driver compliance rate, which is the critical indicator of the variable speed limit system performance, has also been improved and has resulted in significantly lower crash rates and with less severity; (12) Successful completion of research on field evaluation of geogrid-reinforced pavements will result in better methods of design and analysis of both unreinforced and geogrid-reinforced pavement systems within Utah and surrounding states; (13) The developed system model for drone centers for drone delivery in Utah with the optimization component will be implemented onto a web-based platform where people can assess different assumptions of the model and run “what-if” scenarios by generating animation of the optimized airspace network; (14) Research on proposed routes for snowplowing, some of which have already been implemented by UDOT, has shown that they are more efficient compared to UDOT's current routes both in terms of vehicle-miles traveled and turnaround time. As an example, for South Logan, Utah, the proposed routes reduced vehicle-miles traveled by 11% and turnaround time by 22%; (15) Research on connections for bridges constructed with accelerated bridge construction technology in seismic regions will be transferred to transportation agencies that want to use accelerated bridge construction in high seismic regions; the methods developed in this research along with the recommendations provide new ways of designing such connections with very promising results; accelerated construction methods will provide faster and better construction regarding seismic performance; (16) The methods and algorithms developed in research on automated imaged-based aircraft tracking can be used by

transportation agencies as an alternative solution to existing aircraft counting and monitoring methods; (17) Research on coordinated ramp metering strategies will provide transportation agencies with a prediction of potential mobility and safety benefit by adopting coordinated ramp metering; the research has also reviewed historical traffic data and assisted UDOT in identifying control bottlenecks.

University of Wyoming
The main practice is the adoption of a newly developed device to establish passing/no passing zones on two lane highways. We are in the process of producing prototype 2 which will incorporate more ITS technology. There is a good potential that prototype 2 might be commercialized in the future.

Utah State University
The projects at Utah State University will have the following impacts on the adoption of new practices and potential commercialization: (1) provide direction for standardization of electrified infrastructure which in turn will result in interoperability between vehicle types and manufacturers; (2) will eventually help to suggest effective strategies for travel demand management surrounding episodic air pollution events; and (3) can help transit agencies to optimize their planning of a fast-charging BEB system. The research results have potential to facilitate faster adoption of BEBs in urban areas and thereby improve environmental sustainability and the livability of urban communities.

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) New and more advanced models for modeling and detecting deterioration and damage of bridges and pavement pothole.
(2) Traffic performance studies on disrupted traffic network following natural hazards will produce new knowledge on how traffic performance will be affected by disruptions, mechanisms of some disruptions and how scheduling can improve resilience.
(3) New experimental technique has been developed for expansive soil and new findings are found in terms of landslide initiation mechanism.
(4) New simulation models have been developed to study traffic safety risk under adverse driving environment and new guidelines may be developed from the wind-induced rash risk study of high-profile vehicles.

The studies on bridge inspection have developed new image computation and machine learning algorithms, which are effective for damage quantification, tracking and localization. Also have produced new and more advanced models for modeling bridge deterioration, which will contribute to better management and preservation of bridges. The study on pavement pothole will produce new knowledge on the use of machine learning techniques to automate tasks related to inspection and maintenance of road transportation network.

The new mechanisms of disruption caused by earthquakes and tree failure under wind hazards and possible debris have been studied. New algorithms of recovery efforts have been developed to increase traffic network resiliency. A study has produced new knowledge on assessing the mobility of EMS traffic and the possible intervention ways during the response and recovery stages following hazards.

A new experimental methodology for measuring the moisture dependent behavior of expansive soils and expansive soils treated by physical and chemical stabilization technologies. We have shown that vegetation, which impacts cohesion and soil depth, has a large impact on the landslide initiation model. After incorporating climate change effects, we see an increase in the areas susceptible to landslides and a shift to more instability on north-facing slopes. Our study suggests that vegetation changes due to climate change could result in major shifts in the people and infrastructure susceptible to landslides in the Colorado Front Range.

Traffic safety study of traffic under adverse driving environment has developed an improved simulation methodology to assess traffic safety risks of vehicles under adverse driving conditions, which has not been conducted before. The study on high-profile vehicle crash risk under wind help towards improved safety assessment and development of guidelines for management of traffic movement under extreme meteorological conditions. It will also in a broader context inform policy decision making that can mitigate negative (e.g., high economic costs) impacts associated with vehicular accidents.

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; and (5) improved WIM data quality understanding and use in pavement design and performance; (6) advanced, AI-based, traffic prediction methods in real-time estimates.

South Dakota State University
The 11 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 a 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, and producing new data on nutrient removal by water treatment residual coated woodchips.

University of Colorado Denver
Given our extensive publishing 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 is 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 a transportation organizations which will provide a basis for testing the most effective approaches for undertaking organizational change; 3) By 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.

University of Utah
The projects at the University of Utah will have the following impacts on the body of scientific knowledge: (1) greater certainty surrounding the impact of automated vehicles on vehicle-miles traveled to understand future capacity needs; (2) better understanding of how to build a new type of bridge that is functional after a strong earthquake using replaceable structural elements; (3) better understanding of the performance of asphalt pavements and its correlation with low and intermediate temperature tests which will assist in implementation of the technology; (4) laboratory testing of lightweight cellular concrete will be used to determine its fundamental material behavior under static and cyclic loading at varying amounts of saturation and this information will be used to better plan, design, and construct embankments in bridge approach areas; (5) results from research on geogrid use in pavement systems will improve the base of knowledge within the civil engineering field with respect to economical design of pavement systems; (6) results from research on connected vehicle technology will produce new guidance on vehicle dynamic modeling under the connected automated vehicle environment and support other safety-related studies when real-world data is not available; (7) research using photogrammetry technology has demonstrated the extent to which different factors, including the speed of the data

collection platform, can affect image alignment accuracy which is an important step in image-based three-dimensional reconstruction; (8) our understanding of the loading and wetting stress-strain characteristics of various types of soils used in the civil engineering field was greatly enhanced; (9) research has shown that developing a framework that provides the geospatial intelligence required for improving system performance is crucial for micro transit service sustainability, and in addition the influence of COVID-19 on micro transit is easily observable; (10) methods to build bridges with glass fiber reinforced bars and spirals were developed that when combined with traditional steel reinforcement create bridges that are not only durable but also seismically resilient; (11) machine learning safety models including artificial neural network and support vector machine models are developed to study crash frequency and severity along the I-80 corridor and investigate road safety improvements using variable speed limit deployments; (12) results from research on the design and analysis of pavement systems, both without and with geogrid reinforcement, will result in significant improvements in the civil engineering field; (13) utilization of optimization techniques, geographic information system, and visualization will enable the fostering of the next generation traffic engineers with advanced skillsets in analyzing infrastructure conditions; (14) a novel optimization model is being developed to allocate snowplow trucks across cities to minimize the expected turnaround time, subject to stochastic failures of trucks, and bring additional efficiency to snowplow truck operations; (15) knowledge gained from numerical modeling is improving design methods for bridges that will be constructed using accelerated bridge construction methods in high seismic regions; (16) object detection algorithms are implemented for detecting aircraft objects in video footage recorded in airports and accurate models such as deep neural networks are tested for aircraft operation detection; (17) research provides a guideline as to which ramp metering control algorithm should be used, the expected system performance improvement, and the best location for deploying a coordinated ramp metering control system.

Utah State University

The projects at Utah State University will have the following impacts on the body of scientific knowledge: (1) will fill a gap in the body of knowledge surrounding connected vehicles (CVs). There has been significant research on the design of CVs and the benefits (safety, operational, environmental) of deploying CVs. However, there has been little to no research on public acceptance of this technology nor their willingness to share data (which has been heralded as an upcoming, powerful source of big data); (2) provide the framework for simultaneously determining the deployment of fast-charging stations, the battery capacities of BEBs, and the recharging scheduling of BEBs for a fast-charging BEB system. The research findings will have theoretical significance as well as offer a wide range of applications for implementing more sustainable public transportation systems; and (3) solve the simultaneous challenges of heat dissipation from electrified power transfer as well as provide structural reliability and durability.

d. What is the impact on transportation workforce development?

Colorado State University

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

(1) providing training opportunities for graduate students and undergraduate students on almost all projects.
(2) some findings will be integrated into some graduate education.
(3) some projects will help the outreach efforts.

The pavement loophole detection technique will be used in a graduate level course developed by the PI on surrogate models. Also, the example in this project will also be used for outreach activities jointly with the Drone Center at Colorado State University. Findings of high-profile vehicle crash risk study under strong crosswinds pertain to both fluid flow modeling and vehicle dynamics (and their interactions) will be leveraged to challenge and excite students in both of the PIs graduate courses in Computational Fluid Dynamics (Venayagamoorthy) and Traffic Engineering (Chen) at Colorado State University.

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 and project efficacy techniques; (4) existing workforce contribution with improved tribal and local road manager access pragmatic and relevant safety investment data and tools; and (5) increased awareness of individualized driver improvement countermeasures and their integration as data-driven approaches among traffic safety workforce professionals.

South Dakota State University
Three PhD, 12 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 Colorado Denver
The 18 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 (virtually, for now) 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) Providing 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.

University of Utah
The projects at the University of Utah will have the following impacts regarding transportation workforce development: (1) two graduate students are involved in research on modeling and analysis of automated vehicles; a graduate-level course "Traffic Operations Analysis" is being offered every year and the framework developed will lead to new material to teach students practical skills on simulation and analytic techniques; (2) research on accelerated bridge construction in seismic regions has involved one MS and one PhD student and the MS Student is currently employed in Utah; new materials developed in this research is used in a graduate-level course on "Prestressed Concrete Design" and "Bridge Design"; (3) two graduate students involved in research on asphalt pavements have graduated and have joined the workforce; moreover, two new students have joined the research group; (4) research on mitigation of differential settlement is providing support for one PhD and two MS student researchers who study geotechnologies applied to transportation systems; in addition, the methodologies and research results are being used in course materials; (5) research on use of geogrid in pavement systems has provided exposure to many aspects of the transportation field to five students; as the research gets disseminated through workshops and incorporated in coursework, many practitioners and students will be exposed to the outcomes of the research and the importance of transportation systems; (6) two Ph.D. students have received research training in research related to connected vehicle technology; research results have been integrated into the course on "Transportation Engineering"; (7) for the research involving image-based three-dimensional reconstruction of roadway assets, one PhD student, one MS student, and one undergraduate student received research training during the project; (8) research on loading and wetting-induced settlement of bridge approaches has provided exposure to many aspects of the transportation field to three graduate students; (9) two graduate students and one research assistant professor have been involved in the project on impact of mobility as a service mode on transit access; (10) one PhD student is involves in performing research for the project on durable bridges using glass fiber reinforced polymer materials; (11) two Ph.D. students are supported from the project on changeable message signs and have received research training during this project period; one undergraduate student has also been involved in data collection and data analysis; (12) research on field evaluation of geogrid-reinforced systems has provided exposure to many aspects of the transportation field to at least three graduate students who are working on this project; (13) one graduate student is involved in the research on deployment of drone centers; the modeling framework developed will lead to new material included for a graduate-level transportation course on visualization and analytical techniques for modeling air transportation networks; (14) two PhD students have developed technical skills to tackle challenging, real-world optimization problems for the research on snowplowing operations, while UDOT practitioners learned about algorithmic approaches to improve the efficiency of their operations; (15) research on analysis of bridges built with accelerated bridge construction methods in seismic regions has enabled one MS student to be involved in research and who will likely continue for PhD studies; (16) research on automated image-based aircraft tracking provided training to one graduate and one undergraduate student who participated in data collection and airport visits; (17) research on coordinated ramp metering strategies for Utah freeways has supported one PhD student who has also been coordinating his research with UDOT using field data.

University of Wyoming
We have presented lots of workshops and incorporated the findings of our research studies in multiple classes taught at UW.

Utah State University
The projects at Utah State University will have the following impacts on transportation workforce development: (1) provide training and experience for undergraduate and graduate students, as well as post-doctoral researchers in many aspects of the transportation field; and (2) generate significant public interest in advances in electrified transportation which will affect future workforce coming from K-12 as well as the existing adult population.

e. Based on the above responses, please address any significant impacts?
University of Denver
The most significant impact of our research project continues to be: 1) The Safety Culture measures has been adopted by at least one other transportation agency as a tool for measuring its effectiveness; 2) The validation of and 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.

University of Utah
Further research on resilient bridge bents with replaceable stretch length anchors for accelerated bridge construction in seismic regions, which was studied under the MPC-545 project, has recently been funded by the Federal Highway Administration to facilitate future implementation; adoption of this new system will result in significantly shorter recovery times of the transportation network after a large earthquake.

6. Changes/Problems
University of Denver
Overall, due to the highly interpersonal nature of our research involving human subjects, interviews, survey delivery and completion and the associated travel in gathering data, the COVID-19 pandemic has created logistical problems and delays in data collection and technology transfer by prohibiting contact with research study participants, drivers, and other professionals. Some progress has been made recently using electronic data gathering. The IRB approved a change to our protocol and data collection is underway. However, only virtual conferences and meetings were possible during this past reporting period. Plans to do more virtually in the next reporting period are planned.

University of Utah
The Coronavirus has impacted several projects which involve laboratory experiments; as such these projects have been delayed, however, it is anticipated that after some time these effects will be mitigated, and the research will be completed.

Utah State University
Some of the research and studies have been delayed due to restrictions of existing laboratories. Additionally, face to face interactions have slowed progress due to work among colleagues and students. Some projects have been significantly delayed while others have had very little effect. Travel restrictions are another area that has negatively impacted the dissemination of research results.

7. SPECIAL REPORTING REQUIREMENTS:
a. T2 Performance Measures and Targets are listed in Appendix E.