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
NDSU Dept. 2880, P.O. Box 6050, Fargo, ND 58108-6050

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Semi-Annual Progress Report #6

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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 Competiveness, 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-626** which can be found on the Mountain-Plains Consortium website

b. What was accomplished under these goals?

i. Project Selection

Ninety-three 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 6 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 of the necessary internal accounting and financial procedures were established, including subcontract agreements with consortium universities. Ongoing as we receive contract amendments each year.	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) (Apr20)	10/1/2020	09/30/2022
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	09/30/2022
Call for Proposals	Proposals are being solicited from each MPC university using guidelines developed by the MPC director.	12/1/2016	10/01/2021
Peer Review of Proposals	All project proposals are being subjected to external and internal peer review.	02/15/2017	10/01/2021
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	10/01/2021
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	10/01/2021
Site Visit	A site visit to all MPC universities are being conducted annually by the MPC Director.	11/30/2016	09/30/2022

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	09/30/2022

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, **134 transportation and transportation-related courses** were offered this reporting period, for a total of **584 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, **54 training sessions** were offered this reporting period for a **total of 371 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 **328 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 **74 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.

- Acme Distribution, Denver, CO, in-kind support
- Bay Area Transportation Commission, San Francisco, CA, in-kind support
- CALSTART, Pasadena, CA, financial support
- City of Brookings, SD, collaborative research
- City of Denver, Denver, CO, data
- City of Fort Collins, Fort Collins, CO, in-kind support

- City of Westminster, Westminster, CO, in-kind support
- CMA-CGM Maritime, Inc., Washington, DC, in-kind support
- Colorado Associate of Geotechnical Engineers, Denver, CO, in-kind support
- Colorado Dam Safety, Pueblo, CO, technical support
- Colorado Department of Transportation, Denver, CO, in-kind support
- Colorado Department of Transportation, Denver, CO, provided data
- Colorado Water Conservation Board, Denver, CO, financial support
- Compass Data, Inc., Centennial, CO, in-kind support
- Core Brace LLC, West Jordan, UT, in-kind support and collaborative research
- CSU Drone Center, Fort Collins, CO, facilities and assisted in training students
- Daktronics, Brookings, SD, in-kind and financial support
- Dayton Superior Corp., Miamisburg, OH, in-kind support
- Denver Regional Council of Governments, Denver, CO, in-kind support
- Dextra America, Inc., Bangkok, Thailand, financial and in-kind support
- East Dakota Water Development District, Brookings, SD, financial support
- Engineering Department of Larimer County, CO, in-kind support
- Engineering R&D Center, US Army Corps of Engineers, facilities and in-kind support
- Forterra Structural Precast, Salt Lake City, UT, in-kind support
- Headed Reinforcement Corp., Fountain Valley, CA, financial and in-kind support
- Keolis Commuter Services, Boston, MA, in-kind support
- Massachusetts Bay Transportation Authority, Boston, MA, in-kind support
- Mineta Transportation Institute, San Jose, CA, in-kind support
- Minnesota Department of Transportation, Minneapolis, MN, data collection support
- MnROAD facility, Minnesota Department of Transportation, Monticello, MN, in-kind support and collaborative research
- Mountain land Association of Governments, Orem, UT, subject matter experts
- National Renewable Energy Laboratory, Golden, CO, subject matter expert, facilities, collaborative research, and personnel exchanges
- NDDOT Driver License Division, Bismarck, ND, in-kind support
- NDDOT Safety Division, Bismarck, ND, in-kind support
- North Central Regional Sun Grant Center, Brookings, SD, financial support
- North Dakota Association of Counties, Bismarck, ND, provided mailing list
- North Dakota Department of Health, Bismarck, ND, in-kind support
- North Dakota Highway Patrol, Bismarck, ND, in-kind support
- North Dakota Local Technical Assistance Program, Bismarck, ND, survey collection
- Northern Plains Railroad, Fordville, ND, data collection support
- nVent LENTON Corp., Solon, OH, financial and in-kind support
- Owens Corning, Seward, NE, in-kind support
- Owens Corning, USA, Seward, NE, in-kind support
- Predictive Safety, Denver, CO, financial and in-kind support
- RSG, Inc., Salt Lake City, UT, collaborative research
- San Joaquin Regional Transit District, San Joaquin County, CA, in-kind support
- SELECT Center, Logan, UT, collaborative research and in-kind support
- Sheet Metal and Rail Transportation, Washington, DC, in-kind support
- South Dakota Department of Transportation, Pierre, SD, financial support
- South Dakota State University, Brookings, SD, financial and in-kind support

- Spirit Lake Nation, Fort Totten, ND, subject matter experts
- Splice Sleeve North America, Inc., Livonia, MI, financial and in-kind support
- Splice Sleeve North America, Livonia, MI, in-kind support
- Standing Rock Sioux Tribe, Standing Rock Reservation, ND & SD, subject matter experts
- U.S. Department of Energy, Washington, DC, financial support
- University of Alabama, Tuscaloosa, AL, facilities and in-kind support
- University of Colorado Denver, Denver, CO, financial support, facilities, and in-kind support
- University of Sydney, Sydney, Australia, facilities and in-kind support
- University of Texas at Austin, Austin, TX, facilities and in-kind support
- Urban Drainage and Flood Control District, Denver, CO, in-kind support
- Utah Department of Transportation Traffic Operations Center, Salt Lake City, UT, data support
- Utah Department of Transportation Traffic Safety Division & Research Division, Salt Lake City, UT, financial support, data support, and subject matter experts
- Utah Department of Transportation, Salt Lake City, UT, financial support, and subject matter experts
- Utah Department of Transportation, Salt Lake City, UT, in-kind support (data sharing)
- Utah Department of Transportation, Taylorsville, UT, in-kind support
- Utah Department of Transportation, West Valley City, UT, subject matter experts and financial support
- Utah Transit Authority, Salt Lake City, UT, subject matter experts
- Virginia Railway Express, Keolis, Washington, DC, in-kind support
- Wasatch Front Regional Council, Salt Lake City, UT, subject matter experts
- Weiss Janey Elsner, Chicago, IL, facilities and in-kind support
- Wyoming Department of Transportation, Cheyenne, WY, facilities, in-kind, and financial support
- Wyoming Safety Coalition, Worland, WY, in-kind support
- Wyoming Technology Transfer Center, Laramie, WY, collaborative research

The above list of collaborators in research shows a strong federal, state, local, and private industry support of MPC research.

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 **72 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 **131 students from the U.S. and countries around the world.**

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.

Thirteen 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 and Mehmet E. Ozbek. In addition, twenty-six students are working on MPC research projects: Abdelrahman Abdallah, Yangyang Wu, Guangyang Hou, Kaisen Yao, Brandon Perry, Min Li, Douglas Woolridge, Zana Taher, Katie Knight, Qiling Zou, David Trinko, 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.

Nine principal investigators, faculty, and administrators are participating in MPC projects at **North Dakota State University** are: Ying Huang, Pan Lu, Raj Bridgelall, Dinesh Katti, Kalpana Katti, Denver Tolliver, Kimberly Vachal, Joy Annette, and Sharma Kshitij. In addition, sixteen students are working on MPC project: Mohanad Alshandah, Xinyuan Yang, Hafiz Usman Ahmed, Keshab Thapa, H M Nasrullah Faisal, Neeraj Dhingra, Narendra Malalgoda, Yihao Ren, Morgan Jacobson, Amin Keramati, Xiaoyi Zhou, Leonard Chia, Bhavana Bhardwaj, Sajad Ebrahimi, Dawei Zhang, and Erik Johnson.

Eight 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, and Rouzbeh Ghabchi. In addition, eleven students are working in MPC research projects: Euiseok Jeong, Ibin Amatya, Marco Paulo Pereira Castro, Maryam Mihandoust, Blake Jorgensen, Gunnar Kern, Abdoul Kouanda, Matthew LaVoy, Theodore Surest, Selene Tinklenberg, and Brian Kidd.

Nine 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, Yail Jimmy Kim, Meng Li, Carolyn McAndrews, Manish Shirgaokar, and Farnoush Banaei-Kashani. In addition, fourteen students are working on MPC research projects: Shahryar Monghasemi, Ahmed Ibrahim, Mallory Redmon, Shalini Mahanthege, Alayna Truong, Ricardo Gonzalez, Brady Heath, Molly North, Ghazal Batouli, Robert Fitzgerald, Mahdi Ghafoori, Nick Coppola, Yaneev Golomber, and Jun Wang.

Two principal investigator, faculty, and administrator is participating in MPC projects at the **University of Denver**: Patrick Sherry and Jesse Owen. In addition, eight students are working on MPC research projects: Sree Sinha, Emma Porter, Megan Solberg, Jeremy Coleman, Katherin Miller, Kailey Painter, Orphea Wright, and Jessica Mantia.

Eleven 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, Chris Pantelides, Abbas Rashidi, and Xianfeng Terry Yang. In addition, twenty-two students are working on MPC research projects: Zhuo Chen, Nima Haghighi, Zhiyan Yi, Dipendra Thapa, Ijan Dangol, Faramarz Safazadeh, Abu Sufian, Swastik Pohkrel, Abu Asib, Mohammad Farhadmanesh, Qinzheng Wang, Yirrong Zhou, Chandler Cross, Emad Ghodrati, Henrik Burns, Nadereh Adham, Kaden Harris, Bahar Azin, Boe Erickson, Sarah Stropkai, and Zhao Zhang.

Eleven principal investigators, faculty, and administrators are participating in MPC projects at the **University of Wyoming** are: Jennifer Tanner, Khaled Ksaibati, Promothes Saha, Anas Alrejjal, Er Yue, Mohamed Ahmed, Victor Bershinsky, Ahmed Farid, Suresh Muknahallipatna, Milan Zlatkovic, and Amirarsalan Mehrara Molan. In addition, eighteen students are working on MPC research projects: Md. Tarik Hossain, Fayez AlMutawa, Milhan Moomen, Mustaffa Raja, Mohammed Mahdi Rezapour Mashhadi, Waleed Aleadelat, Omar M. Albatayneh, Mutasem Alzoubaidi, Eric Admoah, Arash Khoda, Sara Bashir, Zorica Cvijovic, Sherif Gaweesh, Sean Harrison, Zachary Petersburg, Fayez AlMutawa, Zachary Petersburg, Maxwell Waite, Guangchuan Yang, and Anas Alrejjal.

Nine principal investigators, faculty, and administrators are participating in MPC projects at **Utah State University** are: Ziqi Song, Patrick Singleton, Andrew Sorensen, John Rice, James Bay, Michelle Mekker, Marvin Halling, Paul Barr, and Marc Maguire. In addition, sixteen students are working on MPC research projects: Ikwulono Unobe, Yi He, Prasanna Humagain, Zhaocai Liu, Hossein Nasr-Isfahani, Suman Roy, Pilaiwan Vaikasi, Sailesh Acharya, Brad Davis, Nick Langford, Jared McRory, Niranjan Poudel, Ashikur Rahman, Ferdousy Runa, Zach Benson, and Joshua Ward.

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

Colorado State University: Marie Venner, Venner Consulting
North Dakota State University: Jingnan Zhao, Rutergers, PhD student
University of Denver: Manual Machado, Keolis Commuter Services; Valerie Stark, Metropolitan Transportation Commission
University of Utah: Tony Grubesic, University of Texas, Austin; Kyle Rollins, Brigham Young University; Ran Wei, University of California, Riverside
University of Wyoming: Jeffery Mellor, Wyoming Department of Transportation; Ryan Shields, Wyoming Department of Transportation
Utah State University: Nick Roberts, Mechanical and Aerospace Engineering, Utah State University; Abhi Kamineni, Electrical and Computer Engineering, Utah State 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 **59 peer-reviewed articles or papers** in scientific, technical, or professional journals. Since the beginning of this grant, **we have published 139** different peer-reviewed articles or papers.

b. Conference Papers can be found in Appendix D

i. This reporting period **we have published 35 conference papers and 71 total since the grant began**.

c. Presentations can be found in Appendix C

i. MPC faculty and investigators **have presented at 32 different** scientific, technical, or professional conference this period. In total, we have **had 112 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: http://www.mountain-plains.org/
ii. The MPC Key Personnel can be found at: http://www.mountain-plains.org/personnel/
iii. Other **outputs** that are University specific:

North Dakota State University-

- Alive at 25 training has been completed in an effort to transfer this program into tribal communities.
- Identifying Factors That Predict Teen Driver Crashes, Abstract Update to the NDDOT
- We collected WIM data from New Jersey with 87 out of 95 WIM stations along highways in New Jersey. We performed initial data descriptive data analysis with the collected WIM data.
- We also collected New Jersey State Climate monthly air temperature data.

South Dakota State University

- A research webpage is developed and will be frequently updated.
  - https://sites.google.com/people.unr.edu/mostafa-tazarv/research/mechanically-spliced-columns

University of Colorado Denver

- Redesigned of our previously published route planning solution to allow for "route replanning" during route traversal as well as "smart batch scheduling". These two features not only improve performance of the route planning solution, but also make it suitable for use as an underlying enabler for route planning in the context of three focus application scenarios, i.e., ride sourcing, fleet management and ridesharing. We have already implemented this solution in our in-house simulation testbed. Once we conduct the comprehensive experimentation we have planned for next project period, we plan to report on this new technology by publishing a research paper on the same.

University of Utah

- Results from the ongoing research were used to provide recommended changes to the document titled "Guide for Geosynthetics for Subgrade Improvement", which has been under development by the Four Corners Task Force consisting of representatives of the State DOTs from Utah, Colorado, Arizona, and New Mexico for several years. The document is nearing completion and is expected to be finalized this year (2020).
- A method of attaching a buckling restrained brace damper to reinforced concrete bridge footings and cap beams was developed. The method is innovative because the attachments take into consideration that the bridge columns are allowed to rock during an earthquake.

University of Wyoming

- Autoclave testing to evaluate within-laboratory testing has been completed. Finally, the complete set of CPT tests have been conducted to serve as a baseline for comparison with the autoclave tests. All testing has been completed. The only exception would be if Clemson University has a functioning autoclave. In that case, another set of specimens would be evaluated during July 2020.

4. Outcomes:

i. **Significant** outcomes by university:

NDSU has produced innovative approached to traffic monitoring and rail infrastructure monitoring that rely on rapidly advancing smart technology and data-mining techniques.

University of Wyoming has one of the studies in this contract showed significant results which required contacting potential funding agencies to secure funding for a follow up study. UW has submitted a proposal to WYDOT with MPC matching to implementing the findings of MP540. The proposal has been approved by WYDOT for funding. The new study will first calibrate the findings and then develop new tools to facilitate the implementation of the developed algorithm.

Utah State University work on the electric vehicles has been very well received. We are a finalist for an ERC. We had the site visit during this past reporting period and things went very well. The work that we have done through the MPC has been very important to put us in this position. It is a great example of a cross disciplinary problem that involves multiple stake holders.

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.

The projects at **Colorado State Universities** will have the following major outcomes: (1)improved understanding of the performance, cost, damage detection and inspection techniques of major transportation infrastructures, such as bridges, earthworks, and pavements; (2)increases in the body of knowledge of traffic flow modeling and role of ATMS sensors and CAVs; (3)increased understanding and awareness of transportation system resilience and management under various hazardous conditions, such as flooding, landslides, earthquakes and other multiple hazards.

Specific examples in these three major outcomes include: (a)Advanced deterioration models that can better predict bridge conditions and UAV-based bridge inspection techniques were evaluated; (b) Better information were provided for maintenance workers to make decisions in terms of maintenance of bridges, expansive soils and potholes using advanced experimentations, simulation and deep learning techniques; (c)New methodology was developed to simulate traffic flow on traffic systems with disruptions and also understand the role of ATMS sensors, information, and infrastructure in advancing the safety and environmental benefits of CAVs; (d) Improved simulation techniques were developed to model transportation infrastructure systems subjected to various hazards, such as flooding, earthquakes and landslides etc.; (e) Increased understanding of various mitigation efforts and emergency medical response techniques were achieved for transportation systems and communities.

At **North Dakota State University, t**he projects contribute to knowledge and capacity building

for the state of good repair. Early outcomes from the research include multiple papers associated with smartphone-based sensors process to monitor rail asset based low-cost sensor abnormality detection. This project has a strong workforce development aspect as several PhD students are actively involved as future transportation professionals. Improved AV safety is being supported in a project to improve processing of real-time traffic and roadside data in a mixed vehicle environment that is needed for smart city initiatives. Refinement of weigh-in-motion measurement sensitivity and accuracy is expected to enhance highway system traffic and condition monitoring. It will also increase awareness of data quality issues. Basic research will reduce infrastructure costs by testing and validating reliable predictive models for swelling clays. In addition, safety research is a prominent theme as findings for the rail industry will improve crash forecasting for highway-rail grade crossings along with advisement on using PTC compatible, low-cost sensor technology for crash prevention and risk management. Traffic safety gains will be achievable in improved practices and decision-making capacity for teen driver and Tribal Nations, as high-risk populations.

The projects at **South Dakota State University** will have the following outcomes: (1) understand the structural performance of adhesive connections for dynamic messaging transportation signs; (2) refine the estimation of live load distribution factors and dynamic load allowance factor for double-tee bridge girders; (3) improve understanding and knowledge about the effectiveness of steel byproducts for bacteria removal from stormwater runoff under field conditions; (4) better understanding of the seismic performance of mechanically spliced precast columns for accelerated bridge construction.

State DOTs allow welded connections only to be used in the construction of dynamic messaging signs; the proposed adhesive connections offer more durable and efficient signs. Live load distribution and dynamic load allowance used by engineers for double-tee bridge girders have been refined through field testing. An environmentally-friendly and low cost media filtration system for bacteria removal from stormwater runoff has been developed. A large-scale experimental program was developed to evaluate of the performance of commercially-available mechanical bar splicing systems for precast columns in accelerated bridge construction.

The expected outcomes include: (1) development of environmentally-friendly asphalt mixes using bio-asphalt binders and additives; (2) development of sustainable and economic timber bridge systems for local roads using cross laminated timber (CLT); (3) improve the decision-making process in selecting the type of deicing agents to minimize any damage to asphalt pavement structure in cold climate; (4) enhance the effectiveness of concrete bridge deck sealants; (5) development of improved laboratory techniques for measuring soil critical shear stress and erosion rates.

There is lack of information regarding design of asphalt mixes using bio-asphalt binders and additives. Cross laminated timber could potentially be used as a sustainable construction materials for bridges. Durability of asphalt pavement in cold climates will be increased through selecting the appropriate deicing agents. Premature bridge deck sealant failure could be prevented in South Dakota. Understanding of the flow conditions (e.g., bed shear stress, pressure gradient) producing erosion on both non-cohesive and cohesive soils would be improved.

The projects at **University of Colorado Denver,** all progressed well over the last project period with seven peer-reviewed journal papers published, three conference papers, and six conference presentations. This work has also had an impact on the students that are working on them in terms of providing an opportunity for research and research-related skill development.

The research projects at the **University of Denver** will have the following expected impacts: 1) research on Safety Culture and Operator Fatigue will contribute to workforce development efforts by providing managers with tools to improve the effectiveness of the transportation system by improving safety performance and efficiency through accidents and injuries reductions. 2) Identifying how the introduction of new autonomous

vehicle technologies affect safety performance is also anticipated. 3) Developing a smartphone based app technology that can be commercialized and readily deployed in the operational environment to assess fatigue and alertness of operators and lead to a reduction in drowsy driving, fatigue and an increase in alertness and vigilance. 4) Developing an online assessment of safety culture.

The projects at the **University of Utah** will have the following outcomes: (1) Increased understanding of Automated Vehicle integration and planning; (2) Increased body of knowledge on Mobility-as-a Service mode of transportation; (3) Improved estimates of hourly traffic volumes using machine learning; (4) Improved processes by using a data-driven approach to estimate the optimal utilization age of snowplow trucks, taking into account total cost and operational efficiency; (5) Increased body of knowledge on several Connected Vehicle applications such as cornering warning and break warning; (6) Increased understanding and body of knowledge of how to build bridges in seismic regions that use performance based design principles to build low damage bridges in strong earthquakes; (7) Increased understanding of factors that affect the low temperature performance of asphalt pavements in the state of Utah and identified the benefits of using low temperature testing of asphalt mixtures in the region; (8) Increased the body of knowledge on light-weight cellular concrete for its use as an approach slab system at bridge abutments; (9) Increased knowledge to enable DOTs to change their specifications to preclude the use of native materials in fills supporting roadway pavement systems that do not meet their current requirements for granular borrow, and allow the use of triaxle geogrid within the pavement system for new roadways; and (10) Increased understanding of factors that could lead to the adoption of intermediate temperature tests for asphalt mix road design in Utah.

While it is foreseen that AVs could potentially be on the market in the near future, the long-range transportation planning process has yet to account for their impact. A framework of modeling AVs to seamlessly integrate them into the four-step travel demand models that are widely used by transportation agencies was developed. The research work also leads to another on-going project with MPC and UDOT where we are further modeling mobility-as-a-service as an individual mode in the mode choice model, and as a part of the transit mode to solve the first-mile-last-mile issue of the transit trips.
Research is being carried out that addresses the problem of efficiently estimating hourly traffic volumes over a wide network across different functional classes. The research applies machine learning (ML) methods, which analyze existing data to identify patterns.

A cost-benefit analysis is conducted to determine the optimal life cycle for Class 8 snowplow trucks by leveraging purchase and resale data and maintenance costs through their service span. Meanwhile, to further analyze the operational efficiency at micro-level and to identify the crucial factors that lead to the performance deterioration, a machine learning (ML) approach, random forest (RF) model, is implemented to predict truck performance using endogenous and exogenous attributes and rank the importance of those attributes.

A recently completed test of a bridge under cyclic loads has increased the possibility that bridges built in seismic regions can be designed using performance based principles. The results of the test will soon be compiled into an MPC report, journal paper and conference. In addition, a webinar is planned for the near future.

Load tests were completed on a light-weight cellular concrete (LWCC) test wall at a laboratory scale. This development explores the use of LWCC as an approach slab support system near bridges to reduce differential settlement.

Design procedures in Utah and possibly other states, for pavement systems on soft subgrades will likely be modified to include greater consideration of the effects of settlement/heave from loading and wetting-induced strains within the native subgrades and fills constructed upon the native subgrades that support the pavement systems for new or rebuilt roadways.

Research has quantified the benefits of using intermediate temperature tests to achieve a balanced asphalt mix design for Utah roads.

In addition, further anticipated outcomes may include: (1) Increased understanding of providing supplemental damping to bridge piers to minimize damage after strong earthquakes; (2) Increased understanding of the use of glass fiber reinforced polymer reinforcement in concrete bridge columns for corrosion resistance and resistance to strong earthquakes; (3) Increased understanding of Mobility-as-a Service shared-ride mode and adding this mode with transit for a first mile-last mile feeder to public transit; (4) Increased understanding of the effectiveness of using Connected Vehicle technology to improve roadway safety; (5) Improved understanding of the effect of Variable Speed Limit signs, LED light color, and geometric features on freeway safety; (6) Increased understanding of a cost-effective and easy-to-use solution for asset management of highway systems through point cloud data using photogrammetric techniques and enlargement of the pool of trained professionals; (7) Increased understanding from one-dimensional consolidation tests into the expected magnitude of settlement or heave that will occur from strains within the embankment for each of the ten selected materials to be studied; and (8) Improved understanding of factors affecting the pavement performance and the benefits of a balanced asphalt mix design in Utah.

Most of the studies conducted at the **University of Wyoming** are practical in nature. The following outcomes are anticipated from these studies:
1. Provide tools to reduce crashes on various highway facilities.
2. Provide engineers with tools to enhance their decision making when managing roads.
3. Provide traffic engineers with new designs to reduce congestion at failed interchanges.

At **Utah State University**, we have 20 students working on MPC projects during the reporting period. These include undergraduates all the way through post docs. We are planning on several of these graduating during the next reporting period. We have also had dissemination of the research through publications and presentations.

5. Impacts –

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

The projects at **Colorado State Universities** will have the following impacts: (1) Improved technology will be developed to aid in maintaining bridges in a state of good repair with reduced costs, improved the data processing efficiency and quality of UAV-based bridge inspection and testing the engineering properties of expansive soils and treatment candidates in a more rapid (less expensive) and representative manner;(2) New approaches have been proposed to model traffic speed of partially blocked lanes on the road defined by quantitative measures of disruptions, and to apply two applications for the data in vehicle velocity prediction using real-world derived CAV data as the inputs; (3) The hazard resilience related studies can help reduce the traffic delays related to street flooding, develop more effective EMS vehicle travel planning strategy and locations of new EMS facility, and offer transportation managers a better understanding of the potential risk of the road network have to experience landslide.

Specific examples of the impacts include: (a) The cost-effectiveness of the proposed UAV-based bridge inspection technique can save 60% of inspection cost and meanwhile provide more detailed data on bridge condition assessment. (b) The developed deterioration models can be incorporated in existing bridge management systems to guide risk-informed cost-effective maintenance and inspection decision making for better preservation of bridges.; (c) An improved methodology is developed for testing the engineering properties of expansive soils and expansive soils treated with different candidate treatments in a more rapid (less expensive) and representative manner. Improved characterization of expansive soil treatment methods will enable better engineering design of

transportation earthworks at locations with expansive soils, and thus improved transportation system longevity by correctly accounting for expansive soil behavior; (d) With better understanding the associated risks, more effective EMS vehicle travel planning strategy and locations of new EMS facility can be strategically carried out; (e) Transportation managers will have a better understanding of the potential risk different parts of the road network have to landslide, which will likely be related to the surrounding topography, soils, and vegetation; (f) The developed 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.

State of good repair research at **North Dakota State University** will contribute to the transportation system in expansive (swelling) clays damage reduction, ITS-based techniques in timely rail and highway asset health monitoring, and improved decision systems. Safety is also a strong aspect in the research considering high-risk sites, such as highway-rail grade crossings, and high-risk driver groups such as teens. Smart city infrastructure safety support system will develop a new traffic monitoring network to continuously monitor WIM systems for more effective and timely traffic management.

The projects at **South Dakota State University** will have the following anticipated impacts: (1) provide design methodology for transportation dynamic messaging signs using adhesive bonding; (2) perform realistic structural capacity assessment of existing double tee girder bridges; (3) promote sustainable bio-materials and agricultural byproducts for production of bio-asphalt binder; (4) develop new precast column connection detailing for accelerated bridge construction; (5) improve laboratory techniques for measuring the critical shear stress of cohesive soils; (6) improve the treatment and quality of stormwater runoff generated by transportation activities; (7) improve the selection process of deicing agents; (8) implementation of more advanced methods for predicting bridge scour depths; (9) develop recommendations for bridge deck sealant application.

The **University of Colorado Denver** 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.

The research projects at the **University of Denver** will have the following expected impacts on the effectiveness of the transportation system: 1) the identification of the factors that contribute to the impact of new automated technology on safety performance and safety culture in an operational freight environment; 2) providing leaders and managers of transportation systems and organizations additional insights, knowledge and tools with which to manage their operations an workforce and reducing operator fatigue and subsequent operational errors and accidents; 3) providing a practical training model for managers and leaders of transportation organizations that shows how to create and maintain a safe and efficient operation.

The projects at the **University of Utah** will have the following impacts: (1) Assist public agencies in understanding the impact of Automated Vehicles on travel patterns to further consider the special needs of AV technology in long-range cost estimates and programming processes; (2) Accurate modeling of hourly traffic volume to identify congested roadways, assisting traffic re-distribution, and implement accident prevention strategies to reduce massive sensor deployment; (3) Performance monitoring to help UDOT identify the performance of snowplow trucks under a variety of conditions, which can effectively complement replacement strategies; (4) Technologies are explored for bridge piers using replaceable stretch length bolts or buckling restrained braces to dissipate hysteretic energy before damage starts to accumulate in the columns, thus enabling bridges to be functional after strong earthquakes; (5) Improve effectiveness of the transportation system by better understanding of asphalt pavement performance at intermediate and low temperatures; (6) Reduce the settlement bump at bridge approaches to improve highway safety, reduce damage to freight and decrease the amount of repair and maintenance of approach slabs; (7) Significant reduction of settlement/heave of approach embankments for bridges can mitigate problems with bumps at the ends of newly constructed bridges; (8)

Improve understanding of the influence of native subgrade and fill materials on the performance of pavement systems constructed on soft subgrades to create better roadway systems requiring less maintenance; (9) Safety considerations for different Connected Vehicle geometric features and multi-modal Connected Vehicle systems are being examined; (10) New methods using photogrammetry can reduce the cost of maintaining and updating asset management systems of transportation agencies by up to 30%; (11) Research uses quantitative modeling to answer key questions about future Vehicle Miles Traveled and travel behavior using Mobility-as-a-Service; (12) Reduce maintenance costs and the need for replacement of corroded columns in seismic regions by using glass fiber reinforced polymer reinforcement; (13) Improve traffic operation systems and traveler safety by enhancing the visibility of Variable Speed Limit zone signs along interstates, such as I-80.

The projects at the **University of Wyoming, MPC**-541 related to assessing gravel roads condition will help county engineers with:
1. Securing information about their gravel roads network.
2. Understanding the performance of their gravel roads under different traffic conditions.
3. Allocating funding for various maintenance activities.

As a result of this study, The Wyoming County Commissioners Association (WCCA) requested a proposal showing the cost of implementing a statewide gravel road management system. In addition, UW is in the process of preparing a proposal to FHWA to develop the tools necessary for such implementation.

The projects at **Utah State University** will have the following impacts: (1) increased transportation safety which will lead to a reduction in loss of life and property; (2) increased effectiveness of the transportation system as a whole and (3) innovative solutions for advanced transportation systems. The increased safety come from both the vehicle as well as pedestrian sides. We feel like we will make significant contributions that will increase the effectiveness of the system through increased safety measures. We also believe that our work with connected and electric vehicles will have a lasting impact on the future of the transportation system.

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?

The projects at **Colorado State Universities** will have the following impacts: (1) New techniques and understandings may be adopted by DOTs such as inspection techniques on bridges, bridge designs and soil improvement; (2) Novel datasets are generated that unifies ADAS-derived near-neighbor relative position and velocity, and infrastructure-level transit time and signal phase and timing information. The processed dataset is made available to the research community.

In addition, further anticipated impacts may include: (1) UAV-based bridge inspection will also seek to provide insights about how major changes may occur in DOT practices that might be more generally applied to other aspects of transportation. As such, the proposed study's impact will be broad and supportive of the technology transfer efforts of other MPC projects performed by our colleagues across the MPC schools. (2) The proposed new methodology of traffic flow simulation, traffic safety performance function and EMS response practice advices will offer opportunity to be adopted in engineering practice and research under the disruptions and hazards; (3) The developed automated tools can be adopted by CDOT maintenance teams to facilitate fast and cost-effective road condition data collection and assessment.

North Dakota State University projects contribute to new practices based in smart technology applications. They will increase robustness and effectiveness of the real-time traffic and asset monitoring systems, at a lower cost. In addition, state-of-the-art design procedures that would correctly analyze and accurately predict the engineering response of swelling clays to reduce infrastructure damage. Road safety will be improved in support to decision-makers for more effective program and policy practices. A one-day workshop at NDSU brought together short line railroads and state agencies to learn how the proposed smart-phone rail monitoring can

be a cost-effective initiative that aligns with other functionality such as the PTC safety systems. In a safety project, the NDDOT has initiated a program to send letters to teenagers identified as at risk based on driver record events. It is based on findings in a previous NDSU teen driver study. The program uses individualized intervention in teen driver safety that is risk based in likelihood for future crash involvement. Results may be transferable to other at-risk driver populations and other entities.

The projects at **South Dakota State University** will have the following expected impacts: (1) lifting the ban imposed by transportation agencies on the use of adhesive joints in the construction of transportation dynamic messaging signs, (2) adopting recommendations for assessing the structural performance of in-service double tee bridges, (3) promoting the use of the sustainable biomaterials and agricultural byproducts for production of bio-asphalt binder, (4) developing new sustainable alternative to structurally deficient bridges on local roads, (5) reducing bridge construction time and cost, (6) predicting soil critical shear stress and erosion rates in cohesive soils; (7) reducing the bacteria contamination caused by stormwater water runoff, (8) implementing pavement condition-specific deicing material.

The projects at the **University of Colorado Denver**, specifically MPC-579, for instance, we harnessed recent advances in remote sensing technology to investigate sidewalk infrastructure characteristics at a heretofore unseen geographic scale (the existing sidewalk literature tends to focus on relatively small areas due to a lack of comprehensive data). This project is allowing cities to compare city-level sidewalk characteristics such as availability and width against Americans with Disabilities Act (ADA) requirements and guidelines from organizations such as FHWA, AASHTO, ITE, and NACTO. It will also allow these cities to adopt a new approach to the asset management of sidewalks.

The research projects at the University of Denver will have the following expected impacts on the adoption of new practices and technology 1) the validation and commercialization of a Smartphone-based app to prevent at fatigue risk vehicle operators from engaging in unsafe acts or behaviors and drowsy driving; 2) developing an online assessment of safety culture to reduce accidents, injuries and operational errors.

The projects at the **University of Utah** will have the following impacts: (1) Modeling revealed that Automated Vehicles could increase the total number of trips by 1% to 7% and daily Vehicle Miles Traveled by 4% to 9% due to improved mobility of underserved populations and additional repositioning trips; (2) Computational methods are being developed that are easily implementable on a large-scale dataset and are able to estimate traffic volume with satisfactory accuracy; (3) Life cycle analysis using UDOT's snowplow truck utilization data shows that UDOT should shorten the average life cycle for Class 8 snowplow trucks to cut down overall expenses; (4) AASHTO is currently developing performance-based design methods for seismic design of bridges and research carried out with replaceable stretch length bolts or buckling restrained braces will contribute to advancement of such design methods; (5) Assist UDOT in developing a standardized method that could be used during the design process to assess expected performance of pavements and create longer lasting roads; (6) Research is being developed to better plan, design and construct Light-Weight Cellular Concrete embankments in bridge approach areas; (7) Development of better design and construction guidelines for geogrid-supported pavement systems should result in wider use of this technology within roadway pavement systems; (8) Buckling restrained brace dampers, currently used in buildings to improve seismic performance, are introduced as protective fuse systems for bridges in high seismic regions through large-scale experiments and numerical simulations; (9) A comprehensive benefit/cost analysis has been done to evaluate the Connected Vehicle corridor along Redwood Road in Salt Lake City, and results have been reported to UDOT Traffic Operations Center; (10) Large scale photogrammetry techniques being developed will cost less and are easier to use compared to laser scanning; (11) Material and construction specifications for bridge approach embankments will be used by UDOT and other public agencies; (12) Research will provide a foundation for answering how different demographic groups will respond to AV-Mobility-as-a-Service technology, and how it impacts zero-occupant vehicle trips;

(13) Introduce Glass Fiber Reinforced Polymer reinforcement for construction of concrete bridge columns in seismic regions to reduce corrosion and repair or replacement of bridge columns; (14) Provide a guide to UDOT to improve their Variable Speed Limit operation systems and offer countermeasures to reduce crash rates on freeways.

University of Wyoming has secured new funding from WYDOT/MPC for MPC 540. The new funding will result in developing easy to use computer tools to facilitate the implementation of the new algorithm developed in MPC 540.

The projects at **Utah State University** will have the following impacts: (1) creating the future of connection and electric vehicles and (2) improving safety policies and practices. While nothing have been adopted, as of today, we feel that there are many opportunities for adoption. If adopted, this will have significant impact on the practices within the profession both at a local as well as a national level.

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

The projects at **Colorado State Universities** will have the following impacts: (1) contributing to the body of scientific knowledge in the field of the development of new structural condition assessment techniques and better management and preservation of bridges; (2) helping advancing simulation- and data-based traffic engineering field on traffic simulation, safety improvements and CAV techniques; (3) offering new knowledge to the field of hazard resistance and infrastructure resilience against various hazards.

NDSU research contributes to the scientific body of knowledge in state of good repair several aspects. One substantial scientific contribution will be the multiscale computational framework for swelling clays to evaluate the mechanical response of swelling clay to external loading. The models incorporate the molecular scale clay-fluid interactions and the evolution of microstructure during swelling, the two critical factors that influence the mechanical properties of swelling clays. In addition, machine learning techniques in highway and rail asset management will advance practices based on new modeling techniques and algorithms. A prototype smart traffic monitoring system will improve the basic understanding of the traffic flow to contribute to longer-term operational and safety improvement efforts for traditional and AV vehicles.

The projects at **South Dakota State University** will have the following expected impacts: (1) generation of invaluable data on fatigue and strength of adhesively- connected joints in dynamic messaging sign panels; (2) establishment of field testing and analytical modeling protocols in the field of bridge engineering; (3) added knowledge in the field of biomaterials and the use of environmentally-friendly and renewable fuel sources; (4) contribution of new knowledge to the fields of bridge engineering and design of engineered timber structures; (5) generation of comprehensive test data on mechanically spliced precast bridge columns; (6) better understanding of the critical shear stress and erosion rates in different clay soils and sand-clay mixtures; (7) producing new knowledge on bacteria adsorption by steel byproducts and the long-term bacteria removal from stormwater; (8) addition of new knowledge on the effects of chemicals used in the deicing agents on asphalt mixes subjected to freeze-thaw cycles.

At the **University of Colorado Denver** 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 hope that these results will have broader, multi-disciplinary impacts within the business community, the bridge construction industry, and with Vision Zero cities.

The research projects at the **University of Denver** will have the following expected impacts on body of scientific knowledge: 1) by contributing to the human factors literature by shedding additional light on how

people are likely to perceive safety and risk in work environments with automated technology; 2) contributing to the fatigue hygiene literature and the prevention of drowsy driving in commercial fleet operations and public transportation; 3) adding to an understanding of the knowledge of educators tasked with improving the skill, competence and expertise of members of the transportation industry; 4) adding to the list of tools available for the measurement of fatigue and drowsy driving; 5) contribute to the ability of researchers to more precisely measure the effects of fatigue on operator performance and drowsy driving.

The projects at the **University of Utah** will have the following impacts: (1) in the transportation field advancements were made regarding the effects of Automated Vehicles on travel behavior; (2) machine learning is used to predict hourly traffic volume in a computational efficient manner for a statewide road network managed by UDOT; (3) in the transportation field research is being carried out which has determined that working mileage, fuel consumption, and service span are the most important features influencing truck performance; (4) in the structural design field, seismic performance of bridges is enhanced using self-centering and energy dissipation with replaceable stretch length bolts or buckling restrained braces, which means that after an earthquake bridges will return to their original position practically undamaged; (5) new knowledge on low temperature properties of asphalt mixtures and its relation to pavement performance will contribute to more efficient methods to design asphalt mixtures for better performing pavements; (6) in the geotechnical design field, research underway on Light-Weight Cellular Concrete will be used to determine its fundamental material behavior under static and cyclic loading at varying amounts of saturation; (7) better asphalt mix design practices will result in economical design of pavement systems; (8) in the materials field, understanding of the effect of fracture energy on the development of pavement cracking at intermediate temperature will allow us to supplement the volumetric mix design with a mechanics-based test to improve pavement performance; (9) in the transportation field, understanding the effects of using Connected Vehicle technology has resulted in traffic safety improvement; (10) in the area of infrastructure asset management, data collection and processing methods are being developed based on novel image processing, computer vision and machine learning systems; (11) research will enhance understanding of the loading and wetting stress-strain characteristics of various types of soils; (12) research will result in greater certainty surrounding the impact of AV-Mobility-as-a-Service on partnerships between the Utah Transit Authority and Transportation Network Companies; (13) seismic performance of concrete columns reinforced with glass fiber reinforced polymer spirals and longitudinal bars is not well understood but the potential benefits are substantial in terms of corrosion control; (14) support state DOTs, especially the ones in cold regions, to provide a safer driving environment by considering the impact of speed limit sign visibility, road geometric features, driver behavior, and pavement condition.

At the **University of Wyoming**, MPC-540 resulted in a new algorithm to determine the speed limit on down grades. The previous algorithm was developed more than 40 years ago and it does not reflect new advancements in trucks aerodynamics nor in trucks brakes.

At the **Utah State University**, it is hard to quantify the impact on the body of scientific knowledge. Where the results of these research projects will lead in the short term as well as long term is exciting to consider. Each of the research projects in our main areas of safety, infrastructure and electric vehicles is focused on answering questions that we currently do not have answers for. These research results will also lead to other research questions down the road. This scientific knowledge will directly disseminated to the researchers and students but will be expanded to the community as a whole through publications and presentations.

d. *What is the impact on transportation workforce development?*

The projects at **Colorado State Universities** will have the following impacts: (1) providing opportunities to train graduate research assistants on conducting the research works, such as conducting experiments, writing research papers and presenting findings; (2) offering support to graduate students to finish their degrees; (3) supporting outreach and graduate education like course developments with some findings from these projects. For

example, MPC-620 — Visible and Thermal Imaging in a Deep-Learning Approach to Robust Automated Pothole Detection and Highway Maintenance Prioritization: A graduate research assistant will be hired to conduct the research described in this proposal. The student will be involved in collecting the visible and thermal images, labeling the images, and learning and applying deep learning techniques for pothole detection as well as developing automated tools. The procedure and example from this project 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.

NDSU research has extensive student involvement in field experiments, data collection and ITS applications. Students will take this working knowledge into classroom application and eventually into the workforce. In addition, these students gain valuable experience in disseminating their research to peers and professionals through paper and presentations. In addition, the MPC projects have extended research and outreach opportunities with Native Nations in attracting new students and developing local capacity of transportation practitioners. For example, the Infrastructure Safety Support System for Smart Cities with Autonomous Vehicles introduced five graduate students and several undergraduate students to traffic sensing, road roughness detection, and AV modeling. It is also used by the PI to teach the graduate level class CE782 "Introduction to Intelligent Infrastructure" spring semester 2020. In the swelling clay project, two doctoral students are on this research project and portions of the research work conducted will go towards their dissertation. Safety projects are providing PhD students with opportunities do predictive modeling, risk analysis, build planning tools, and gain knowledge about stakeholders and their priorities.

The projects at **South Dakota State University** will provide the following educational and training opportunities to graduate students and engineers: (1) design of new structural system for transportation dynamic messaging signs; (2) field inspection/testing and simulation of bridges, (3) fundamental experimental methods in bridge engineering; (4) structural performance of the CLT bridge systems; (5) modern laboratory techniques of flow measurements and the theory and methods used to predict pier and contraction scour in cohesive soils; (5) application of a new technology to improve stormwater treatment.

At the **University of Colorado Denver**, the twelve MPC projects have been instrumental in providing opportunities for numerous graduate 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.

The research projects at the **University of Denver** will have the following expected impacts on transportation workforce development: 1) improving the overall competence and safety of the existent work force. 2) adding to the available techniques for effectively managing the risk of operator fatigue, drowsy driving, and reducing operations errors, accidents and injuries. 3) increasing the efficiency of staff safety leadership training by state DOTs and transit agencies.

The projects at the **University of Utah** will have the following impacts: (1) support for graduate student researchers who study traffic operations and travel demand forecasting; (2) support for graduate student researchers who study big data applications in transportation; (3) support for three graduate researchers who study structural design and earthquake engineering; (4) support for graduate students who study material testing and pavement design; (5) support for graduate research assistants to learn professional and analytical skills needed in bridge design and geotechnical engineering; (6) support five students who have worked on transportation related project; (7) support for graduate and undergraduate student researchers who study materials, asphalt mixtures and pavement performance; (8) five graduate students have received research training in the transportation area and have written analysis code/scripts using Python; (9) two graduate students have received research training about

implementing state of the art photogrammetric software packages and also writing necessary computer codes in MATLAB to improve their performance.

In addition, further impacts include: (1) Implementation in courses on Introduction to Transportation Engineering and Transportation Planning where the four step model is introduced; (2) Implementation in course material for a course on Traffic Network Modeling; (3) Methodologies and results of research are being implemented in courses on civil engineering materials, pavement design, and materials sustainability; (4) Practitioners and students will be exposed to the outcomes of research and the importance of transportation systems to our everyday lives; (5) Research results will enrich the material covered in the Transportation Engineering Course; (6) Research will be used to enrich a graduate level on Advanced Computer Aided Construction; (7) Research is used to enrich teaching material for the course on Smart Cities and Infrastructure.

At the **University of Wyoming**, all findings of research studies are being presented at professional conferences to raise the awareness among engineers with regard to new techniques to optimize their operations.

Utah State University has the most significant item in this area is the direct impact of the 20 students that we are currently employing. Each of them are involved in a significant research project and are providing a major contribution to the successful completion. We are also contributing with the dissemination of the research. This can be through the implementation but also within the profession.

e. Based on the above responses, please address any significant impacts?

North Dakota State University has wide and ongoing opportunities in the development of the future transportation workforce through basic and applied research in materials, autonomous vehicles, intelligent transportation system, and safety.

Many of the projects at **Utah State University** are not at the final phase in the research yet so the contributions are still forthcoming. We feel that we will have contributions in terms of the infrastructure (durability and safety), vehicle and pedestrian safety, and connected and electric vehicles. The portfolio of research is board and touches on many significant areas that are of interest to the DOT.

6. Changes/Problems

North Dakota State University -Most projects do not have an immediate impact from the Coronavirus but as the duration lengthens it will negatively impact several projects. The field optimization field testing for the AV mixed traffic environment integration may be affected by the Coronavirus, as would the WIM sensor installation, if continues between into summer. The LRSP remains behind schedule, due to seasonality in the local road manager participation availability, but is progressing with a refined approach/output set. With regard to the traffic safety project state and local road stakeholder collaboration, it will likely delay these initiatives as Coronavirus needs to be prioritized with regard to resources and response agility. Generally, the remote student involvement may also affect the efficiencies due to changes required in oversight and communication.

South Dakota State University- All of our projects require intensive experimental investigation and the testing cannot be conducted remotely. Campus lock-down due to the Coronavirus pandemic has limited the faculty and students access to the offices and laboratories during the last three weeks of this reporting period. Some of the completed experimental work can be analyzed from remote locations. It is uncertain how long the lock-down will be in place, but it is anticipated that it will continue in the near future. This will cause a delay in the project execution of most of the projects under this grant.

University of Denver - The University of Denver projects has seen delays in feedback to stakeholders, data

collection activities, conference presentations and other technology transfer reporting opportunities due to the corona virus pandemic. The project on the Effects of Automated Technology Safety Culture has encountered some challenges in recruiting participants due to the controversial nature of the topic. The perceived potential displacement of transportation workers by technology was viewed by some as an inflammatory topic. After initial consultation, company officials expressed some need to be cautious n with this topic during contract negotiations with labor. Meetings were recently held with the national leaders of the Sheet Metal and Trainmen Union (SMART) who expressed a desire to move forward with the project. To rectify the problem, a decision was made to broaden the scope of the sample to non-union professionals. Unfortunately, subsequent meetings have been postponed due to the corona virus pandemic. With other projects, the coronavirus pandemic has delayed the feedback to stakeholders, the presentation at conference and other technology transfer reporting opportunities. Meetings had been scheduled for March and April that have now been postponed. The presentation at the International Fatigue Conference has been postponed due to the corona virus pandemic.

University of Utah - Current COVID-19 conditions are expected to disrupt operations, including laboratory experiments and data collection from highways and roads. Due to the Coronavirus Pandemic, the University of Utah has shut down all on-campus laboratory work as of March 24, 2020. The main tasks remaining for several projects involved the completion of large-scale laboratory tests. Due to this shutdown of all laboratory work for an indefinite time completion of these projects will be delayed, and the length of the delay cannot be determined at this time.

Utah State University - The Coronavirus has impact everyone in one way or another and research is included. We currently have a stay-at-home policy that the university is following. This has limited the day-to-day interactions with students and has slowed down the research. We have tried very hard to keep things going as much as possible but there have been consequences. I also think the restriction on travel has impacted some of the outputs. We are not traveling to conferences nor sending in papers because we don't know how long it will last. These delays will ripple for a while.

7. SPECIAL REPORTING REQUIREMENTS:

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