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 #7

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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 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-641** which can be found on the Mountain-Plains Consortium website

b. What was accomplished under these goals?

i. Project Selection

One hundred eight research projects have been selected and have undergone a rigorous peer review process which is required to meet the requirements for selection. The projects reflect substantial input and matching resources from state departments of transportation and MPOs in the region. Collectively, this set of projects addresses all five of the Secretary's strategic goals and several of USDOT's requested emphasis areas under State of Good Repair—e.g., (1) bridge condition monitoring, (2) locating critical infrastructure defects, (3) identifying tools to prevent and detect corrosion in transportation infrastructure, (4) analytical tools for infrastructure performance management, and (5) methods and criteria to measure performance of new materials and methods. Some MPC projects relate to more than one USDOT Strategic Goal and will then be listed more than once in Appendix A.

ii. Programmatic Milestones

In addition to the programmatic milestones described below, several milestones embedded within individual projects have been achieved. Most of the research projects call for literature reviews. The literature reviews for those projects with the earliest starts are substantially complete. Interim reports are not required after the literature review stage. At this time, all projects are on schedule to be completed as planned during the grant period. The program accomplishments to date are summarized in Table 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, **152 transportation and transportation-related courses** were offered this reporting period, for a total of **736 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, **57 training sessions** were offered this reporting period for a **total of 428 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 **293 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 **91 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 **77 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 **163 students from the U.S. and countries around the world. This includes 74 doctoral students; 51 master's students; and 38 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.

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-five students are working on MPC research projects: Abdelrahman Abdallah, David Trinko, Yangyang Wu, Guangyang Hou, Kaisen Yao, Craig Staples, Douglas Woodridge, Brandon Perry, Min Li, Zana Taher, Katie Knight, 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, twenty-three students are working on MPC project: Mohanad Alshandah, Xinyi Yang, Hafiz Usman Ahmed, Keshab Thapa, H M Nasrullah Faisal, Neeraj Dhingra, Narendra Malalgoda, Yihao Ren, Morgan Jacobson, Amin Keramati, Xiaoyi Zhou, Bhavana Bhardwaj, Sajad Ebrahimi, Dawei Zhang, Niloy Saha, Ratna Yasoda, Omar Abdelkader, Riley Fisher, Malachi Graupman, Erik Hagerty, Joshua Pistorius, Kaylin Tomas, 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, fifteen 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, Kallan Hart, Rosanna Novellinio, Brenden Olevson, Aric Jensen, and Brian Kidd.

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, Yail Jimmy Kim, Meng Li, Carolyn McAndrews, Kevin Rens, Manish Shirgaokar, and Farnoush Banaei-Kashani. In addition, twenty-one 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, Ryanne Ototivo, Ali Alatify, Andrew Hill, Selvakumar Jayaraman, Wei Li, Tobby Lei, Sohil Vaidya, 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.

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, Jeff Phillips, Abbas Rashidi, and Xianfeng Terry Yang. In addition, twenty-three 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, Roghayeh Zoleikani, 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.

Fourteen 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, Marwan Hafez, Kam Ng, Mahdi Rezapour, and Amirarsalan Mehrara Molan. In addition, twenty-two students are working on MPC research projects: Md. Tarik Hossain, 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, Maxwell Waite, Guangchuan Yang, Benjamin Fosu-Saah, Md Nasim Khan, Sahima Nazneen, Zephaniah Connell, Lokendra Khatri, James Mock, and Anas Alrejjal.

Eight 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, and Marc Maguire. In addition, twenty-two students are working on MPC research projects: Ikwulono Unobe, Yi He, Prasanna Humagain, Hossein Nasr-Esfahani, Suman Roy, Pilaiwan Vaikasi, Sailesh Acharya, Brad Davis, Nick Langford, Jared McRory, Niranjan Poudel, Ashikur Rahman, Ferdousy Runa, Zach Benson, Abdullah Al Sarfin, Yiming

Zhang, Trevor Gardner, Nate Raine, Allie Boyer, Sadie Boyer, Maren Chadwick, Jordan Duncan, Conner Howard, Nichole Rogers, Michael Ruiz-Leon, 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.

North Dakota State University-
Karin Mongeon, North Dakota Department of Transportation
Brad Schaffer, North Dakota Department of Transportation
Jingnan Zhao, Rutgers, Doctorate Student
University of Denver-
Noel Beck, Keolis Commuter Services, VRE
Chris Harrington and Manuel Machado, Keolis Commuter Services, MBTA
University of Utah-
Kyle Rollins, Brigham Young University, Department of Civil and Environmental Engineering

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 **66 peer-reviewed articles or papers** in scientific, technical, or professional journals. Since the beginning of this grant, **we have published 205** different peer-reviewed articles or papers.

b. Conference Papers can be found in Appendix D
i. This reporting period **we have published 31 conference papers and 102 total since the grant began**.

c. Presentations can be found in Appendix D
i. MPC faculty and investigators **have presented at 18 different** scientific, technical, or professional conference this period. In total, we have **had 130 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-
- Contributed to a revised teen parent letter. The letter was finalized in August. The revised letter was instituted in late August a product of the continuous improvement process for an individualized driver intervention, supported by this MPC research.
- A Decision Support Framework for Risk Assessment of Speeding-related Crashes: Application of Modified FMEA, working draft research report.
- Draft Delphi Survey and cover letter

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-
- In this period, we performed a comprehensive empirical analysis of our proposed "replanning" and "smart batch scheduling" based approach for system optimal route planning for route sourcing. With this approach vehicle with potential shared route are batched in small groups as needed to replan their routes for optimized route performance. Our experiments demonstrate that our proposed solution can improve the total travel time of the vehicles up to a high %85 over user equilibrium state.

- We are currently working with the CU Tech Transfer office to file a provisional patent application on this work. This patent application is currently in preparation and due for submission in 2 weeks.
- We have also started the process to obtain license agreement between NREL and CU to integrate this solution into the NREL project HIVE (Highly Integrated Vehicle Ecosystem) www.nrel.gov/transportation/hive.html for tech transfer.

University of Denver-

- We have created a web page describing our tools for measuring and managing safety culture: https://www.du.edu/ncit/safety.html
- Also, we have created a new web page for summarizing our work on "Railroad Trespasser Fatality Prevention" at: https://www.du.edu/ncit/prevention/

University of Utah-

- With the work conducted and jointly sponsored by the UDOT, UDOT further funded the phase II of the project titled "Assessing the operational efficiency of snowplow operations via data and analytics". The project strives to evaluate the efficiency of the current UDOT snow plowing operations based on the available UDOT data (i.e., AVL, GIS layers of road network and salt dome locations, truck information), and to improve the snowplowing operations given the current resources.

University of Wyoming-

- Publishing a paper related to modeling dust levels on gravel roads.
- We've developed and delivered a prototype of the two-vehicle method used to measure passing sight distances on two-lane highways.
- An invitation brochure was presented in the 2020 Utah Asphalt Conference, sponsored by the Utah Asphalt Pavement Association, describing the feasibility study and potential partnership.
- A comprehensive online survey was developed and sent out to interested states, including Alaska, Colorado, Idaho, Kansas, Montana, Nebraska, Nevada, North Dakota, Oregon, South Dakota, Utah, and Washington. A feedback was received from participants showing their experience and thoughts on building and operating the proposed testing facility. The results from the survey were summarized showing key aspects of the testing facility, including the layout design, supporting facilities, test sections, design of experiments, instrumentation, data collection, and research needs proposed for the regional testing facility.

Utah State University-

- Two papers are currently being prepared for submission to journals/conferences. The participating graduate student, Ashikur Rahman, wrote his Master's thesis on this project, passed his defense, and is currently revising it for final submission.
- Techniques have been developed and improved for the wireless transfer of power to vehicles in both the stationary and dynamic conditions.
- A paper is currently being developed regarding the literature review element of this project.

4. Outcomes:

i. **Significant** outcomes by university:

University of Utah -The research published on "Inferencing Hourly Traffic Volume Using Data-Driven Machine Learning and Graph Theory", "Multi-vehicle Trajectory Optimization for Cooperative Adaptive Cruise Control (CACC) Platoon Formation", and "Freeway Traffic Speed Estimation by Regression Machine Learning Techniques Using Probe Vehicle and Traffic Sensor Data" is important for transportation agencies since it involves artificial intelligence and optimization methods.

University of Wyoming - One of the most important accomplishment during this period is the completion of the first version of a device which will help transportation zone in identifying passing/no passing zones. There device is essential in identifying patterns for pavement marking. The old existing devices are not functional anymore and the newly developed device has been passed to WYDOT for statewide implementation.

Utah State University - A journal paper by He, Yi, Zhaocai Liu, and Ziqi Song. This paper will be impactful for moving forward the overall field of infrastructure electrification and for greater adoption of electric vehicles. The second is the report by McRory, Jared W., Fray F. Pozo-Lora, Zachary Benson, and Marc Maguire. This report details the lessons learned from a comprehensive study of fiber reinforced concrete deck slabs for both flexure and punching shear. Included are issues of durability and the economic impact of the use of these fibers in the concrete mixes.

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) improved technologies on conducting bridge inspection, inspection planning and assessment of bridge deterioration and scour impact by adopting stochastic modeling, UAV and lifecycle cost analysis techniques; 2) increased understanding of traffic simulation and operation including new methodology to simulate the travel speed and travel time for roadways with disruptions, planning for emergency medical response and assessment of the traffic safety risks during various adverse driving conditions; 3) increases in the body of knowledge of developing more resilient transportation system against various hazards, such as landslide, earthquakes, flooding and wind storms. 4) the novel testing methodology developed to assess swelling potential of expansive soil and effectiveness of treatment technologies; 5) improved understanding of de-risking the concept of integrating vehicle level and traffic system level datasets; 6) increased understanding of the runoff mechanisms that are active for large storm events with improved accuracy of such modeling efforts.

North Dakota State University - Safety and mobility improvements are expected outcomes from multiple projects at North Dakota State University related to goals in state of good repair, safety and economic competitiveness in the following outcomes: (1) improved functionality of AV algorithms with real-time data from V2X in a mixed environment with human factors; (2) molecular-scale knowledge building to develop more reliable predictive models for swelling clays; (3) broad understanding broad understanding for enhancing railroad technological capabilities as part of the Internet-of-things (IOT) in connected vehicle technology and big data environments; (4) improved decision processes and technologies for highway-rail grade crossing safety, WIM fixed sensor information, and in rail track surface condition monitoring; (5) reduced crash risk related to capacity and knowledge building in at-risk areas associated with tribal communities, teen drivers, alcohol-impairment and local roads.

South Dakota State University - The projects at South Dakota State University will have the following outcomes:(1) increased understanding of ultimate and fatigue strength of transportation dynamic messaging signs (DMS) with adhesive joints and welded connections; (2) increased understanding of the effect of bridge width-to-span length ratio effect on live load distribution factors of double-tee (DT) bridge girders; (3) increased knowledge of structural performance of cross laminated timber (CLT) girders and CLT bridge system; (4) improved understanding and knowledge regarding the effectiveness of steel byproducts for bacteria removal from stormwater runoff under field conditions.

State DOTs allow welded connections only to be used in the construction of DMS structures; the proposed adhesive connections offer more durable and efficient construction technique for DMS structures. Live load distribution and dynamic load allowance used for the design of DT 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. Cross laminated timber could potentially be used as a sustainable material for bridge construction. The expected outcomes include (1) improved understanding of the benefits of using cellulose nano-fibers (CNF) in asphalt mixes; (2) identification of new and feasible detailing for mechanically spliced precast columns to promote accelerated bridge construction (ABC) for bridge bents; (3) improved soil erosion testing methods and procedures to reduce measurement uncertainties and improve the repeatability of test results; (4) increased knowledge regarding the effects of deicing agents on durability of asphalt mixes; (5) adoption of concrete bridge deck sealants that will delay deterioration of South Dakota's bridge decks; (6) development of an appropriate methodology for traffic safety network screening; (7) update testing methodologies for in-situ acceptance of the compacted granular bases.

The new gained knowledge regarding the performance of asphalt mixes using bio-asphalt binders and additives will allow for the design of sustainable asphalt pavements. A large-scale experimental program will allow for evaluating the performance of commercially available mechanical bar splicing systems for precast columns in accelerated bridge construction. Premature bridge deck sealant failure on South Dakota bridges could be prevented. Understanding of the flow conditions (e.g. bed shear stress, pressure gradient) that produce erosion in both non-cohesive and cohesive soils would be improved. Verification of in-situ acceptance test methodologies of granular soil compaction will lead to improved performance and expedited construction of bridge foundations.

University of Colorado Denver -These projects all progressed well over the last project period and with 18 journal papers and 4 conference papers. This work has also had an impact on the students that are working on them 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) Validation of Smartphone Alertmeter Fatigue Assessment Device for Transportation Workers which will provide validating data for a new device and technology that can be readily deployed in the operational environment to assess fatigue and alertness of operators and drivers before they being operating vehicles. The technology will hopefully lead to a reduction in drowsy driving, fatigue and an increase in alertness and vigilance. Ultimately, the utilization of the device could lead to a reduction in accidents and injuries in the transportation system. 2) The identification of linkages between Safety Culture, Leadership & Fatigue in Transportation Operations and how best practices are effective in reducing accidents and injuries in various transportation/transit organizations. An online safety culture assessment has been posted on our web site. 3) The Development of a Safety Leadership Training Model to Improve Safety Culture will aid leaders of transportation organizations in demonstrating the behaviors and best practices that will lead to the development of an effective safety culture characterized by reduced numbers of accidents and injuries. Previous research has not specified to either safety organizations or transportation. Consequently, there is still seen to be a need to develop a standard model or approach to developing a safety culture within the transportation industry.

University of Utah - The projects at the University of Utah will have the following outcomes: (1) assist public agencies in understanding the impacts of Shared Automated Vehicles on travel patterns to further consider the special needs of Automated Vehicle technology in long-range cost estimates and programming processes; (2) develop a computationally efficient model to spatially predict hourly traffic volume using a variety of features; (3) develop a highly accurate predictive model of snowplow truck performance; (4) increase understanding of safety benefits brought by advanced vehicle technologies such as connected vehicle and vehicle automation; (5) field video recording has shown that the legend color of the Variable Speed Limit LED light can greatly affect the visibility at different locations of the freeway; (6) provide potential methods or best practices to mitigate bridge end differential settlement that can be implemented in addition to or in lieu of preloading of foundation soils at the time of bridge construction, or during subsequent bridge maintenance operations; (7) the design procedures in Utah, and possibly other states, for pavement systems on soft subgrades will 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; (8) results from the laboratory one-dimensional consolidation tests will provide great insight 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; this information will provide state DOTs with enhanced methods to predict the settlement or heave or approach embankments, thereby allowing them better ways to ensure that bumps at the ends of bridges are minimized; (9) application of the project outputs has produced an appropriate testing protocol to evaluate the expected performance of asphalt mixtures at intermediate temperatures; (10) the experiment of the self-centering bridge bent was successful and can be used in high seismic regions since it established that stretch length bolts can be used to dissipate hysteretic energy with minor and replaceable damage to the columns; (11) the research on hybrid bridge bents in seismic regions is expected to increase our understanding and promote the implementation of resilient bridges in earthquake regions; (12) increase our understanding of how corrosion free spirals behave with a combination of corrosion free vertical and steel bars in bridge columns under strong earthquakes; (13) recognize the factors that lead to more accurate 3D models of the roadway assets' as-is condition using the proposed technology (i.e., close-range photogrammetry). The results help increases understanding of how useful photogrammetry can be as an alternative to laser scanning in highway infrastructure modeling.

One main finding is that many near-crash events can be provided with some connected vehicle applications such as cornering warnings. Another finding is that the Variable Speed Limit visibility can be affected by the light conditions, driving direction, weather conditions, and highway vertical and horizontal alignment; moreover, the yellow color has much better visibility than the white color during both summer and winter seasons. The research on bridge end settlement will determine whether the proposed methods are intended to address primary consolidation or secondary consolidation settlement, or both.

In addition, further anticipated outcomes may include: (1) since the predictive model of snowplow truck performance disentangles feature importance, transportation agencies can further refine truck replacement strategies by identifying crucial factors impacting truck performance; (2) connected vehicle automation contributes to the design of connected vehicle communication systems to avoid distracting drivers; (3) providing to UDOT practical information, data, detailed analysis, evaluations, documentation and recommendations regarding the various methods with respect to design details, construction practices and post-construction performance including the following: case histories of the technologies with descriptions, estimated costs, construction time, design and construction details (e.g., typical drawings, construction specifications, special provisions and long-term performance, as available) for the bridge end settlement research; (4) UDOT's publication "Guide for Geosynthetics for Subgrade Improvement" will be modified based on the results of the research; (5) a technology transfer protocol for local transportation agencies' use in the State of Utah was developed which enables the users (e.g., asset management division) to adopt the technology in their asset inventory system in the most efficient fashion using the current commercially available digital cameras and 3D reconstruction software packages.

The research on bridge end settlement will assist UDOT in selecting and deploying the recommended methods in new construction, or maintenance operations, as applicable; recommendation will be provided to UDOT concerning emerging methods and technologies for future research and potential implementation. It is also possible that UDOT will (1) 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 (2) allow the use of triaxle geogrid as an alternate to the currently allowed biaxial geogrid within the pavement system for new roadways. It is likely that specifications for approach embankment materials will be improved for at least some state DOTs based on research regarding settlement of bridge approach embankment materials. The research on hybrid bridge systems will allow DOTs in seismic regions to select buckling restrained braces as fuses or stretch length bolts to dissipate earthquake input energy and re-center the bridge piers with minor damage that is easily repairable, while downtime will be minimized thus creating earthquake resilient bridges.

University of Wyoming – In MPC 539, the researchers increased the understanding about using RCA in ASR test. The newly developed method will help in selecting materials which will increase the service life of concrete. In MPC 540, a four-step travel demand model for estimating tourism ADT on low-volume roads was developed in this study by using a variety of variables related to tourism. The model had a reliable prediction accuracy, with an R-square greater than 0.8 compared to the actual traffic volumes. The model outputs indicated that tourism trips are a main traffic generator on low-volume roads in Wyoming. Tourism trips play a significant role in Northwest Wyoming, where Yellowstone National Park is located. The findings of MPC 599 will increase the understanding of connected technologies for special signal operations. This will ultimately lead to increased operations and safety in the vicinity of signalized intersections. The main focus is on freight and transit vehicles, which have multiple implications on transportation systems. MPC 630 will improved the process of collecting, cleansing and annotating images of weather conditions from road webcam for seamless ML application. In MPC 633, a literature review was conducted showing a historical background of major road track testing facilities in the nation. This includes a well-description of existing pavement research and details of operation and management on the testing facilities. The outcomes of the literature review increase the body of knowledge and understanding of testing pavement under full-scale testing and actual environmental conditions.

Utah State University - The projects at Utah State University will have the following outcomes: (1) improved planning for the deployment of charging infrastructure for electric vehicles; (2) increased knowledge of travel behavior leading to reductions in air pollution in the state of Utah; (3) increased awareness of transportation agencies of landslide risks; (4) increased understanding of constructability and durability issues associated with embedded wireless charging systems in pavements; (5) improved traffic operations and improved adoption by transportation agencies related to autonomous vehicles; (6) improved adoption of electric busses; (7) improved understanding and possible adoption of fiber reinforced bridge decks; (8) increased safety of bicycles at roundabouts; (9) improved safety for pedestrians at intersections; (10) increased understanding of the post impact behavior of bridge pier couplers; (11) increased pool of educated transportation professionals and better trained transportation workforce.

These outcomes are coming and will continue to come as a result of the well planned research projects. These projects consistently utilize students and in some cases, outside companies and agencies, to perform the studies. In all cases, the

students develop a deeper understanding of the complexities and challenges facing current transportation professionals. Additionally, the Utah LTAP Center provides training to many in the current workforce.

5. Impacts –

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

Colorado State University - The projects at Colorado State University will have the following impacts:
1) the developed technology and planning process will offer some low-cost bridge inspection procedures such as using unmanned aerial vehicles (UAVs) and will ultimately lead to cost-effectiveness of bridge inspection practice; 2) the new technology on traffic modeling can increase travel time simulation accuracy which will contribute to improved evacuation and traffic planning and potentially saving millions of dollars and hundreds of human lives by improving more efficient and safe EMS service to the community following hazards; 3) the findings of these projects may improve the effectiveness of developing a more resilient transportation system against various hazards by improving our ability to assess the probability these hazards, minimize crashes and plan recovery of critical infrastructures during hazards like landslide, earthquake and flooding etc.

In addition, further anticipated impacts may include: 1) 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;
2) the coordination and synthesis of data streams from both traffic management systems, and the vehicles traversing the streets network can allow for connected and autonomous vehicles to optimize their operations for fuel economy and emissions improvements. The value of these benefits are only available under conditions where the vehicles can have access to TMS datasets; 3) the improved modeling of runoff mechanisms and watershed response will increase the reliability of transportation infrastructure and will reduce the possibility that such infrastructure is damaged or destroyed by large storm events and the resulting floods.

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 projects at South Dakota State University will have the following anticipated impacts: (1) develop design methodology for transportation DMS structures using adhesively-connected joints; (2) perform realistic structural capacity assessment of existing DT bridges; (3) promote sustainable bio-materials and agricultural byproducts for production of bio-asphalt binders; (4) develop new precast column connection detailing for accelerated bridge construction; (5) improve the treatment and quality of stormwater runoff generated by transportation activities; (6) improve the selection process of deicing agents; (7) improve laboratory techniques for measuring the critical shear stress in cohesive soils; (8) implementation of advanced methods for predicting bridge scour; (9) development of recommendations for bridge deck sealant applications; (10) development of an improved network screening method for meaningful safety remediation measures; (11) reduce the possibility of insufficient field soil compaction.

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.

University of Denver - The research projects at the University of Denver will have the following expected impacts: 1) Provide leaders of transportation organizations with information about how to reduce costly accidents and injuries and improved safety culture, operational fatigue levels, and reduce accidents and injuries. 2) Provide leaders of transportation organizations with a Safety Leadership Training Model to Improve Safety Culture that is expected to refine and improve how to develop safety culture which will lead to fewer crashes, accidents and injuries resulting in greater safety and reduced costs. 3) The validation of a mobile hand-held alertness measuring device, integrated into existing mobile phones, will significantly improve access to fatigue information and increase ability to better manage fatigue potentially saving lives and money. And also, improve the effectiveness of the transportation system by reducing fatigue and accidents among vehicle operators.

University of Utah - The projects at the University of Utah will have the following impacts: (1) Given the growing interests and promising market of Shared Automated Vehicles (SAV), it is important for DOTs to start modeling how SAV technology would impact the regional travel patterns and consider the special needs of SAV in long-range cost estimates and programming process; (2) annual average daily traffic (AADT) prediction using statistical techniques is not able to reflect traffic flow variation in fine granularity for operational analysis purposes and hourly volume estimation is challenging due to larger fluctuation induced by spatial-temporal features; our research predicts hourly traffic volumes with high accuracy and requires larger datasets and more features that potentially affect traffic flow, and as such, predictive capability and time complexity is taken into account; (3) predictive models using UDOT's snowplow data suggest a threshold of work intensity for preventing rapid deterioration of truck performance under various operational environments; (4) simulation study can help researchers and engineers better understand the benefits and risks of adopting different types of connected vehicle applications in practice; (5) state DOT agencies have a better understanding on how the speed limit legend color design can affect the visibility of the sign and the corresponding road safety; (6) identification of innovative means to mitigate the bump at the bridge issue during design and construction, whether through initial cost savings or by providing superior long-term performance, will provide value to DOTs either through savings from initial capital investment or through life-cycle cost reductions, hence assisting in the preservation of key infrastructure; (7) improved understanding of influence of native subgrade materials and fill materials on performance of pavement systems constructed on soft subgrades should result in roadway systems that will perform better and require less long-term maintenance than current practice; (8) significant reduction settlement or heave of approach embankments for bridges, thereby mitigating problems with bumps at the ends of newly constructed bridges; (9) improved durability of the transportation system thanks to better understanding of material performance; with better characterization and understanding, specific materials for specific conditions can be selected so that the performance of pavements is optimized; (10) bridges constructed in the future will be self-centering for immediate use after an earthquake with columns suffering minor damage that is easily repairable; (11) a cost-effective method of building new bridges in seismic regions by utilizing buckling restrained braces as replaceable fuses has been developed and tested; the method could be used for rehabilitation of bridges after an earthquake by replacing the buckling restrained brace while there will be no damage to the reinforced concrete bridge components; (12) a cost effective corrosion-free column for bridges in seismic regions could result from current research; (13) manual asset inventory can no longer fulfill the growing need, and current methods (e.g., laser scanning) fall behind new technologies in terms of being frequent and inexpensive; implementing a method using photogrammetry in asset inventorying can save $100,000 in each data collection crew's initial equipment cost.

Research on SAVs paves the way by presenting a framework of modeling SAVs to seamlessly integrate them into the existing four-step travel demand models. Compared to life-cycle cost analyses used in previous studies, the proposed prediction model using UDOT’s snowplow data can assist transportation agencies to better prioritize fleet replacement. By taking the geometric design of highways into account, simulation can help provide a guideline on how to identify potential crash risks and which type of connected vehicle application can help prevent them. Considering that white LED signs have much lower visibility during the winter seasons, research carried out can greatly benefit areas suffering from long winters. By preventing the formation of the bump at the bridge, roads will be

safer and keep the citizens moving with fewer maintenance closures. Seismically resilient bridges can save bridge owners significant time and cost due to minor repairs required after an earthquake. Fabrication errors and traffic collisions could cause roadway asset deterioration in much less time than the period of data-acquisition for asset inventory using laser scanners (currently every two years in Utah), thereby leaving the damaged facility no longer serviceable. On the contrary, a more frequent asset inventory system by leveraging photogrammetry as a complementary technology to laser scanning can address the mentioned service deficiency.

University of Wyoming - MPC-540 — Updating and Implementing the Grade Severity Rating System (GSRS) for Wyoming Mountain Passes will provide better selection for speed limits on downgrades which would result in a significant reduction in fatal/high severity crashes. MPC-633 — A Feasibility Study for Establishing a Regional Road Track Pavement Testing Facility in Wyoming will hopefully result in the construction of the test tracks. Such tracks will provide better selection of paving materials and construction techniques in the dry-freeze region.

Utah State University - The projects at Utah State University will have the following impacts: (1) provide the information needed for the infrastructure of the US to move into the modern electrified and autonomous era; (2) provide the research required to radically change the construction of concrete bridge decks. Several of these projects provide the groundwork for the increased adoption of electrified vehicles as well as the adoption of autonomous transportation in the near future. The use of fiber reinforced concrete for bridge decks will improve durability and therefore make the transportation system much more effective.

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

Colorado State University - The projects at Colorado State University will have the following impacts:
1) The studies on bridge inspection techniques are expected to inform the ongoing discussion of how to enhance bridge management practices in the U.S. and may be adopted by CDOT maintenance teams to facilitate fast and cost-effective road condition data collection and assessment. 2) The study may help develop the probabilistic landslide hazard maps will be able to be used by transportation planners and managers to build and adapt road networks in a way that reduces likelihood of landslide-related closures. 3) The proposed simulation techniques on roads with disruptions, including after earthquakes and other hazards will provide insight potentially be adopted in future traffic planning guidelines.

In addition, further anticipated impacts may include:
1) The project on Data-Derived Fuel Economy and Safety Improvements may be adopted by stakeholders across Colorado including consulting industry, Dept. of Transportation, and policy making entities. These stakeholders have proposed to adopt these new practices because they can (a) realize value for cities and counties that collect and disseminate signal phase and timing data, (b) realize fuel economy and emissions improvements that can be allocated to localized policy and human health goals, including climate action plans. 2) The findings from the project "Mitigation of Flooding-Related Traffic Disruptions with Green Infrastructure Stormwater Management" are relevant to stormwater drainage municipal entities and will be further disseminated through an invited seminar at the Salazar Center and other upcoming venues.

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.

South Dakota State University - 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 for the construction of transportation dynamic messaging signs; (2) adoption of recommendations for assessing the structural performance of in-service double-tee bridges; (3) promoting the use of sustainable bio-materials and agricultural byproducts for production of bio-asphalt binders; (4) developing new sustainable alternatives to structurally deficient bridges on local and rural

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 runoff; (8) implementing pavement condition-specific deicing materials; (9) reducing rapid deterioration of bridge deck sealants; (10) codifying a methodology for traffic safety network screening; (11) developing a new practice for evaluation of the field compaction quality quickly and efficiently.

University of Colorado Denver - One of our project teams is currently working with the CU Tech Transfer office to file a provisional patent application. This patent application is currently in preparation and will be submitted in 2 weeks' time. No start-up companies have been initiated.

University of Denver - The research projects at the University of Denver will have the following expected impacts on adoption of new practices and new technologies: 1) The measurement of Safety Culture with a standard Survey measurement instrument has been adopted by at least one other transportation agency as a tool for measuring its effectiveness. 2) The adoption of a new approach to training and development of Safety Culture 3) The increased marketability and availability of a new and more portable and accessible device for measuring fatigue and alertness in the workplace that produces accurate measurements and valid results comparable to those that have previously only been obtained with larger, non-mobile static devices.

University of Utah - The projects at the University of Utah will have the following impacts: (1) the framework of modeling SAVs can be seamlessly integrated into the four-step travel demand models and directly implemented by public agencies; (2) an innovative spatial prediction method of hourly traffic volume on a network scale was developed using a state-of-the-art tree ensemble model - extreme gradient boosting tree (XGBoost) - to handle the large-scale features and hourly traffic volume samples, due to the model's powerful scalability; the model was tested on the road network in Utah; (3) using the snowplow truck fleet managed by UDOT, two models are implemented (random forest (RF) algorithm and linear support vector machine (SVM))- to predict the performance of snowplow trucks and it is demonstrated that the RF outperforms the linear SVM with regard to prediction accuracy; (4) assist UDOT and its agents in developing performance goals, design methods, standard design details, specifications, special provisions, and other contract and design documents to mitigate the bump at the bridge issue; (5) development of better design and construction guidelines for geogrid-supported pavement systems should result in wider use of this technology within roadway pavement systems as designed by all pavement designers, including those practicing in both the private and public sectors; (6) material and construction specifications for approach embankments for bridges will possibly be revised by UDOT and other public agencies; (7) improved tests that predict intermediate temperature performance of asphalt mixtures will be used both by UDOT and other public agencies to improve the durability of asphalt mixtures; (8) the IDEAL test, was developed to predict intermediate temperature performance of asphalt mixtures and is currently being considered for adoption by UDOT and other public agencies to improve the durability of asphalt mixtures; (9) self-centering bridge piers for accelerated bridge construction in seismic regions can save cost and time and this knowledge will be transferred to UDOT and other DOTs; (10) adoption of replaceable components after an earthquake such as a buckling restrained brace with no damage to the original bridge components could become a new practice; this is the case since the reinforced concrete columns, cap beam and footings remained intact in the experiment; (11) corrosion-free columns with excellent seismic performance will be of interest to DOTs in seismic regions where steel corrosion of bridge piers is an issue; (12) use of photogrammetry could be considered as a feasible alternative for laser scanners for several divisions at UDOT and other public transportation agencies to benefit construction and asset management; (13) research on connected vehicle technology and traffic safety will be brought to the attention of the Traffic Operation Center at UDOT to support field implementation; currently, UDOT is conducting an FHWA project that installs connected vehicle infrastructures to support several types of applications and the research results are expected to help design the implementation plan and predict potential benefits; (14) changeable message sign research selected the I-80 freeway corridor for analysis and the research outcomes can be applied to the I-15 freeway in Utah for future implementation.

Currently, no tests have been adopted due to the complexity in the procedure for predicting intermediate temperature performance of asphalt mixtures; UDOT would prefer a simpler test but before a final recommendation is made, its ability to predict performance must be verified. It is much easier and cheaper to replace a buckling restrained brace in a bridge bent with post-tensioned columns than to try and repair reinforced concrete columns with buckled or fractured steel bars

after strong earthquakes. Photogrammetry is a more cost effective, faster and less complex technology compared to laser scanners.

University of Wyoming - MPC-600 — Developing a Prototype System for Establishing Passing and No-Passing Zones of Two-Lane Highways resulted in developing the first version of the device which will help transportation agencies in establishing passing zones on two lane highways. The Wyoming Department of Transportation is currently implementing this new device which will provide enhanced safety on two lanes highways in the state.

Utah State University - The projects at Utah State University will have the following impacts: (1) provide the in-pavement technology to make wireless power transfer a reality. This technology will be expanded from limited static applications to broader reaching dynamic applications for roads and commercial applications.

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

Colorado State University - The projects at Colorado State University will have the following impacts:
1) The projects on bridge and highway inspection techniques and planning proposed more advanced deterioration models and filled the gap between computationally intensive approaches that are not practical for adoption by DOTs and less computational methods that rely heavily on expert opinion. The study on robust automated pothole detection and highway maintenance prioritization will produce new knowledge on the use of machine learning techniques to automate tasks related to inspection and maintenance of road transportation network.
2) The projects on traffic simulation and planning on disrupted traffic system following hazards will produce new knowledge on how traffic performance will be affected by disruptions and produce a better understanding of mechanisms and risks of disruptions under various hazards.
3) The landslide runout modeling is likely to be a major advancement in modeling landslide hazard. Most models of landslide runout are overly simplistic and may lead to inaccurate prediction of landslide hazard. We are developing a model that more explicitly accounts for the nature of the topography over which a landslide moves so that we can more accurately predict how far a landslide will travel.

In addition, further anticipated impacts may include:
1) The project on representative testing of expansive soil treatment technologies for transportation earthworks has produced a new experimental methodology for measuring the moisture dependent behavior of expansive soils and expansive soils treated by physical and chemical stabilization technologies.
2) The project on the experiments and modeling for infrastructure data-derived fuel economy and safety improvements contribute to the body of scientific knowledge include a quantification of the fuel economy and emissions benefits that come from the integration of traffic management system data and vehicle level data to improve the powertrain and dynamic control of Connected and Autonomous Vehicles.

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.

South Dakota State University - The projects at South Dakota State University will have the following expected impacts: (1) generation of invaluable data on fatigue and strength of adhesively-constructed joints of dynamic messaging signs; (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 resources; (4) contribution of new knowledge to the field of bridge engineering and design of engineered timber bridges; (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) expanding the knowledge on

traffic safety screening methodologies; (9) addition of new knowledge on the effects of chemicals used in deicing agents on asphalt under freeze-thaw conditions; (10) expanding the knowledge on soil compaction testing methodologies.

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.

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 to fatigue management which can have a is a direct impact on reducing accidents injuries and associated expenditures. 2) Contributing a standardized model for the training of leaders intending to implement and develop a safety culture in a transportation organization which will provide a basis for testing the most effective approaches for undertaking organizational change. 3) By contributing to the concurrent and predictive validity and accuracy of a mobile based assessment tool for detecting fatigue in vehicle operators. Currently, there are very few ultra-brief measures of fatigue/vigilance that have been validated. The current project validated the accuracy of a tool that is able to assess vigilance within 2 min (other assessments can take up to 30 min).

University of Utah - The projects at the University of Utah will have the following impacts: (1) mode share comparison among scenarios showed that while Mobility-as-a-Service (MaaS) can take market shares away from all conventional transportation modes, it competes more with auto; reducing the generalized cost of MaaS makes the mode more appealing against conventional modes; (2) an innovative and computationally efficient approach (Breadth First Search) to account for spatial dependencies by leveraging large-scale trajectory data, which significantly improves model accuracy; a tree ensemble model was developed that is scalable to large-scale datasets to spatially predict hourly traffic volume using a variety of features; (3) implemented mean decrease impurity measure to explore which variables are significant in explaining the deterioration of performance in snowplow activities; (4) a safety assessment model was developed to evaluate road safety performance under the connected vehicle environment; the new model will be able to fully account for the interactions between connected vehicles and human-driven vehicles and study how the operation of connected vehicles can impact overall traffic flow; (5) a safety model will be developed that fully considers the roadway geometric features, weather condition, traffic congestion levels, and the speed limit sign visibility into account to help future decision makers on speed limit signing designs; (6) improved understanding of the role of stretch length bolts and post-tensioning in bridge construction to protect bridges in earthquakes; stretch length bolts can easily be replaced after a strong earthquake because of the innovative construction methods developed; (7) improved understanding of the performance of post-tensioned bridges with replaceable fuses such as buckling restrained braces; the combination of post-tensioned columns with buckling restrained braces can produce a bridge system that can dissipate significant amount of earthquake input energy and since the only damage that occurs is to the buckling retrained braces, these could be easily replaced after an earthquake without any damage to the rest of the bridge; (8) increased understanding of how fiberglass spirals behave along with fiberglass vertical and steel vertical bars in bridge columns subjected to earthquakes; (9) recommendations to UDOT regarding methods, practices and technologies holding the most promise for immediate implementation of bump on the bridge research; in addition, develop a technology screening and selection process for use by future UDOT project teams to identify best alternatives for individual projects based on project-specific constraints and considerations; (10) improve the base of knowledge within the Civil Engineering field with respect to the economical design of pavement systems; (11) understanding of the loading and wetting-induced stress-strain characteristics of various types of soils will be greatly enhanced; (12) new knowledge on asphalt mixture testing at intermediate temperature and performance of such asphalt mixture once placed in the field; this will contribute to better road surfaces; (13) use of three different data acquisition procedures (i.e., mobile, terrestrial, and unmanned aerial system sensors) is assessed by the performance measurement method to clarify the accuracy and efficiency of each one of the above-mentioned methods for being used in conducting a roadway asset inventory system; as a result, transportation agencies can decide more decisively when it comes to choosing between using photogrammetry and/or laser scanning in different applications.

Higher market shares were found for shared ride MaaS due in part to the larger average household size in Utah; this finding, however, does not account for potential disbenefits of sharing a ride, such as discomfort in traveling with

strangers. Hybrid bridges with post-tensioning and stretch length bolts will be immediately serviceable after a strong earthquake with minimum repairs required for the next earthquake or aftershocks. This is the first time that a buckling restrained brace has been tested along with post-tensioned columns in a hybrid bridge system.

University of Wyoming - The University of Wyoming projects have the following impacts on the body of scientific knowledge: In the passing /no passing zone study, a new instrument has been developed to establish passing/no passing zones on two lane highways. There are no similar operational devices at this point.
MPC 598 and 599 have documented new development in the ITS area with the connected vehicle technologies.

Utah State University - The projects at Utah State University will have the following impacts: (1) One of the projects at USU will affect the policy implications of government investment in the infrastructure-enabled autonomous driving systems; (2) provide for the future powering of vehicles while in motion. These technological advancements will change the way the traveling public interacts with the infrastructure in the future.

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 research opportunities for graduate students to participate various activities including experiments and simulations; 2) improving the current teaching in transportation related fields to train the next generation of engineers. 3) The students 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.

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 - The projects at South Dakota State University will provide the following training opportunities to graduate students and engineers: (1) design of a new structural system for transportation dynamic messaging signs; (2) field inspection/testing and structural simulation of bridges; (3) fundamental experimental methods in bridge engineering; (4) structural performance of CLT bridge systems; modern laboratory techniques for flow measurements and the theory and methods used to predict pier and construction scour in cohesive soils; (5) application of new technology to improve stormwater treatment; (6) application of statistical, GIS, and coding concepts for traffic safety screening; (7) incorporation of research findings into course material.

University of Colorado Denver - The 14 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.

University of Denver - The research projects at the University of Denver had the following expected impacts on the transportation workforce development by: 1) Four graduate students received training and experience in the research process including literature review, data collection and analysis suing excel and SPSS and report writing.
2) Safety managers at two railroads were given information on how to improve their safety culture. 3) Presentations on the preliminary aspects of the safety culture training model have provided useful information to safety managers in planning their next organizational safety culture program. 4) Managers at several trucking companies received information about how to manage fatigue levels as a result of this project.

University of Utah - The projects at the University of Utah will have the following impacts: (1) two graduate students have received research training and were funded; the students worked closely with the consulting partner, RSG, Inc. to

build and modify the CUBE code of the travel demand model; (2) one graduate student has received training during another project and developed customized packages written in Python; the analysis methods and data are used in CVEEN 7545 Traffic Network Modeling course to teach the students advanced computing methods for traffic data analysis; (3) two graduate students received research training during another project; the model package and data processing written in Python was developed by the students and is used in CVEEN 5560/6560 to teach students to use data to make informed decisions; (4) two Ph.D. students are directly funded by another project and have received modeling training; research outcomes will be brought to course CVEEN 3520 Transportation Engineering to enrich teaching materials and research findings will be presented at conferences; (5) two Ph.D. students are directly funded by another project and they have received training to carry out the project activities; the research outcomes will be brought to the PI's course CVEEN 5920 Smart City and Infrastructure to enrich the teaching materials; (6) research on another project is providing support for two graduate students; one of them recently graduated and is now part of the work force; (7) research on another project is providing support for one graduate student; (8) another research project provided an opportunity for an MSc student to perform the research who has graduated and found employment in the Salt Lake City area working for an infrastructure-related company; the results of the research will be incorporated in a course on prestressed concrete; (9) in another project, one PhD student will graduate with improved skills that will likely be employed by the transportation industry; analytical skills developed by the student will enhance our prediction capabilities for the performance of bridges in earthquakes; (10) two graduate students were involved in conducting both data collection and data processing for another project; the students learned two different methods of 3D reconstruction technology and the technical project information regarding the transportation side and the computer science side gave them a good sight of their possible future work in a transportation agency; during the project, they had the opportunity to enhance their skills in various scopes required for a transportation workforce, including in-field data collection experience, acquaintance with different 3D reconstruction software packages and digital cameras, acquaintance with the application of different laser scanners (i.e., mobile-sensors, unmanned aerial systems (drones), and stationary terrestrial-sensors), and in-field and virtual roadway asset inspection procedures.

University of Wyoming - All MPC project at UW have workforce development components. Each study has involved undergraduate

Utah State University - The projects at Utah State University will have the following impacts: (1) Provided opportunities for many graduate students and undergraduate students to be involved in research that expanded their knowledge and interest in transportation related fields; (2) Provided training classes and improved abilities to 271 individuals involved in the transportation workforce; (3) provided scholarships and stipends to support students in their career path to contribute even more to the profession from what they have learned.
Our projects are all involved in supporting these impacts. Additionally, the Utah LTAP Center provided interaction and training for many members of the workforce on a regular basis.

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

University of Utah - In the transportation field, Shared Automated Vehicles (SAV) were modeled to see how they would impact regional travel patterns in long-range cost estimates and programming processes. Research on annual average daily traffic (AADT) prediction using advanced techniques provides high accuracy with larger datasets and predictive capability is improved. A simulation study helps understand the benefits and risks of adopting different types of connected vehicle applications in practice. State DOT agencies have a better understanding on how the speed limit legend color design can affect sign visibility and corresponding road safety. In the geotechnical field, innovative means to mitigate the bump at the bridge issue during design and construction will provide assist in the preservation of key infrastructure. The influence of native subgrade materials and fill materials on performance of pavement systems constructed on soft subgrades will result in roadway systems that will perform better and require less long-term maintenance than current practice. Significant reduction settlement of approach embankments for bridges, will be achieved thereby mitigating problems with bumps at the ends of newly constructed bridges. In the pavement materials area, with better characterization and understanding of specific materials for specific conditions, the performance of pavements is optimized thus improving durability of the transportation system. In the structures field, bridges constructed in the future will be self-centering for immediate use after an earthquake with columns suffering minor damage that is easily repairable. A cost-effective and accelerated method of constructing new bridges in seismic regions by utilizing buckling

restrained braces as replaceable fuses has been developed and tested; the method could be used for rehabilitation of bridges after an earthquake by replacing the buckling restrained brace while no damage to the reinforced concrete bridge components occurs. A cost effective corrosion-free column for bridges in seismic regions is being tested which could minimize bridge maintenance costs.
In the emerging cyberinfrastructure field, manual asset inventory can no longer fulfill the growing need, and current methods fall behind new technologies which are more frequent and inexpensive; implementing a method using photogrammetry in asset inventorying can result in significant savings.

Utah State University - Part of the work funded by the MPC has contributed to USU being awarded an NSF Engineering Research Center (ERC) named: Advancing Sustainability through Powered Infrastructure for Roadway Electrification (ASPIRE). Several of the PI's associated with the MPC are also part of the ASPIRE Center. The projects related to power transfer and autonomous vehicles are particularly related.

6. Changes/Problems

Colorado State University -There was some delay on the projects primarily due to the pandemic (MPC 571, 618 and 619), such as lab access and shortage of research staff support etc. It is expected the projects will come back to normal soon.

In addition, MPC-538 — Representative Testing of Expansive Soil Treatment Technologies for Transportation Earthworks, in March 2020, long duration testing was terminated before the end of the experiments due to the COVID-19 pandemic and the mandatory ceasing of all non-essential laboratory tests at Colorado State University on March 23rd, 2020. Given the size of these tests, re-running these tests is not possible with the project budget. Our plan is to analyze and use the data that were generated prior to test termination to assess the effectiveness of the proposed testing methodology. Our intent is to supplement partial test results with tests on other geo-materials.

North Dakota State University - Four of the North Dakota State University projects have been delayed and/or slowed, in three cases the cause is at least partly related to the COVID-19 pandemic with the remaining delayed by cost and Co-PI personnel disruptions.

MPC-548 (Development of Models for the Prediction of Shear Strength of Swelling Clays) encounter problems with molecular dynamics simulations indicated that the molecular interactions between clay and fluids play a critical role in the mechanical behavior of swelling clays. We built and attempted to model the real clay sheet sizes using molecular dynamics, but due to the enormous computational costs and limited availability of computational resources we realized that we would need to use another approach. We are in the process of building coarse grained models for the clay from scratch, computing new parameters and validating the models. These models will be able to allow us to accomplish the task with existing computational resources. The task of building robust coarse grained model for clay is not trivial and considerable efforts are being placed in this endeavor. One positive aspect is that the coarse grained model will be available to the research community. The discrete element modeling studies will be accomplished after the CG model simulations are completed, and would require additional time and resources. In addition, laboratory work has slowed down since mid-march due to COVID-19, but we are strategizing to minimize the impact. With the help of college of engineering IT and NDSU CCAST, we have enabled remote student access (from home) to high performance computational facilities and the needed software. In the next period we will be focusing on modeling tasks and publications and resume experimental work when more easy access to the laboratories are available in the next few months. Experimental work is conducted at multiple laboratories across campus. Most conferences have been cancelled and many upcoming conferences will involve the use of remote attendance exclusively or in some cases using a hybrid model.

MPC-566 (Supporting Tribal Crash Data Utilization and Strengthening Institutional Capacity for Effective Traffic Safety Programs) is experiencing ongoing COVID-19 related-delays that substantially impacted progress in our collaborations with the tribes. Most stakeholders are completely consumed with COVID related activities in their communities. While the tribal liaison continues to reach out with regard to continuing work, a start-up is not in sight at this time due to continued uncertainties and risk based on stakeholder communications.

MPC-601 (Sensitivity and Accuracy Assessment of Vehicle Weigh-in-Motion System Measurement Errors Using In-Pavement Strain-Based Sensors) has forced timeline adjust due to the COVID-19 pandemic inhibited us from installing our weather sensors during that period. Currently, we plan to install the sensor in Spring 2021 based on the estimated vaccine available time so the weather data collection and weather impact analysis will be delayed.

MPC-602 (Local Road Safety Program Evaluation: Perceptions, Experiences & Implementation) has had several personnel disruptions due Co-PI vacancy in the engineer aspects twice within the project at this point. This remains an uncertainty as the position has most recently been filled by an individual with a different skillset that does not include research.

South Dakota State University - The majority of our projects require intensive lab and field investigations. Campus lockdown, which lasted until the end of summer 2020, due to the pandemic has limited the faculty's and students' ability to pursue those investigations in a timely manner. This has resulted in delays of project execution.

University of Denver - Two projects have encountered some challenges and delays in recruiting participants due to the controversial nature of the topic as well as lack of access to human participants due to quarantine and social distancing. 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. However, meetings were held with the national leaders of the Sheet Metal and Trainmen Union (SMART) in January of 2020 who expressed a desire to move forward with the project. Unfortunately, subsequent meetings have been postponed due to the corona virus pandemic social distancing. In addition, the coronavirus pandemic has delayed the feedback to stakeholders, the presentation of papers at conferences and other technology transfer reporting opportunities.

University of Utah - Due to the Coronavirus, although some of the research laboratories were allowed to reopen in May 2020, several experimental projects were affected to different degrees. Projects involving large-scale laboratory tests were affected the most. In other projects, the Coronavirus has slowed down some processes such as data collection. In other projects, due to travel restrictions, field performance data could not be collected and this delayed the research.

Utah State University - Some of the projects have been significantly impacted by the Covid pandemic. Projects utilizing laboratory facilities have been slowed due to limitations on the use of on campus laboratories. The supply of graduate students, particularly international students have been unable to enter the US which has had an impact on the number of students available to work on projects.

7. SPECIAL REPORTING REQUIREMENTS:

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