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

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Mountain-Plains Consortium, North Dakota State University
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North Dakota State University
Upper Great Plains Transportation Institute
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Semi-Annual Progress Report #8

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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-656** which can be found on the Mountain-Plains Consortium website

b. What was accomplished under these goals?

i. Project Selection

One hundred twenty-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 1 by reference to milestones.

Table 1: Program Milestones

Milestone Event	Description	Start Date	End Date
Execution of Grant Agreement	The grant was received from RITA and executed by NDSU's Sponsored Programs office. All 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, **120 transportation and transportation-related courses** were offered this reporting period, for a total of **856 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 501 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 **143 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 **89 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 **160 students from the U.S. and countries around the world. This includes 82 doctoral students; 53 master's students; and 25 undergraduate students.**

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

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

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, eighteen students are working on MPC project: Xinyi Yang, Hafiz Usman Ahmed, Ihsan Khan, Yun Zhou, Salman Ahmed, Keshab Thapa, H M Nasrullah Faisal, Neeraj Dhingra, Narendra Malalgoda, Yihao Ren, Morgan Jacobson, Amin Keramati, Xiaoyi Zhou, Bhavana Bhardwaj, Sajad Ebrahimi, Dawei Zhang, Ratna Yasoda, and Erik Johnson.

Nine principal investigators, faculty, and administrators are participating in MPC projects at **South Dakota State University** are: Junwon Seo, Nadim Wehbe, Guanghui Hua, Kyungnan Min, Christopher Schmit, Mostafa Tazarv, Francis Ting, Michael Pawlovich, and Rouzbeh Ghabchi. In addition, seventeen students are working in MPC research projects: Euiseok Jeong, Ibin Amatya, Marco Paulo Pereira Castro, Bipin Adhikari, Evan Greenway, 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, Jimmy Kim, Meng Li, Carolyn McAndrews, Kevin Rens, Manish Shirgaokar, and Farnoush Banaei-Kashani. In addition, twenty students are working on MPC research projects: Shahryar Monghasemi, Mallory Redmon, Shalini Mahanthege, Alayna Truong, Ricardo Gonzalez, Brady Heath, Ghazal Batouli, Robert Fitzgerald, Mahdi Ghafoori, Nick Coppola, Yaneev Golomber, Ryanne Ototivo, Ali Alatify, Wei Li, Tobby Lei, Sohil Vaidya, Yongechen Ji, Selvakumar Jayaraman, Khang Nguyen, and Jun Wang.

Three principal investigator, faculty, and administrator is participating in MPC projects at the **University of Denver**: Patrick Sherry, Ruth Chu-Lien Chao, and Jesse Owen. In addition, eleven students are working on MPC research projects: Sree Sinha, Emma Porter, Megan Solberg, Jeremy Coleman, Katherin Miller, Kailey Painter, Orphea Wright, Catherin Bianci, Matthew Cole, Jessica Solano, and Jessica Mantia.

Twelve principal investigators, faculty, and administrators are participating in MPC projects at the **University of Utah** are: Xiaoyue Cathy Liu, Chris P. Pantelides, Steven Bartlett, Evert Lawton, Pedro Romero, Tiffany Hortin, Mark Bryant, Nikola Markovic, Zhuo Chen, Jeff Phillips, Abbas Rashidi, and Xianfeng Terry Yang. In addition, thirty-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, Abdullah Mamum, Ali Hassandokht, Seth Miller, David Sacharny, Yinhu Wang, Victoria Binifarias, Ryan Burton, Suman Neupane, Remy Thigpen, Dylan Brow, Cyrus Safai, Sarah Stoplkai, and Zhao Zhang.

Fourteen principal investigators, faculty, and administrators are participating in MPC projects at the **University of Wyoming** are: Jennifer Tanner, Khaled Ksaibati, Promothes Saha, Anas Alrejjal, Er Yue, Mohamed Ahmed, Ahmed Farid, Suresh Muknahallipatna, Milan Zlatkovic, Marwan Hafez, Kam Ng, Mahdi Rezapour, Muhammad Tahmidual Haq, and Amirarsalan Mehrara Molan. In addition, seventeen students are working on MPC research projects: Sherif Gaweesh, Md. Tarik Hossain, Esraa Alomari, Vincent Ampadu, Osama Nasri Abu Daoud, Waleed Aleadelat, Omar M. Albatayneh, Arash Khoda, Sara Bashir, Zorica Cvijovic, Benjamin Fosu-Saah, Md Nasim Khan, Sahima Nazneen, Zephaniah Connell, Lokendra Khatri, James Mock, and Anas Alrejjal.

Six principal investigators, faculty, and administrators are participating in MPC projects at **Utah State University** are: Ziqi Song, Patrick Singleton, Andrew Sorensen, Michelle Mekker, Marvin Halling, and Keunhyun Park. In addition, eighteen students are working on MPC research projects: Ikwulono Unobe, Yi He, Prasanna Humagain, Hossein Nasr-Esfahani, Suman Roy, Pilaiwan Vaikasi, Sailesh Acharya, Nick Langford, Niranjan Poudel, Ashikur Rahman, Zach Benson, Abdullah Al Sarfin, Yiming Zhang, Trevor Gardner, Nate Raine, Doo Hong Lee, Thad Hansen, Ahadul Islam, Md Rafiur Rahman.

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

North Dakota State University
Chengbo Ai, University of Massachusetts, Amherst
Jingnan Zhao, Ruters, Postdoc researcher
University of Denver
Noel Beck, Keolis Commuter Services, VRE
Patti Gillette, Colorado Motor Carriers Association
Chris Harrington, Keolis Commuter Services, MBTA
Manuel Machado, Keolis Commuter Services, VRE
University of Utah
Jamie Mackey, Utah Department of Transportation
Mark Parry, Utah Department of Transportation
Kyle Rollins, Brigham Young University
Scott Stevenson, Utah Department of Transportation
University of Wyoming
Dima Husein, German Jordanian 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 **69 peer-reviewed articles or papers** in scientific, technical, or professional journals. Since the beginning of this grant, **we have published 274** different peer-reviewed articles or papers.

b. Conference Papers can be found in Appendix D

i. This reporting period **we have published 26 conference papers and 128 total since the grant began**.

c. Presentations can be found in Appendix D

i. MPC faculty and investigators **have presented at 45 different** scientific, technical, or professional conference this period. In total, we have **had 175 presentations on MPC research**, results and outcomes.

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

i. The MPC website is fully operational at: https://www.mountain-plains.org/
ii. The MPC Key Personnel can be found at: https://www.mountain-plains.org/personnel/
iii. Other **outputs** that are University specific:

Colorado State University:
Bhaskar, Aditi, Katie Knight, Stephanie Kampf, Sam Zipper, Greg Newman, Suren Chen, and Guangyang Hou. "Patterns and Mitigation of Street Flooding in Denver, Colorado" Colorado Water, 37(3), 2020. https://watercenter.colostate.edu/wpcontent/uploads/sites/33/2020/12/ColoradoWaterV37December.pdf

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:
The developed MBCOS system can be used by employers to incentivize their employees in exploring new commute plans that can minimize transportation emissions as well as travel time and cost. Employers will be able to set budgets to incentivize employees to adopt the recommended commute plans by the system and cover potential inconveniences such as increase in commute duration. The new system can be used via a website developed in a previous grant https://www.commuteopt.com/

We obtained a license from NREL to incorporate our solutions in an NREL software, called Hive: https://www.nrel.gov/transportation/hive.html
We completed our testbed that consolidates and implements the three constrained route planning scenarios we had originally proposed to study, namely, ride sourcing, ridesharing, and fleet management.
The Accessible City Study website (https://www.accessible.city/) under development will have a place for participants, and other audiences who are interested in the topic, to access information about the project. Specifically, the project team is writing up content to connect visitors to volunteer for interview and app use. Public-facing reports will be posted here along with options for readers to provide commentary and feedback.
We have developed new deep learning based models for bridge deterioration forecasting. In particular, we have developed two categories of deep learning based models: 1) baseline deep learning models, and 2) advanced deep learning models. The baseline models that will serve as baseline include Feed-Forward Neural Networks (FFNN), Long Short-Term Memory (LSTM) Networks, Bidirectional LSTM (BiLSTM) Networks, Gated Recurrent Unit (GRU) Networks, Convolutional Neural Networks (CNN), and CNN + BiLSTM networks. For advanced models, we have designed and developed two models: a Multi-Channel CNN model, and Temporal Convolutional Network (TCN). As expected, our preliminary results show that TCN, which benefits from features of many baseline solutions outperforms other models.

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

University of Utah:
Reports compering current and proposed routes for 3 cities in Utah, together with animations illustrating these routes. Example animations are provided below:
https://youtu.be/yPGiIaw7yLk
https://youtu.be/gSs1u-EXMGQ

University of Wyoming:
The updated GSRS model was automated through an interactive, intuitive, aesthetically appealing, and user-friendly software application, written in Visual Basic.net. Currently, the software is still under development. After submitting the final report, the software will be shared with highway agencies as a desktop or web-based application. A systematic method for ascertaining the level of service (LOS) of gravel roads in the U.S. A methodology comprising eight criteria that affect gravel road traffic operations is developed. For each criterion, a rating is assigned. It is either "Good", "Fair" or "Poor". The results of each individual criterion rating are combined to develop an overall LOS rating. The developed methodology is intended to benefit traffic engineers, decision-makers, and any other stakeholders. This methodology is compiled and managed in a GIS shape file prepared for the purpose of this research. That is in order to provide decision-makers in local agencies a computerized tool to efficiently track the performance of their gravel road network. Routing criteria were developed using the Network Analyst tool of ArcGIS software based on the restrictions on average daily traffic (ADT) volume values, speed limits, driving distances, and driving hours per day. Results indicated that the routing maps created by ArcGIS software were an easy-to-use method to plan and schedule data collection on gravel roads. The routing analysis provided a reliable means to minimize driving time and distance. This methodology is compiled and managed in the ArcGIS software where it is an easy-to-use method to plan and schedule data collection on gravel roads. The methodology developed in this study may be employed by local transportation agencies for road maintenance purposes in rural areas.

A computational method for gravel roads riding quality utilizing smartphones. In this study, smartphones were used to collect gravel road condition data in terms of the International Roughness Index (IRI) and corrugation to develop an objective computational method to estimate the riding quality on gravel roads. The developed method will help local agencies to reduce subjectivity in their data collection process and support them with a solid computational justification for their evaluation data and decisions.

Hafez, M. "A Proposed Road Track Pavement Testing Facility on I-80 in Wyoming for the Dry-Freeze Climatic Region." Wyoming Technology Transfer Center, 2021 Newsletter, Issue 1, February, 2021. https://www.uwyo.edu/wyt2/newsletter/february-newsletter-2021.pdf [Accessed April 5, 2021]

The discussions of the best practices of implementing a full-scale road track testing facility were enriched through three virtual meetings with the officials of the major testing facilities in the country. A meeting was held between the principal investigators (PIs) and three representatives of MnROAD including the MnROAD operations engineer and the research project engineers. the second virtual meeting was held between the PIs and the officials of the NCAT testing track. The third virtual meeting was held between the PIs and the Florida DOT new testing track on US-301 which will be opened to real traffic in 2023. All the meeting briefings and findings were documented into summary reports. WYDOT can consider several recommendations documented in these reports based on the successful experiences of MnROAD, NCAt, and FDOT combined.

Utah State University:
Online folder of LiDAR data collected during project (link provided with final report and is published on MPC website).

News about a publication: de Needf, Matt. "Roundabouts Suck For Cyclists: Here's Why." Cycling Tips, March 2021. https://cyclingtips.com/2021/03/roundabouts-suck-for-cyclists-heres-why/

News about a publication: Pennington, Anessa. "Roundabouts Not as Safe for Cyclists, New Research Says." USU Engineering Newsroom, March 2021. https://engineering.usu.edu/news/main-feed/2021/roundabouts-not-as-safe-for-cyclists-new-research-says

4. Outcomes:

i. **Significant** outcomes by university:

South Dakota State University: A detailed methodology was developed by SDSU researchers for use by bridge inspectors in South Dakota to determine safe load carrying capacity of damaged double-tee girder bridges. The methodology, which is based on visual inspection and damage classification of the bridge girders, would allow county officials in South Dakota to post their damaged or deteriorated bridges without the need for sophisticated and expensive testing methods.

University of Utah: The paper by Yi et al. (2021) published in the Journal of Computers, Environment and Urban Systems titled "Inferencing Hourly Traffic Volume Using Data-Driven Machine Learning and Graph Theory" makes an important contribution using machine learning which is a new development in this area. In addition, the paper by Wang et al. (2021) "Adaptive and Multi-Path Progression Signal Control under Connected Vehicle Environment" published in Transportation Research Part C: Emerging Technologies, focuses on connected vehicles and signal control which is a new and important area of research.

Utah State University:

The paper by Singleton is significant. Poudel, Niranjan and Patrick A. Singleton. "Bicycle Safety at Roundabouts: A Systematic Literature Review." Transport Reviews, 1877207, 2021. DOI:10.1080/01441647.2021.1877207.
Dr. Singleton is become very well known nationally for his work on bicycle and pedestrian modes of transportation.

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 technique to assess deterioration risk and condition assessment and inspection techniques of bridge infrastructures; (2)increased understanding of traffic network performance and development of new techniques to improve the traffic safety and mobility of traffic system; (3)increased in the body of knowledge of pavement and soil condition over traffic and environment loads and the approach of mitigating the potential damage risks under hazardous conditions.

Specifically:

1) Low-cost and high efficiency UAS based inspection techniques have been developed along with advanced data analytics tools for extracting structural condition information from the images. Further, current bridge inspection practices have been reviewed thoroughly accounting of the factors that provide levers and limit the capacity for change within transportation agencies. Some studies will lead to new bridge management practices that leverage detailed information on a few bridges to make better estimates of bridge service life and maintenance needs for a whole network of bridges.
2) New traffic flow simulation techniques with partial obstruction on the road has been developed, which increases the understanding of the new methodology to simulate the traffic performance such as traffic speed and travel time for roadways with disruptions. In addition, improved road disruption modeling technique has been developed during natural hazards, such as tree-caused debris and flooded roadways.
3) The researchers have improved the understanding of the geomorphic and hydrologic controls on landslide initiation through Monte Carlo simulation of hillslope instability. Moreover, multiple natural hazard responses (rock fall, flood, mudslide) have been evaluated using a single computational platform to evaluate the influence of these threats on an equal level.

In addition, further anticipated outcomes may include: (1) increased understanding of the process toward development of visible and thermal imaging technique for robust Automated Pothole Detection and Highway Maintenance Prioritization. Automated tools for pothole detection, pothole mapping and updating for use by state DOTs and highway maintenance team are expected. (2) improved process of assessing traffic safety risk under various hazardous driving Conditions.

Specially, (1) A unique and valuable database of geotagged and labeled trios of visible, thermal and fused images for training pothole detection algorithms. A set of procedures for integrating images from multiple types of sensors to enhance accuracy and robustness of pavement distress assessment. (2) increased understanding of the traffic safety risks on roads with various work zones, crosswind and possible adverse driving environments. New simulation technique has been developed to assess such risks.

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 and enlarged the pool of trained transportation professionals in AV safety field; (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; (6) expanded future transportation professionals trained to develop and apply risk analysis, data mining, and machine learning methods to improve the utility of benefit-cost analysis.

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 14 journal papers, 2 conference papers, and 5 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 the various research-related skill development.

University of Denver
The research projects at the University of Denver will have the following expected outcomes: 1) access to smartphone based app for assessment of fatigue and alertness in the operational environment; 2) an online measurement tool for the assessment of safety culture; 3) development of a training model and module to teach effective leadership techniques for developing and maintaining safety culture and; 4) the discovery of the impact of USDOT policies on the health and safety of drivers during the pandemic.

1) The project "Validation of Smartphone Alertmeter Fatigue Assessment Device for Transportation Workers (MPC-605)" 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 are 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 (MPC-582)" 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 (MPC-604) will aid leaders of transportation organizations in demonstrating the behaviors and best practices that will lead to the development of an effective safety culture characterized by reduced numbers of accidents and injuries. 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.
4) The "Fatigue, Health and Driving Behavior During COVID (MPC-646)" and "Effects of Autonomous Vehicles (MPC-552" projects will provide a greater understanding of how the USDOT policy and regulatory changes during the COVID-19 affected driver safety, health, and productivity. Recommendations for policy improvements will be made.

University of Utah

The project at the University of Utah will have the following outcomes: (1) provide improved estimates of the effects of increased capacity from AV technology such as platooning and knowledge from which the issue of "zero-occupant vehicles" can be systematically investigated; (2) determine whether statistical modeling and/or machine learning can be applied to for estimating/predicting traffic conditions; (3) evaluate and measure the impacts of allocated funds for snowplow truck lifecycle performance assessment and explore the possibility of using Verizon's real-time automatic vehicle location (AVL) data to update the lifecycle model; (4) improvement of efficiency of snowplowing operations in Utah through route optimization; (5) study intercorrelation between crash severity, frequency and highway geometric characteristics based on statistical analysis of crash data in Salt Lake City and use simulations to evaluate the impact of Connected Vehicle technology on highway safety improvement under different highway designs; (6) improve roadway asset management by using photogrammetry for generating point clouds as an alternative to LiDAR; (7) improved knowledge on estimating the effect of combined automated vehicle and mobility-as-a-service technology on future transit ridership and vehicle miles traveled; (8) improved our knowledge on the intercorrelation between crash severity/frequency and freeway geometric characteristics based on statistical analysis of crash data for evaluating the visibility of the yellow-legend and white-legend changeable message sign systems; (9) knowledge on developing a computer vision-based air-traffic control system able to count and identify the airplane models in Utah airports; (10) improved knowledge on identifying the freeway bottleneck locations in Salt Lake County that are suitable for coordinated ramp metering and evaluating both the safety and operational performance of the control system; (10) knowledge on alternative methods for constructing bridge bents in high seismic regions using self-centering in terms of post-tensioning of bridge columns with either stretch length anchors or buckling restrained braces as supplementary energy dissipation devices; (11) improved our understanding through analytical models of alternate designs for column-to-footing joints with recessed splice sleeve connectors and to develop design guidelines for bridges constructed using accelerated bridge construction methods in seismic regions; (12) improved knowledge on the seismic performance of bridge columns built with longitudinal GFRP bars and GFRP spirals including self-centering; (13) propose changes to specifications related to problematic materials for acceptable engineering performance when used in bridge embankment approaches; (14) knowledge on potential methods or best practices to mitigate bridge end differential settlement; (15) improved our knowledge on whether geogrid reinforcement adds any benefit to the long-term performance of pavement systems; (16) improved our knowledge on low and intermediate temperature properties of representative asphalt mixtures produced in the state of Utah; (17) improved our knowledge regarding the early cracking performance of seven pavements in Utah and its relation to the flexibility index; (18) improved knowledge of the performance of asphalt mixtures related to field cores.

University of Wyoming

Increase the body of knowledge in various areas related to traffic operation, materials, and safety. Adoption of a new technique to predict traffic volumes of low volumes roads. Improve the process of establishing speed limits on downgrade segments.

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; (12) improved durability of charging infrastructure for the future of electrified transportation in the US. These outcomes are coming and will continue to come as a result of the well-planned research projects. These projects consistently utilize students, and in some cases, outside companies and agencies, to perform the studies. In all cases, the students develop a deeper understanding of the complexities and

challenges facing current transportation professionals. 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 in terms of effectiveness of the transportation system: (1)improved technology of inspection techniques and practices of bridge infrastructures using UAVs may save considerable cost and help establish new bridge infrastructure inspection practice techniques for DOTs; (2) the new technology developed for traffic performance assessment of disrupted traffic system, emergency medical response can improve current simulation accuracy and potentially save more lives during post-hazard emergency response; (3) the automated data collection and damage identification of pavement technology will help decrease the cost associated with pavement condition assessment; (4)the new landslide risk prediction model can reduce potential risk of landslides.

Specifically, 1) UAV techniques can potentially save inspection costs up to 40%. The new inspection technique also allows more quantitative condition assessment by enabling identification of damage location, severity and type, which is superior to the existing practice; (2) The new traffic flow simulation technology and crash risk assessment techniques of disrupted road segments like work zone during hazards can increase the accuracy of prediction of traffic safety risk and travel time. As a result, it will contribute to improved evacuation and traffic planning and protecting drivers and conducting site-specific traffic operation and management strategy by considering potential crash risks; (3) the automated data collection and damage identification of pavement technology and will help decrease the cost of road condition data collection and assessment and will help improve safety of roads; (4)The landslide initiation model will be useful in quantifying the probability of landslides occurring across the landscape for a given hydrologic condition. The landslide routing model, which can be combined with the initiation model, then extends that risk analysis to evaluate hazard downslope from landslide source areas, including to transportation infrastructure.

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 on the effectiveness of the transportation system: 1) Provide leaders of transportation organizations with tools to measure safety culture and how to train to Improve Safety Culture that is expected to lead to fewer crashes, accidents and injuries resulting in greater safety and reduced costs. 2) Provide leaders of transportation organizations with a mobile hand-held alertness measuring device, integrated into existing mobile phones, which will significantly improve access to fatigue information and increase the ability to better manage fatigue potentially saving lives and money. 3) Provide leaders of transportation organizations with recommendations on the most effective of policies for maintaining driver health and safety operating during a pandemic.

University of Utah
(1) increased capacity from automated vehicle technology such as platooning will improve the environmental and economic advantages associated with the technology; (2) predicting traffic conditions with statistical modeling and/or machine learning has the potential to reduce traffic congestion; (3) optimizing snowplow truck lifecycle performance and efficiency of snowplowing operations with real-time automatic vehicle location can improve traffic conditions and result in economic maintenance; (4) intercorrelation between crash severity, frequency and highway geometric characteristics will result in improved highway safety; (6) improve roadway asset management using photogrammetry will result in efficient and economic maintenance; (7) improvements in combined automated vehicle and mobility-as-a-service technology will increase transit ridership and result in significant savings; (8) intercorrelation between crash severity/frequency and freeway geometric characteristics using changeable message sign systems will improve traveling conditions; (9) improved identification of freeway bottleneck locations will improve safety and operational performance; (10) alternative methods for constructing bridge bents in high seismic regions using self-centering will improve seismic resilience and reduce down time after a large earthquake which has favorable economic impacts; (11) accelerating bridge construction methods in seismic regions reduces time delays and saves bridges from earthquake damage and costly repairs; (12) acceptable seismic performance of bridge columns built with longitudinal GFRP bars and GFRP spirals can promote non-corroding bridges having significant economic benefits; (13) improving the performance of engineering materials used in bridge embankment approaches can reduce repair costs; (14) mitigation of bridge end differential settlement saves the public funds and reduces time delays; (15) geogrid reinforcement improves long-term performance of pavement systems and reduces maintenance; (16) low and intermediate temperature asphalt mixtures can result in economic and durable roadways; (17) identifying early cracking of pavements in Utah can result in more economic highways.

University of Wyoming
MPC 540 will result in establishing safer speed limits on downgrade segments which will result in safety operation and reduction in crashes.
MPC 539 will result in using recycled materials in construction projects which would help in the preservation of the environment.
MPC 541 will result in utilizing better techniques to manage gravel roads which will result in significant saving for local agencies.

Utah State University
The projects at Utah State University will have the following impacts on the effectiveness of the transportation system: (1) reduced petroleum consumption and reduced local emissions; (2) reduced freight transportation costs; (3) increased durability of electrified infrastructure; (4) improve transportation agency decision making regarding data collection and management from AVs.

Several of these projects provide the groundwork for the increased adoption of electrified vehicles as well as the adoption of autonomous transportation in the near future. The use of fiber reinforced concrete for bridge decks will improve durability and therefore make the transportation system much more effective.

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

Colorado State University

The projects at Colorado State University will have following impacts on the adoption of new practices and potential commercialization:

1) Some models and software may be developed for potential applications by government, research and commercialization usage; (2) some practices of design, inspection and management of transportation infrastructures may be adopted by DOT and governments; (3) some methods of powertrain optimization and prediction have potential to be adopted by private industry such as auto manufactures.

Specifically, (1) several potential models and software which may be adopted by government, research community and commercialization. These include those adopting Material Point Method (MPM) in analyzing the response of transportation systems to a wide variety of threats, physics-based and probabilistic landslide analysis, improved tool based for systematic planning for EMS traffic following earthquakes. (2) The developed UAV-based data analytics tools for quantifying, tracking and localizing the changes of bridge damage are expected to be useful for inspection industry and state DOTs. The developed automated tools can be adopted by DOT maintenance teams to facilitate fast and cost-effective road pavement condition data collection and assessment. (3) The methods of vehicle powertrain optimization under predictive powertrain control will be used by automotive original equipment manufacturers to improve their algorithms for local vehicle control and coordinated control with TMS.

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 worked with the CU Tech Transfer office to file a provisional patent application.
No start-up companies have been initiated.

University of Denver

The research projects at the University of Denver will have the following expected impacts on the adoption of new practices and new technologies: 1) The Safety Culture measures has been adopted by at least one other transportation agency as a tool for measuring its effectiveness; 2) the ready availability of a portable smartphone-based app for measuring driver/operator fatigue and alertness in the workplace that produces accurate measurements and valid results comparable to those that have previously only been obtained with larger, non-mobile static devices. It is

anticipated that 1) the results of the research will also lead to the adoption of a new and more streamlined model for training and development leadership practices required for the development and maintenance of a Positive of Safety Culture. and the leadership techniques needed to implement. 2) data gathered will document the impact of USDOT policies on the health and safety of drivers/operators during the COVID-19 pandemic.

University of Utah

Regarding the project on optimizing snowplow truck lifecycle performance and efficiency of snowplowing operations with real-time automatic vehicle location, UDOT tested routes for one of the three cities for which they were prepared.

University of Wyoming

WYDOT will utilized the new findings from MPC 574 to better select speed limits while considering geometric conditions.

MPC 633 will hopefully result in the construction a regional pavement testing facility which will help in selecting better materials and construction techniques.

MPC 600 resulted in developing a new system for establishing passing zones. The system has been implemented by WYDOT.

Utah State University

The projects at Utah State University will have the following impacts on the adoption of new practices and process commercialization: (1) the use of electrified infrastructure will change the way electricity is delivered into vehicles; (2) effective strategies for travel demand management surrounding episodic air pollution events. Governments and organizations can utilize these behavior-change-strategies for dealing with the negative impacts of air pollution.

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 on the body of scientific knowledge: 1) new simulation methodologies have been developed for traffic performance assessment following hazards, modeling deterioration of aged bridges and effective strategy of recovery planning of transportation system following hazards; (2) improved algorithms have been developed for new image computation and machine learning used for UAV-based bridge inspection, assessing traffic safety risks of vehicles under work zone conditions and automated pavement inspection and maintenance of road transportation network; (3) new knowledge has been gathered on the mobility risk of EMS traffic following hazards, the nonlinearity relationship between precipitation and streamflow, and the mechanisms and risks of some disruptions caused by tree failure and flooding and possible disruptions caused by such failures.

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 and fatigue management which can have a is a direct impact on reducing accidents injuries and associated expenditures; 2) Contributing to the development of a standardized model for the training of leaders intending to implement and develop a safety culture in a transportation organizations which will provide a basis for testing the most effective approaches for undertaking organizational change; 3) By contributing to the concurrent and predictive validity of a smartphone-based assessment tool for detecting fatigue in vehicle driver/operators. Currently, there are very few ultra-brief measures of fatigue/vigilance that have been validated. 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). 4) The research may have an impact on the recommended number of hours that can be driven during emergency situations. Also, there may be some recommendations for additional services needed to support this essential component of the freight transportation and supply industry.

University of Utah
The project "MPC-542 — Exploratory Modeling and Analysis for Automated Vehicles in Utah" will have the following impacts on automated vehicle technology: (1) SAVs could increase the total number of trips by 1% to 7% across designed scenarios; (2) while MaaS can take market shares away from all conventional transportation modes, it competes more with auto; (3) reducing the generalized cost of MaaS makes the mode more appealing against conventional modes; and (4) higher market shares were found for shared ride MaaS due in part to the larger average household size in Utah. The project "MPC-543 — Big Transportation Data Analytics" will have the following impacts on machine learning: (1) hourly traffic volume gives more valuable information than AADT for micro-level operational analysis; (2) machine Learning approaches could predict hourly traffic volume in a statewide road network managed by UDOT. The project "MPC-544 — Lifecycle Assessment Using Snowplow Trucks' Automatic Vehicle Location Data" will have the following impacts on data-driven research: (1) a cost-benefit model is used to provide an optimal year for replacement of specific types of snowplow trucks; (2) available maintenance and operation data from 2000 to 2017 confirms the effectiveness of a data-driven approach. The project "MPC-590 — Impact of Connected Vehicle Technology on Traffic Safety under Different Highway Geometric Designs" will have the following impacts on geometric highway design: (1) improved understanding of modeling vehicle dynamics considering driving behaviors and road geometric features; (2) better traffic safety assessment when historical crash data are not available; and (3) development of crash modification factors when new countermeasures are placed. The project "MPC-606 — Image-Based 3D Reconstruction of Utah Roadway Assets" will have the following impacts on scanning and ranging technology: (1) provide a comparison between photogrammetry and laser scanning in terms of reconstructing highway assets; (2) while laser scanning is still marginally superior in terms of accuracy and quality, photogrammetry is a more cost effective and easy to use technology. The project "MPC-608 — The Impact of the Mobility as a Service Mode on Transit Access" will have the following impacts on data analysis: (1) the analytics developed can be used to analyze trip data, such as micromobility, to infer trip purposes and assess efficacy, and detect the community formation for better planning. The project "MPC-610 — Impact of Regulatory Hybrid Changeable Message Sign on Traffic Safety under Different Freeway Geometric Designs" will have the following impacts on machine learning methods: (1) machine learning (ML) models, including Artificial Neural Network (ANN) and Support Vector Machine (SVM), are developed to model crash frequency and severity along the I-80 corridor; (2) safety models can help evaluate the road safety improvement for future VSL deployments. The project "MPC-636 — Strategic Deployment of Drone Centers and Fleet Size Planning for Drone Delivery in Utah" will have the following impacts on optimization and GIS: (1) guidance on expanding transportation options through

optimization techniques, geographic information systems; (2) visualization to enable the next generation of traffic engineers to develop advanced skillsets in analyzing infrastructure conditions. The project "MPC-637 — Assessing and Improving Efficiency of Snowplowing Operations via Data and Analytics" will have the following impacts regarding operations research: (1) develop algorithms for allocating snowplow trucks across different cities. The project "MPC-639 — Automated Image-Based Aircraft Tracking and Record-Keeping for Utah Airports" will have the following impacts on aviation operations: (1) a proposed light-aircraft detection system; (2) the Haar cascade classifier provides competitive accuracy at a much-reduced processing time and makes the method suitable for real-time applications at local airports. The project "MPC-641 — Design and Evaluate Coordinated Ramp Metering Strategies for Utah Freeways" will have the following impacts on transportation systems: (1) develop a new model to evaluate the increased delay of ramps for a certain performance level of the freeway; (2) develop assessment models to evaluate the safety and operational performance of coordinated ramp metering under different control scenarios. The project "MPC-545 — Self-Centering Bridge Bent for Accelerated Bridge Construction in Seismic Regions" will have the following impacts on bridge design in seismic regions: (1) improve seismic resilience through self-centering of bridges after earthquakes; (2) use of stretch length anchors for a tension-only hybrid bridge bent to improve functional recovery after earthquakes. The project "MPC-588 — Hybrid Bridge Bents Using Post-tensioned Precast Columns for Accelerated Bridge Construction in High Seismic Regions" will have the following impacts on bridge design in seismic regions: (1) improve bridge performance in earthquakes by hysteretic energy dissipation for a bridge bent equipped using a buckling restrained brace; (2) how much drift can be accommodated before the post-tensioning tendons would yield in a bridge bent in an earthquake; and (3) focus the damage after an earthquake to the buckling restrained brace which could be replaced easily after an earthquake. The project "MPC-609 — Durable Bridges Using Glass Fiber Reinforced Polymer and Hybrid Reinforced Concrete Columns" will have the following impacts on durable bridge design: (1) mitigate corrosion of bridges in seismic regions to a large extent; (2) evaluate the seismic performance of bridges constructed with non-corroding composite materials. The project "MPC-638 — Analysis of ABC Bridge Column-to-Footing Joints with Recessed Splice Sleeve Connectors" will have the following impacts on accelerated construction of bridges: (1) analytical methods will contribute to the efficient design of column-to-footing joints for bridges constructed using the Accelerated Bridge Construction method in seismic regions; (2) time of construction can be reduced very significantly to one or two weekends without compromising the seismic resistance of these bridges. The project "MPC-586 — Mitigation of Differential Settlement at Highway Bridge Approaches" will have the following impact on geotechnical engineering: (1) determine the fundamental material behavior of the LWCC under static and cyclic loading at varying amounts of saturation; (2) better plan, design and construct LWCC embankments in bridge approach areas. The project "MPC-587 — Use of Geogrid in Pavement Systems to Provide Longer Service Life and Reduced Maintenance" will have the following impact on pavement design: (1) improve the base of knowledge within the Civil Engineering field with respect to the economical design of pavement systems. The project "MPC-589 — Use of the IDEAL-CT Test for Pavement Cracking to Achieve a Balanced Asphalt Mix Design" will have the following impact on pavement design: (1) better understanding of the capability of the IDEAL-CT test to evaluate potential intermediate temperature cracking in asphalt pavements. The project "MPC-607 — Loading and Wetting-Induced Settlement of Bridge Approach Embankment Materials" will have the following impact on pavement design: (1) enhance understanding of the loading and wetting-induced stress-strain characteristics of various types of soils. The project "MPC-635 — Field Evaluation of Geogrid-Reinforced Pavement Systems on Soft Subgrades" will have the following impacts on geotechnical engineering: (1) significantly improve the base of knowledge within the Civil Engineering field with respect to the design and analysis of pavement systems both without and with geogrid reinforcement. The project "MPC-546 — Field Performance of Asphalt Pavements at Low and Intermediate Temperatures" will have the following impact on pavement design: (1) better understanding of the behavior of asphalt mixtures at low and intermediate temperatures once placed in the field; (2) enable the design of optimum asphalt mixtures capable of extending the life of road surfaces while utilizing innovative or cost efficient materials. The project "MPC-611 — Field Performance of Asphalt Mixtures Based on Flexibility Index Results" will have the following impacts on pavement design: (1) long-term impacts on the quality of road surfaces by allowing the selection of material that is not prone to cracking; (2) longer lasting roads with the respective economic savings for agencies and the traveling public. The project "MPC-640 — Testing of Field Cores to Determine Performance of Asphalt Mixture Performance Parameter" will have the following impact on pavement design: (1) better understanding of the effects of field aging of asphalt materials by documenting the measured properties of field cores under specific conditions.

University of Wyoming

MPC 600 resulted in developing a new system for establishing passing zones. The system has been implemented by WYDOT.
MPC 599 has added a significant amount of information to the body of scientific knowledge since the connected vehicle technology is a new field.

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

d. What is the impact on transportation workforce development?
Colorado State University
The projects at Colorado State University will have following impacts on transportation workforce development: 1) 15 PhD and MS students and 11 undergraduate students have been involved in all the projects who have received extensive research training. 2) Some topics will be incorporated into some courses, such as "Bridge Engineering" and "Hydrometry".

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) Providing five additional graduate students training and experience in the research process including literature review, data collection and analysis using Excel and SPSS and report writing, and also understating the principles for the ethical conduct of field research; 2) Safety managers at two railroads were given

information on how to improve their safety culture; 3) Managers at several trucking companies received information about how to manage fatigue levels as a result of this project.

University of Utah
The projects at the University of Utah will have the following impacts: (1) provide support for undergraduate and graduate student researchers; (2) prepare graduating MS and PhD students for employment in engineering companies in the fields of bridge design, structural design, pavement design, and transportation engineering; (3) results of the research are being implemented in course materials for courses on transportation planning, transportation network modeling, transportation engineering, bridge design, smart city and infrastructure, photogrammetry, drone technology and drone piloting, LiDAR scanning, and data science; (4) disseminate new knowledge to practitioners (primarily DOT employees) in transportation engineering, bridge design, geotechnical design, and pavement design.

University of Wyoming
The projects conducted at UW will help transportation professionals in implementing new techniques to do their jobs more effectively. As an example, several training sessions have been were conducted to show WYDOT engineers how to use the new device developed in MPC 600.

Utah State University
The projects at Utah State University will have the following impacts on transportation workforce development: (1) inform the many students involved in performing the research; (2) influence many undergraduates to study transportation as a career due to the exposure to so many interesting projects. USU's projects are having a broad impact on students as well as those who learn about the projects.

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

University of Denver
The most significant impact from our research is the development of 1) The Safety Culture measures has been adopted by at least one other transportation agency as a tool for measuring its effectiveness; 2) The validation of and availability of a portable smartphone based app for measuring driver/operator fatigue and alertness in the workplace that produces accurate measurements and valid results comparable to those that have previously only been obtained with larger, non-mobile static devices.

Utah State University
The contributions of several of the USU researchers in the area of electrified transportation and the electrification of transportation system and system modeling will have a significant impact in the next few years.

6. Changes/Problems

North Dakota State University - MPC-566 (Supporting Tribal Crash Data Utilization and Strengthening Institutional Capacity for Effective Traffic Safety Programs) continues to experience 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, the investigators remain optimistic that the tribal communities will be more open to outside visitors and community safety efforts, beyond COVID-19, this summer.

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. Plans still indicate sensor installment can resume this spring so the weather data collection and weather impact analysis will be back on track for full function.

University of Denver - Overall, the COVID-19 pandemic has created logistical problems in data collection and technology transfer by prohibiting contact with research study participants, drivers, and other professionals. Some progress has been made recently through the use of electronic data gathering. The IRB approved a change to our

protocol and data collection is underway. However, no conferences or meetings were possible during this past reporting period. Plans to do more virtually in the next reporting period are planned.

University of Utah - The pandemic has delayed several projects with an experimental or laboratory component.

Utah State University - Most of the changes, problems, or delays in project progress can be attributed to the Covid pandemic. Projects utilizing laboratory facilities have been slowed due to limitations on the use of on campus laboratories. Many graduate students, particularly international students, have been unable to enter the US which has had an impact on the number of students available to work on projects. Also, several researchers have reported that the dissemination of research results has been affected due to travel restrictions. In some cases, conferences and workshops have been cancelled, delayed, or switched to a virtual format. Laboratory facilities, as well as travel and other "normal" activities are beginning to return to pre-Covid status.

7. SPECIAL REPORTING REQUIREMENTS:

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