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

**Grant No. 69A3551747108**
**Mountain-Plains Consortium, North Dakota State University**
**Denver Tolliver, Director**
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**(701)231-7190**

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**North Dakota State University**
**Upper Great Plains Transportation Institute**
**NDSU Dept. 2880, P.O. Box 6050, Fargo, ND 58108-6050**

**Grant period: June 30, 2016 – March 31, 2022**

**Reporting Period End Date: September 30, 2019**
**Semi-Annual Progress Report #5**

**Denver D. Tolliver**

**Director, Mountain-Plains Consortium**
**North Dakota State University**

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

**a. What are the major goals of the program?**

The overall objectives are to: (1) conduct basic and applied research, the products of which are judged by peers or other experts in the field of transportation to advance the body of knowledge in transportation; (2) offer educational programs in transportation that includes multidisciplinary course work and participation in research; (3) conduct workforce development activities and programs to expand the workforce of transportation professionals; and (4) provide an ongoing program of technology transfer to make transportation research results available to potential users in a form that can be readily used. Other program goals are to select projects and activities using peer review principles and procedures and client input that: (1) address the Secretary's five strategic goals (2) leverage UTC funds with matching funds from state and local governments and private industry. The chief operational goals are to make important contributions to research and technology transfer in key areas related to the Secretary's goals of State of Good Repair, Safety, Economic 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-605 which can be found on the Mountain-Plains Consortium website

**b. What was accomplished under these goals?**

**i. Project Selection**

Seventy-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.

Note: Some MPC projects relate to more than one USDOT Strategic Goals. These projects will be listed more than once.

**Table 1: MPC Research Projects Most Directly Correlated with Safety**

MPC-534 — Traffic Performance Assessment of Disrupted Roadway Networks Following Earthquakes
MPC-540 — Updating and Implementing the Grade Severity Rating System (GSRS) for Wyoming Mountain Passes
MPC-545 — Self-Centering Bridge Bent for Accelerated Bridge Construction in Seismic Regions
MPC-552 — The Effects of Autonomous Vehicles on Safety and Safety Culture in Freight Operations
MPC-556 — Forging a Path to Vision Zero in the US: A Critical Analysis of Road Safety in Australia
MPC-557 — Reassessing Child Pedestrian Mode Choice & Safety via Perceived Parental Risk
MPC-561 — Reliability-Based Assessment of Landslide Risk Along Roadways
MPC-563 — Optimized Adhesive Performance in Electronic Transportation Sign Construction
MPC-565 — Study on Structural Performance Evaluation of Double-Tee Bridges
MPC-566 — Supporting Tribal Crash Data Utilization and Strengthening Institutional Capacity for Effective Traffic Safety Programs
MPC-567 — Assessing Teen Driver Safety Interventions: Graduated Driver Licensing and Parent Advisory Letters
MPC-573 — Proposing the Super DDI Design to Improve the Performance of Failing Service Interchanges in Mountain-Plains Region
MPC-574 — Proposing New Speed Limit in Mountainous Areas Considering the Effect of Longitudinal Grades, Vehicle Characteristics, and the Weather Condition
MPC-576 — Sustainable Alternative to Structurally Deficient Bridge
MPC-582 — Safety Culture, Leadership & Fatigue in Transportation Operations
MPC-588 — Hybrid Bridge Bents Using Post-Tensioned Precast Columns for Accelerated Bridge Construction in High Seismic Regions

MPC-590 — Impact of Connected Vehicle Technology on Traffic Safety under Different Highway Geometric Designs
MPC-591 — Reliability-Based Traffic Safety Risk Function of Traffic System in Hazardous Driving Conditions to Promote Community Resilience
MPC-593 — Probabilistic Modeling of Landslide Hazards to Improve the Resilience of Transportation Infrastructure
MPC-596 — Measurement of Turbulent Flow Characteristics and Bed Shear Stress in Laboratory Soil Erosion Tests
MPC-598 — Assessing the Effectiveness of the Wyoming Connected Vehicle Pilot Program: New Traffic Safety Research Perspectives
MPC-599 — Connected-Autonomous Traffic Signal Control Algorithms for Trucks and Fleet Vehicles
MPC-600 — Developing a Prototype System for Establishing Passing and No-Passing Zones of Two-Lane Highways
MPC-602 — Local Road Safety Program Evaluation: Perceptions, Experiences & Implementation
MPC-604 — Improving Safety in Transit and Freight Operations: Development of a Safety Leadership Training Model to Improve Safety Culture

**Table 2: MPC Research Projects Most Directly Correlated with State of Good Repair**
MPC-534 — Traffic Performance Assessment of Disrupted Roadway Networks Following Earthquakes
MPC-540 — Updating and Implementing the Grade Severity Rating System (GSRS) for Wyoming Mountain Passes
MPC-545 — Self-Centering Bridge Bent for Accelerated Bridge Construction in Seismic Regions
MPC-552 — The Effects of Autonomous Vehicles on Safety and Safety Culture in Freight Operations
MPC-556 — Forging a Path to Vision Zero in the US: A Critical Analysis of Road Safety in Australia
MPC-557 — Reassessing Child Pedestrian Mode Choice & Safety via Perceived Parental Risk
MPC-561 — Reliability-Based Assessment of Landslide Risk Along Roadways
MPC-563 — Optimized Adhesive Performance in Electronic Transportation Sign Construction
MPC-565 — Study on Structural Performance Evaluation of Double-Tee Bridges
MPC-566 — Supporting Tribal Crash Data Utilization and Strengthening Institutional Capacity for Effective Traffic Safety Programs
MPC-567 — Assessing Teen Driver Safety Interventions: Graduated Driver Licensing and Parent Advisory Letters
MPC-573 — Proposing the Super DDI Design to Improve the Performance of Failing Service Interchanges in Mountain-Plains Region
MPC-574 — Proposing New Speed Limit in Mountainous Areas Considering the Effect of Longitudinal Grades, Vehicle Characteristics, and the Weather Condition
MPC-576 — Sustainable Alternative to Structurally Deficient Bridges
MPC-582 — Safety Culture, Leadership & Fatigue in Transportation Operations
MPC-588 — Hybrid Bridge Bents Using Post-Tensioned Precast Columns for Accelerated Bridge Construction in High Seismic Regions
MPC-590 — Impact of Connected Vehicle Technology on Traffic Safety under Different Highway Geometric Designs
MPC-591 — Reliability-Based Traffic Safety Risk Function of Traffic System in Hazardous Driving Conditions to Promote Community Resilience
MPC-593 — Probabilistic Modeling of Landslide Hazards to Improve the Resilience of Transportation Infrastructure
MPC-596 — Measurement of Turbulent Flow Characteristics and Bed Shear Stress in Laboratory Soil Erosion Tests
MPC-598 — Assessing the Effectiveness of the Wyoming Connected Vehicle Pilot Program: New Traffic Safety Research Perspectives
MPC-599 — Connected-Autonomous Traffic Signal Control Algorithms for Trucks and Fleet Vehicles
MPC-600 — Developing a Prototype System for Establishing Passing and No-Passing Zones of Two-Lane Highways
MPC-602 — Local Road Safety Program Evaluation: Perceptions, Experiences & Implementation
MPC-604 — Improving Safety in Transit and Freight Operations: Development of a Safety Leadership Training Model to Improve Safety Culture

**Table 3: MPC Research Projects Most Directly Correlated with Economic Competitiveness**
MPC-535 — Development of Unmanned Aerial Vehicle (UAV) Bridge Inspection Procedures
MPC-542 — Exploratory Modeling and Analysis for Automated Vehicles in Utah
MPC-543 — Big Transportation Data Analytics
MPC-547 — Infrastructure Safety Support System for Smart Cities with Autonomous Vehicles
MPC-555 — Testing Irrationality in Metered Parking Payment Compliance
MPC-558 — Optimal Deployment of Dynamic Charging Lanes for Plug-in Hybrid Trucks

MPC-564 — Quantifying the Range of Variability in the Flexural Strength of Fiber Reinforced Concrete using Monte Carlo Simulation
MPC-572 — Incorporating Tourism Data in Traffic Estimation on Wyoming Low-Volume Roads
MPC-578 — Integrated Strategic and Operational Planning for a Fast-Charging Battery Electric Bus System
MPC-585 — Constrained System-Optimal Route Planning in support of Fleet Route Planning, Ride sourcing, and Ridesharing
MPC-592 — Development of an Autonomous Transportation Infrastructure Inspection System Based on Unmanned Aerial Vehicles
MPC-595 — Mechanically Spliced Precast Bridge Columns

**Table 4: MPC Research Projects Most Directly Correlated with Livable Communities**
MPC-553 — Multi-Business Commute Optimization System: System Development and Pilot Case Study
MPC-569 — Traffic Performance Modeling and Planning of Emergency Medical Response in Rural Areas

**Table 5: MPC Research Projects Most Directly Correlated with Environmental Sustainability**
MPC-539 — Ultra-accelerated Method to Evaluate Recycled Concrete Aggregate in New Construction
MPC-559 — Identifying Effective Travel Behavior Change Strategies for Poor Air Quality Events in Northern Utah
MPC-560 — Rapid Set Cement for Precast Prestressed Bridge Girder Applications
MPC-562 — Evaluation of Durability and Structural Performance of Concrete with Embedded Inductive Coils
MPC-568 — Mitigation of Flooding-Related Traffic Disruptions with Green Infrastructure Stormwater Management
MPC-570 — Experiments and Modeling for Infrastructure Data-Derived Fuel Economy and Safety Improvements
MPC-575 — Characterization of the Plant-Based Bio-Asphalt Binder and Bio-Additives
MPC-580 — Implementation of Precast Concrete Segments for Electrified Roadway [On-time]
MPC-584 — Expanding the Capabilities of Business Commute Optimization System to Model Additional Transportation Alternatives and On-Demand Needs
MPC-597 — Bacteria Removal from Stormwater Runoff Using Steel Byproduct Filters
MPC-603 — Investigating Bicyclist Safety Perceptions and Behaviors at Roundabouts

**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 6: 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 |

| | | | |
|---|---|---|---|
| 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 A 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, 143 transportation and transportation-related courses were offered this reporting period, for a total of 450 transportation courses offered since the beginning of this grant. In addition to the courses listed in Appendix A, 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, 105 training sessions were offered this reporting period for a total of 317 offered under this grant period. Due to the page limits of this documents, we have listed all workforce development activities in Appendix B. The listing in Appendix B of workforce development activities illustrates the diversity of our workforce offerings for transportation professionals.

**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 59 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.

- Bay Area Transportation Commission, San Francisco, CA, in-kind support
- California State University, Fresno, CA, in-kind support City of Denver, Denver, CO, data
- City of Brookings, SD, collaborative research
- City of Fort Collins, Fort Collins, CO, in-kind support
- City of Westminster, Westminster, CO, in-kind support
- Clemson University, Clemson, SC, facilities and in-kind support
- Colorado Associate of Geotechnical Engineers, Denver, CO, in-kind support
- Colorado Dam Safety, Pueblo, CO, technical support
- Colorado Department of Transportation, Denver, CO, in-kind support
- Colorado Water Conservation Board, Denver, CO, financial support
- CoreBrace LLC, West Jordan, UT, in-kind support and collaborative research
- CTS Cement, Anaheim, CA, in-kind support
- Daktronics, Brookings, SD, in-kind and financial support
- Dayton Superior Corp., Miamisburg, OH, in-kind support
- Denver Regional Council of Governments, Denver, CO, in-kind support
- Dextra America, Inc., Bangkok, Thailand, financial and in-kind support
- East Dakota Water Development District, Brookings, SD, financial support
- Engineering Department of Larimer County, CO, in-kind support
- Engineering R&D Center, US Army Corps of Engineers, facilities and in-kind support
- Forterra Structural Precast, Salt Lake City, UT, in-kind support
- Headed Reinforcement Corp., Fountain Valley, CA, financial and in-kind support
- Keolis Commuter Services, Boston, MA, in-kind support
- Massachusetts Bay Transportation Authority, Boston, MA, In-kind support
- Mineta Transportation Institute, San Jose, CA, in-kind support
- Minnesota Department of Transportation, Minneapolis, MN, data collection support
- MnROAD facility, Minnesota Department of Transportation, Monticello, MN, in-kind support and collaborative research
- Mountainland Association of Governments, Orem, UT, subject matter experts

- National Renewable Energy Laboratory, Golden, CO, subject matter expert, facilities, collaborative research, and personnel exchanges
- NDDOT Driver License Division, Bismarck, ND, in-kind support
- NDDOT Safety Division, Bismarck, ND, in-kind support
- North Central Regional Sun Grant Center, Brookings, SD, financial support
- North Dakota Association of Counties, Bismarck, ND, provided mailing list
- North Dakota Department of Health, Bismarck, ND, in-kind support
- North Dakota Highway Patrol, Bismarck, ND, in-kind support
- North Dakota Local Technical Assistance Program, Bismarck, ND, survey collection
- Northern Plains Railroad, Fordville, ND, data collection support
- Olympus Precast, Bluffdale, UT, in-kind support
- Owens Corning, USA, Seward, NE, in-kind support
- RSG, Inc., Salt Lake City, UT, collaborative research
- San Joaquin Regional Transit District, San Joaquin County, CA, in-kind support
- SELECT Center, Logan, UT, collaborative research and in-kind support
- Sheet Metal and Rail Transportation, Washington, DC, in-kind support
- South Dakota Department of Transportation, Pierre, SD, field testing collaboration
- South Dakota State University, Brookings, SD, financial and in-kind support
- Spirit Lake Nation, Fort Totten, ND, subject matter experts
- Splice Sleeve North America, Inc., Livonia, MI, financial and in-kind support
- Standing Rock Sioux Tribe, Standing Rock Reservation, ND & SD, subject matter experts
- University of Alabama, Tuscaloosa, AL, facilities and in-kind support
- University of Colorado Denver, Denver, CO, facilities, financial, and in-kind support
- University of Sydney, Sydney, Australia, facilities and in-kind support
- University of Texas at Austin, Austin, TX, facilities and in-kind support
- Urban Drainage and Flood Control District, Denver, CO, in-kind support
- Utah Department of Transportation, Salt Lake City, UT, subject matter experts and financial support
- Vent LENTON Corp., Solon, OH, financial and in-kind support
- Virginia Railway Express, Keolis, Washington, DC, in-kind support
- Wasatch Front Regional Council, Salt Lake City, UT, subject matter experts
- Wyoming Safety Coalition, Worland, WY, in-kind support
- Wyoming Department of Transportation, Cheyenne, WY, facilities, in-kind, and financial support
- Wyoming Technology Transfer Center, Laramie, WY, collaborative research

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

**b. Have other collaborators or contacts been involved?**

USDOT's continued support with the award of this grant has allowed us to encourage and support 61 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 97 students from the U.S. and countries around the world.

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

Thirteen principal investigators, faculty, and administrators are participating in MPC projects at **Colorado State University**: Rebecca Atadero, Suren Chen, Yanlin Guo, John W. van de Lindt, Gaofeng Jia, Jeffrey Niemann, Joseph Scalia, Chris Bareither, Aditi Bhaskar, Thomas Bradley, Paul Heyliger, Peter A. Nelson

and Mehmet E. Ozbek. In addition, fifteen students are working on MPC research projects: Abdelrahman Abdallah, Yangyang Wu, Guangyang Hou, Kaisen Yao, Brandon Perry, Min Li, Douglas Woolridge, Zana Taher, Katie Knight, Constance Dayan, Qiling Zou, David Trinko, Aaron Rabinowitz, Elizabeth Byron, and Chao Jiang.

Twelve 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, Sharma Kshitij, Jerilyn Swenson, Andrew Wurke, and Laurel Benson. In addition, fourteen students are working on MPC project: Mu'ath Al-Tarawneh, Mohanad Alshandah, Xinyuan Yang, Hafiz Usman Ahmed, Keshab Thapa, H M Nasrullah Faisal, Neeraj Dhingra, Amin Keramati, Xiaoyi Zhou, Leonard Chia, Bhavana Bhardwaj, Sajad Ebrahimi, Dawei Zhang, and Erik Johnson.

Eight principal investigators, faculty, and administrators are participating in MPC projects at **South Dakota State University** are: Junwon Seo, Nadim Wehbe,Guanghui Hua, Kyungnan Min, Christopher Schmit, Mostafa Tazarv, Francis Ting, and Rouzbeh Ghabchi. In addition, ten students are working in MPC research projects: Euiseok Jeong, Ibin Amatya, Marco Paulo Pereira Castro, Blake Jorgensen, Gunnar Kern, Abdoul Kouanda, Matthew LaVoy, Theodore Surest, Selene Tinklenberg, and Brian Kidd.

Eight 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, and Farnoush Banaei-Kashani. In addition, thirteen 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 Ferenchak, Nick Coppola, Yaneev Golomber, and Jun Wang.

One principal investigator, faculty, and administrator is participating in MPC projects at the **University of Denver**: Patrick Sherry. In addition, four students are working on MPC research projects: Sree Sinha, Emma Porter, Megan Solberg, and Jessica Mantia.

Eight 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, and Xianfeng Terry Yang. In addition, seventeen students are working on MPC research projects: Zhuo Chen, Nima Haghighi, Zhiyan Yi, Roghayeh Zoleikani, Dipendra Thapa, Ijan Dangol, Faramarz Safazadeh, Abu Sufian Mohammad Asib, Swastik Pohkrel, Emad Ghodrati, Henrik Burns, Nadereh Adham, Kaden Harris, Bahar Azin, Boe Erickson, Sarah Stropkai, and Zhao Zhang.

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

Nine principal investigators, faculty, and administrators are participating in MPC projects at **Utah State University** are: Ziqi Song, Patrick Singleton, Andrew Sorensen, Robert J. Thomas, John Rice, James Bay, Michelle Mekker, Marvin Halling, Paul Barr, and Marc Maguire. In addition, ten students are

working on MPC research projects: Zhaocai Liu, Joshddddv **of Streamflow Production Mechanisms for Dam Safety Applications in the Colorado Front Range," Master of Science Thesis, Colorado State University, Fort Collins, CO, 2019. Acknowledgement of federal support: Yes.**

**North Dakota State University -**

Al-Tarawneh, M. Traffic Monitoring System Using In-Pavement Fiber Bragg Grating Sensors. Ph.D. Dissertation, North Dakota State University, August 2019. Acknowledgement of federal support: Yes.

Thapa, K.B., Received an Award, Runner up at the ASCE Geo-Institute (G-I) Student Poster Competition, Engineering Mechanics Institute Conference, California Institute of Technology, Pasadena, CA, June 20, 2019.

**University of Colorado Denver –**

Techniques: We have extended our generic system optimal solution for route planning to generate the baseline solutions for the three modes of constrained route planning for fleet management, ride sourcing, and ridesharing. These solutions take into account the specific constraints imposed by each of the aforementioned modes while providing a globally optimized route for individual vehicles. We have also started implementing our system optimal solution for ride sourcing in the context of a simulation application for EV station location optimization in collaboration with NREL.

**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 C.

**a. Publications can be found in Appendix C**

i. During this period MPC faculty and investigators have published 34 peer-reviewed articles or papers in scientific, technical, or professional journals. Since the beginning of this grant, we have published 80 different peer-reviewed articles or papers.

**b. Conference Papers can be found in Appendix C**

i. This reporting period we have published 14 conference papers and 36 total since the grant began.

**c. Presentations can be found in Appendix C**

i. MPC faculty and investigators have presented at 31 different scientific, technical, or professional conference this period. In total, we have had 80 presentations on MPC research, results and outcomes.

**d. 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/

**4. Outcomes:**

**Colorado State University:** All of our projects have resulted in many outcomes as summarized below:
**MPC-533** — Use of Life Cycle Cost Analysis to Enhance Inspection Planning for Transportation Infrastructure - This project is expected to provide knowledge that will help bridge managers consider new policies for planning inspections. Current prescriptive inspection cycles may not be making the most efficient use of available inspection resources including new technology and deterioration models.
**MPC-534** — Traffic Performance Assessment of Disrupted Roadway Networks Following Earthquakes - Increased the understanding of the performance of disrupted traffic network. Increase the knowledge of how to understand the impacts of disrupted traffic network and potentially recover from it.

**MPC-535** — Development of Unmanned Aerial Vehicle (UAV) Bridge Inspection Procedures - The research outcomes during this reporting period include developed new technologies for bridge inspection, trained a graduate student who has graduated in May 2019.
**MPC-536** — Development of Age and State Dependent Stochastic Model for Improved Bridge - Deterioration Prediction Increased knowledge on improved modeling and calibration of bridge deterioration.
**MPC-537** — Quantifying Mountain Basin Runoff Mechanisms for Better Hydrologic Design of Bridges and Culverts - This project examined the active runoff production mechanisms for large events in the Colorado Front Range. Using a combination of soil moisture observations and hydrologic modeling, the results show that either infiltration-excess or saturation-excess runoff can be the primary runoff mechanism for large historical and design storms. Infiltration-excess runoff typically dominates for shorter events while saturation-excess runoff dominates for longer events. Many existing guidelines for hydrologic analysis only consider infiltration-excess runoff. The project also developed modeling methods that can be used to simulate both mechanisms.
**MPC-538** — Representative Testing of Expansive Soil Treatment Technologies for Transportation Earthworks - Expected outcomes from this project include increased understanding and awareness of how testing and comparison of the effectiveness of expansive soil treatment technologies for transportation applications are accomplished, and improved equipment and techniques to address the effectiveness of novel expansive soil treatment technologies to mitigate impacts on the state of good repair of transportation infrastructure built on expansive soils.
**MPC-568** — Mitigation of Flooding-Related Traffic Disruptions with Green Infrastructure Stormwater Management - Expected outcomes from this project are increased understanding of where and when street flooding conditions and related transportation issues occur in the Denver, Colorado metropolitan area. The increased knowledge of where and when street flooding occur can be used to better manage stormwater infrastructure in the Denver metropolitan area.
**MPC-569** — Traffic Performance Modeling and Planning of Emergency Medical Response in Rural Areas - Provide the key step toward understanding the risks of and conducting more effective EMS planning during hazardous conditions.
**MPC-570** — Experiments and Modeling for Infrastructure Data-Derived Fuel Economy and Safety Improvements - Through collaboration with Colorado DOT and the City of Fort Collins, we have **increased the body of knowledge surrounding the costs and benefits of connected vehicles.**
**MPC-571** — Monitoring Transportation Structure Integrity Loss and Risk with Structure-From-Motion - Using imaging methods has allowed for a far more consistent method of reporting damage since three-dimensional models can be reconstructed from these images rather than a sequence of simple 2d photos. This, combined with the analysis, can provide a transient view of the structure that can be recorded or adjusted over time.
**MPC-591** — Reliability-Based Traffic Safety Risk Function of Traffic System in Hazardous Driving Conditions to Promote Community Resilience - Gained better understanding of the traffic safety issues through literature review.
**MPC-592** — Development of an Autonomous Transportation Infrastructure Inspection System Based on Unmanned Aerial Vehicles - The outcomes during this reporting period include: improved technology in UAV-based bridge inspection; enlargement of the pool of trained transportation professionals.
**MPC-593** — Probabilistic Modeling of Landslide Hazards to Improve the Resilience of Transportation Infrastructure - We expect that this project will increase our understanding of the risk of landslides and debris flows on transportation infrastructure, and it should provide useful tools enabling managers to assess the likelihood of landslide hazard to road networks.
**MPC-594** — Transferring Research Innovations in Bridge Inspection Planning to Bridge Inspection Practice - This project is expected to produce a thorough accounting of the factors that provide levers and limit the capacity for change within transportation agencies.
**North Dakota State University**

The state of good repair is supported in several project. Expected outcomes from the research include new traffic monitoring technologies for smart cities along with smarter rail asset monitoring in smartphone based low-cost sensor abnormality detection. Refinement of weigh-in-motion measurement sensitivity and accuracy will enhance highway system traffic and condition monitoring. Basic research will reduce infrastructure costs by testing and validating reliable predictive models for swelling clays. In addition, safety research is a prominent theme as findings for the rail industry will improve crash forecasting for highway-rail grade crossings along with advisement on using PTC compatible, low-cost sensor technology for crash prevention and risk management. Traffic safety gains will be achievable in improved practices and decision-making capacity for teen driver and Tribal Nations, as high-risk populations.

**South Dakota State University**

The expected outcomes include development of: a new structural system for transportation dynamic messaging signs, accurate live load distribution and dynamic load allowance factor in double tee deck bridges, asphalt mixes using bio-asphalt binders and additives, cross laminated timber (CLT) bridge systems, detailing for mechanically spliced precast columns to promote accelerated bridge construction (ABC) in seismic areas, and media filtration technology for E. coli removal from stormwater runoff.

**University of Colorado Denver**

These projects all progressed well over the last project period and with six journal papers published and 1 conference paper. 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 main outcome has been the application the results of the instrument assessments to the modification of the activities which contributes to increases in managers understanding of how to improve safety culture at the MBTA in Boston. Results of the assessment were used to make changes in the various activities and practices at MBTA operated by the Keolis Company.

**University of Utah**

Increased understanding of the autonomous vehicles impacts on the regional travel demand and vehicle-mile traveled was achieved. Big transportation data analytics has improved our understanding of the applicability of various models for predicting hourly traffic volumes. Machine learning techniques were used to predict the performance of snowplow trucks using automatic vehicle location data, which will assist transportation agencies with further refinement of truck replacement strategies. Connected vehicle technology has increased our knowledge of the relationships between crash frequency, crash severity, intersection geometric design, and traffic signal plans, thus improving traffic safety at intersections. The field performance of asphalt pavements at low and intermediate temperatures increases our understanding of transportation issues through improved material performance. The IDEAL-CT test for pavement cracking allows for the adoption of new technologies that benefits the traveling public through an improved process to characterize materials. Mitigation of differential settlements at highway bridge approaches will produce new or improved methods of assessment and construction for bridge approaches on soft soil conditions. The use of geogrid in pavement systems will result in improved guidelines for designing and constructing geogrid-supported pavement systems. Research on self-centering and hybrid bridge bents for accelerated bridge construction in seismic regions will improve the technology of bridges that are easy to construct, and will self-center after an earthquake thus improving infrastructure resilience after an earthquake.

**University of Wyoming**

The initial findings of the GSRS study are very significant. They will impact the process for selecting speed limits on downgrades.

**Utah State University**

While only one of the projects have been completed under this grant, we have already increased the body of knowledge in several areas including electric and autonomous vehicles, bicycle safety and infrastructure improvements. We have also enlarged the transportation workforce with at least one student being employed on each of the projects.

**5. Impacts**

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

**Colorado State University -** These projects have caused and will continue to cause impact on many aspects, including infrastructure inspection, hazard design, infrastructure design and maintenance. The details are summarized below:

**MPC-533** — Use of Life Cycle Cost Analysis to Enhance Inspection Planning for Transportation Infrastructure - We expect this project will help to promote a state of good repair by helping bridge managers to make more cost effective decisions about bridge inspection and maintenance.

**MPC-534** — Traffic Performance Assessment of Disrupted Roadway Networks Following Earthquakes - By understanding the performance of the disrupted traffic system, the study can help designers to develop more resilient transportation system to avoid or minimize the negative impact of such disruptions.

**MPC-535** — Development of Unmanned Aerial Vehicle (UAV) Bridge Inspection Procedures - The research outcomes will lead to cost-effective bridge inspection.

**MPC-536** — Development of Age and State Dependent Stochastic Model for Improved Bridge Deterioration Prediction - The improved deterioration model that will be developed can be incorporated in existing bridge management systems and the condition prediction results can be further used to guide risk-informed cost-effective maintenance and inspection decision making for better preservation of bridges.

**MPC-537** — Quantifying Mountain Basin Runoff Mechanisms for Better Hydrologic Design of Bridges and Culverts - The results of this project suggest that guidelines for hydrologic analysis of transportation and other infrastructure may need to be updated to ensure that infrastructure is properly design for anticipated flows. Neglecting the occurrence of saturation-excess runoff may underestimate the flows that occur for a given return period, which could make transportation infrastructure more vulnerable to failure than expected.

**MPC-538** — Representative Testing of Expansive Soil Treatment Technologies for Transportation Earthworks - Results will be transferred to DOTs to help in the assessment of commercial polymer-based expansive soil mitigation technologies.

**MPC-568** — Mitigation of Flooding-Related Traffic Disruptions with Green Infrastructure Stormwater Management - An expected impact of the project is to reduce the traffic delays related to street flooding by better cataloging and managing traffic consequences of street flooding.

**MPC-569** — Traffic Performance Modeling and Planning of Emergency Medical Response in Rural Areas - The study will help conduct more smooth and effective EMS transportation even in hazardous conditions.

**MPC-570** — Experiments and Modeling for Infrastructure Data-Derived Fuel Economy and Safety Improvements - This project seeks to impact the safety, emissions and fuel consumption of the transportation system. Through the integration of the datasets described for this project, vehicles will be able to be controlled to operate more efficiently and safely through the transportation system.

**MPC-571** — Monitoring Transportation Structure Integrity Loss and Risk with Structure-From-Motion - Tracking the changes in the structure or its surrounds allows for a historical pathway of mechanic's variables that can be monitored and viewed over time. This allows for a long-term view of structures that can often be designed for use over many decades.

**MPC-591** — Reliability-Based Traffic Safety Risk Function of Traffic System in Hazardous Driving Conditions to Promote Community Resilience - By offering safety function, the study will provide more effective tool to assess the traffic safety risks and lead to safer traffic with fewer and less severe accidents.

**MPC-592** — Development of an Autonomous Transportation Infrastructure Inspection System Based on Unmanned Aerial Vehicles - The developed automated UAV based bridge inspection and BIM can largely improve the efficiency, transparency, and consistency of the bridge inspection process.
**MPC-593** — Probabilistic Modeling of Landslide Hazards to Improve the Resilience of Transportation Infrastructure - This research will provide physics-based understanding of landslide hazard to roadways. We expect outcomes from this research will allow transportation managers to better identify areas at risk of landsliding for different storms, and potentially prepare for effects of a changing climate.
**MPC-594** — Transferring Research Innovations in Bridge Inspection Planning to Bridge Inspection Practice - This project primarily addresses the USDOT strategic goal: State of Good Repair. Inspection is a critical part of managing bridges and other transportation assets. Current inspection practices are well established and seem resistant to large scale changes. The aim of this project is to understand how researchers can better facilitate change in federal and state inspection practices.

**North Dakota State University**

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

**South Dakota State University**

The expected impact includes: design of transportation dynamic messaging signs using adhesive bonding, realistic performance assessment of existing double tee girder bridges, use of the sustainable bio-materials and agricultural byproducts for production of bio-asphalt binder, new precast column connection detailing for accelerated bridge construction, improved laboratory techniques to measure the critical shear stress of cohesive soils, and a media filtration technology for bacteria removal from stormwater runoff.

**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 impact of our research on the effectiveness of the transportation system can and will be seen in the form of improved safety culture and fewer accidents and injuries among transportation organization employees. Successful adoption of our instrument as a standard operating tool for planning, prevention and training means that it has had an impact and has led to improvements in the organizational culture and specific practices and techniques employed by transportation safety professionals. The development of an implementation model will provide an effective roadmap for transportation professionals and agencies to improve safety culture.

**University of Utah**

Modeling and analysis of automated vehicles is directly linked to the updates of long-range transportation planning. Big transportation data analytics uses tree-ensemble models to accurately predict traffic volumes instead of massive sensor deployment. The predictive model on lifecycle assessment using snowplow truck data suggests the threshold of work intensity for preventing rapid deterioration of truck performance under various working environments. A cost/benefit analysis of whether to adopt connected vehicle technology and prioritize locations with a high crash frequency/severity is being evaluated by the project on connected vehicle technology and traffic safety under different highway geometric designs. Studying asphalt pavements at low and intermediate temperatures, will improve knowledge of the performance of materials placed in the field, thus allowing for longer lasting road surfaces. Research on the use of the IDEAL-CT test for pavement cracking will impact the transportation system positively by allowing better characterization of materials. Mitigation of differential settlement at highway bridge approaches will reduce settlement that occurs at bridge approaches. Development of

better design and construction guidelines for geogrid supported pavement systems will result in more economical and better-performance roadway pavement systems. Research on hybrid and self-centering bridge bents using post- tensioned precast columns will result in new protective systems for bridges for earthquakes and other natural disasters that have no residual deformations thus improving their resilience.

**University of Wyoming**

The implementation of the initial GSRS findings will result in safety speed limits on downgrades. Appropriate speed limits will reduce the number of crashes on downgrades.

**Utah State University**

The completed project that has focused on the use of CSA cement is focused on effectively building and repairing the transportation system. It was a successful project that could be very beneficial for certain situations. Also, the focus area of electric and autonomous vehicles is very much in line with the effectiveness of the transportation system. As we move to include these types of vehicles onto the system there will need to be some changes. It is critical that we make that changes taking into account the most effective way. These projects focus on that.

***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 -** These projects have shown potential to be transferred to government agencies, private traffic sector and interested individuals. The details can be found in the following:

**MPC-533** — Use of Life Cycle Cost Analysis to Enhance Inspection Planning for Transportation Infrastructure - Because this research will consider costs, it is expected to provide the type of information that can lead to changes in bridge inspection policy.

**MPC-534** — Traffic Performance Assessment of Disrupted Roadway Networks Following Earthquakes - Transfer the study results to city and state DOT to implement more effective infrastructure repair and traffic planning efforts.

**MPC-535** — Development of Unmanned Aerial Vehicle (UAV) Bridge Inspection Procedures - This is the feasibility study (phase I study) of the UAV- based bridge inspection, it is an important initial step towards future technology adoption in the industry.

**MPC-536** — Development of Age and State Dependent Stochastic Model for Improved Bridge Deterioration Prediction - The adoption of the improved deterioration model in existing bridge management systems will help bridge managers establish more cost-effective maintenance and inspection decisions.

**MPC-537** — Quantifying Mountain Basin Runoff Mechanisms for Better Hydrologic Design of Bridges and Culverts - The results of the project are already being used by Colorado Dam Safety to develop new guidelines for the hydrologic analysis of dams. These new guidelines would allow the possibility of either infiltration-excess or saturation-excess runoff production. It is possible that similar updates could be developed for transportation related infrastructure in the future.

**MPC-538** — Representative Testing of Expansive Soil Treatment Technologies for Transportation Earthworks - Development of a new large-scale apparatus for representative testing of expansive soil mitigation techniques. Large-scale apparatus is anticipated to result in the development of new practices for the testing of polymer-treated soils.

**MPC-568** — Mitigation of Flooding-Related Traffic Disruptions with Green Infrastructure Stormwater Management - The expected impact of this project will be the transfer of our results to those in the City of Denver and Mile High Flood District which could lead them to more informed adoption of green infrastructure stormwater practices.

**MPC-569** — Traffic Performance Modeling and Planning of Emergency Medical Response in Rural Areas - The study may potentially can provide advices and strategy for emergency management department and hospitals to function more effectively.

**MPC-570** — Experiments and Modeling for Infrastructure Data-Derived Fuel Economy and Safety Improvements - We are expecting to transmit much of the information gained to the OEMs and to city transit agencies through direct presentation and engagement. These results will allow OEMs to put new

types of powertrain and vehicle level controls on next-generation vehicles. These research outcomes for the cities will include a valuation of the incentives that might exist to do the data management and curation tasks required.

**MPC-571** — Monitoring Transportation Structure Integrity Loss and Risk with Structure-From-Motion - By changing the way that damaged structures are scheduled for replacement based on quantified metrics (such as the percent of ultimate load that a structure can still resist) would allow for a far more efficient direction of limited resources. This method would help answer the question: we can only afford to repair two of these three damaged structures - which ones should we choose?"

**MPC-591** — Reliability-Based Traffic Safety Risk Function of Traffic System in Hazardous Driving Conditions to Promote Community Resilience - It may be incorporated into some state practice or future traffic safety manual, if the proposed function is found valuable enough.

**MPC-592** — Development of an Autonomous Transportation Infrastructure Inspection System Based on Unmanned Aerial Vehicles - This project paves the road to the adoption of the new robotics sensing-based method in the bridge inspection practice.

**MPC-593** — Probabilistic Modeling of Landslide Hazards to Improve the Resilience of Transportation Infrastructure - Results from this research may ultimately be used by government or industry entities to assess where transportation infrastructure should be built, or where resources for mitigating landslide hazard should be allocated.

**MPC-594** — Transferring Research Innovations in Bridge Inspection Planning to Bridge Inspection Practice - The results of this project are expected to help DOTs take advantage of advances in inspection techniques and new methods of inspection planning. The intent is to conduct inspections in ways that preserve safety, save money and provide more useful information for decision making which will be adopted by transportation agencies.

**North Dakota State University**

New practices based in smart technology applications will increase robustness and effectiveness of the real-time traffic and asset monitoring systems, at a lower cost. In addition, state-of-the-art design procedures that would correctly analyze and accurately predict the engineering response of swelling clays to reduce infrastructure damage. Road safety will be improved in support to decision-makers for more effective program and policy practices.

**South Dakota State University**

The expected impacts include: lifting the ban imposed by transportation agencies on the use of adhesive joints in the construction of transportation dynamic messaging signs, adopting recommendations for assessing the structural performance of in-service double tee bridges, promoting the use of the sustainable bio-materials and agricultural byproducts for production of bio-asphalt binder, developing new sustainable alternative to structurally deficient bridges on local roads, reducing bridge construction time and cost, predicting soil critical shear stress and erosion rates in cohesive soils, and reducing the bacteria contamination caused by stormwater water runoff.

**University of Colorado Denver**

With respect to completed project MPC 557, we were contacted by Nancy Pullen-Seufert, the director of the National Center for Safe Routes for Schools, to discuss our results. She was interested in how our proactive approach to child pedestrian safety could be implemented in other communities. Based on such conversations, we created a GIS tool that will help facilitate such studies. No start-up companies have been initiated.

**University of Denver**

The expected impact on new practices would be that the knowledge gained in this project will lead to the adoption of sate of the art approaches that will aide transportation agencies and private non-governmental companies in the improvement of their safety program.

**University of Utah**

DOTs can use the results of the analysis of shared automated vehicles to understand the impacts on travel patterns and to further consider the needs of this technology in long-range cost estimates and programming. The project on connected vehicle technology is expected to support industry to produce a

decision-making tool for government entities that will help develop long-term strategies regarding construction budget allocations. The project on mitigation of differential settlements at bridge approaches is expected to result in recommendations for modifying DOTs construction practices at bridge approaches. The development of better design and construction guidelines for Geogrids supported pavement systems is expected to result in wider use of the technology within roadway pavement systems including those practicing in the private and public sector. Self- centering and hybrid bridge bents will likely be adopted as new bridge systems in high seismic regions because of their improved resilience.

**University of Wyoming**

MPC-572 will help transportation agencies in quantify the impact of tourism on traffic volumes. MPC 598 will facilitate the implementation of connected vehicles technology which will result in crash reductions system wide.

**Utah State University**

The CSA concrete project proposed to UDOT as a potential option for repair. It was proposed as a girder project that could speed up production but there are many applications in repair. This is under consideration. The electric and autonomous vehicle is another that has significant impact to new practices. The researchers are working closely with state agencies to insure input is solicited along the way.

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

**Colorado State University -** These projects have considerable impact on the body of scientific knowledge covering several aspects. The following is the detailed information.

**MPC-533** — Use of Life Cycle Cost Analysis to Enhance Inspection Planning for Transportation Infrastructure - This project will add to the body of scientific knowledge by proposing a way to consider the opportunity costs of poorly timed inspections, i.e. inspections that are conducted too early to identify damage or too late to conduct preventative maintenance.

**MPC-534** — Traffic Performance Assessment of Disrupted Roadway Networks Following Earthquakes - The study will make impact on improving the theory of community resilience against major hazards.

**MPC-535** — Development of Unmanned Aerial Vehicle (UAV) Bridge Inspection Procedures - This project contributed to the body of scientific knowledge in the field of smart sensing, structural health monitoring, and bridge inspection.

**MPC-536** — Development of Age and State Dependent Stochastic Model for Improved Bridge Deterioration Prediction - The techniques that will be developed will provide methodologies for model calibration considering uncertainty in the data and also incorporation of incomplete data, which are frequently encountered in bridge inspection and maintenance practice.

**MPC-537** — Quantifying Mountain Basin Runoff Mechanisms for Better Hydrologic Design of Bridges and Culverts - This project demonstrated that either infiltration-excess or saturation-excess runoff can occur for large historical or design storms in the Colorado Front Range. Previous hydrologic guidelines assumed that infiltration-excess runoff was the dominant mechanism. By including saturation-excess runoff as a possibility, stream flows would be better estimated for longer duration and lower intensity storms, such as the floods that occurred in September 2013 along the Colorado Front Range.

**MPC-538** — Representative Testing of Expansive Soil Treatment Technologies for Transportation Earthworks - The results and findings from this study will increase the base of knowledge on the functionality of commercially available polymer treatment technologies for mitigation of expansive soils in Civil Engineering.

**MPC-568** — Mitigation of Flooding-Related Traffic Disruptions with Green Infrastructure Stormwater Management - The causes and solutions for street flooding are not well known. This project is expected to lead to greater knowledge of the causes of street flooding and which green infrastructure solutions are most appropriate.

**MPC-569** — Traffic Performance Modeling and Planning of Emergency Medical Response in Rural Areas - This study will help the public health and emergency response fields to have better understanding and tools.

**MPC-570** — Experiments and Modeling for Infrastructure Data-Derived Fuel Economy and Safety Improvements - This project expects to demonstrate the additive value of using both infrastructure and vehicle-level datasets in local speed prediction, and in emissions and fuel economy improvement in vehicles. This is a topic of considerable concern in the control of automotive powertrains, and in the connected cities domain. In each case these stakeholders are attempting to build up controls and infrastructure to enable the new capabilities of connected vehicles, but the types of information and their costs of implementation are uncertain. This research attempts to answer these questions.
**MPC-571** — Monitoring Transportation Structure Integrity Loss and Risk with Structure-From-Motion Quantifying damage of large systems is not typical, and this method would allow for such a task in a consistent and evenly applied way.
**MPC-591** — Reliability-Based Traffic Safety Risk Function of Traffic System in Hazardous Driving Conditions to Promote Community Resilience - This will help transportation engineering field with a better tool to assess traffic safety risks.
**MPC-592** — Development of an Autonomous Transportation Infrastructure Inspection System Based on Unmanned Aerial Vehicles - This project has contributed to the knowledge body in the fields of bridge inspection, remote sensing, robotics sensing, and structural health monitoring.
**MPC-593** — Probabilistic Modeling of Landslide Hazards to Improve the Resilience of Transportation Infrastructure - Connecting probabilistic modeling of landslide initiation with models of landslide runout across landscapes has not been done before, so this research will expand our scientific understanding of how to evaluate landslide hazard in a probabilistic framework. Additionally, we hope to explore how landslide hazard may evolve with a changing climate.
**MPC-594** — Transferring Research Innovations in Bridge Inspection Planning to Bridge Inspection Practice - The findings of this project are expected to be both specific to changes in bridge inspection practice and have some generalizability to other significant changes to engineering practice at DOTs.

**North Dakota State University**

The research contributes to the scientific body of knowledge in state of good repair several aspects. One outcome will be the multiscale computational framework for swelling clays to evaluate the mechanical response of swelling clay to external loading. In addition, machine learning techniques in highway and rail asset management will advance practices based on new modeling techniques and algorithms. A prototype smart traffic monitoring system will improve the basic understanding of the traffic flow to contribute to longer-term operational and safety improvement efforts for traditional and AV vehicles.

**South Dakota State University**

The expected impacts include: generation of invaluable data on fatigue and strength of adhesively connected joints in dynamic messaging sign panels, establishment of field testing and analytical modeling protocols in the field of bridge engineering, added knowledge in the field of biomaterials and the use of environmentally-friendly and renewable fuel sources, contribution of new knowledge to the fields of bridge engineering and design of engineered timber structures, generation of comprehensive test data on mechanically spliced precast bridge columns, better understanding of the critical shear stress and erosion rates in different clay soils and sand-clay mixtures, and producing new knowledge on bacteria adsorption by steel byproducts and the long-term bacteria removal from stormwater.

**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**

This research will demonstrate a conceptual link between new technology and safety culture and other aspects of workforce attitudes towards technology. A significant impact in the literature will be in connecting the concept of safety culture to the behavioral realm of fatigue risk management. The

development of an effective safety culture implementation model will be of use to the scientific community and serve as a road map for transferring scientific theory into practice.

**University of Utah**

Data-driven approaches in transportation projects have the potential to advance the body of scientific knowledge by addressing concerns existing in macro-level lifecycle assessment through predictive machine learning techniques. The project on connected vehicles will advance the scientific knowledge in developing simulation models under the connected vehicle environment, which account for the impact of geometric features of intersections. Knowledge of the performance of asphalt pavements at low and intermediate temperatures will benefit civil engineering by allowing the design of longer lasting transportation systems. The use of geogrid will improve the economical design of pavement systems. Self-centering and hybrid bridge bents will improve the design of bridges by resulting in innovative and resilient energy dissipation systems.

**University of Wyoming**

The scientific knowledge is lacking in some of the areas such as the impact of connected vehicles on reduction in crashes and the impact of tourism on traffic volumes of rural facilities. The UW projects will fill in these gaps.

**Utah State University**

Each project has contributions to the body scientific knowledge. There isn't one of them that doesn't contribute in one way or another. The primary discipline is civil engineering. Within Civil Engineering there are applications in the area of structural, transportation and geotechnical. There are also significant applications to electrical engineering as well on the electric and autonomous area

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

**Colorado State University -** The impacts of these projects are found to be significant on developing new methodology, analytical and experimental approaches and also new findings. The details are as follows.

**MPC-533** — Use of Life Cycle Cost Analysis to Enhance Inspection Planning for Transportation Infrastructure - A doctoral student has been working on the project for the past year. He has significantly increased his understanding of transportation asset inspection and management.

**MPC-534** — Traffic Performance Assessment of Disrupted Roadway Networks Following Earthquakes It will help train future graduate students and future engineers

**MPC-535** — Development of Unmanned Aerial Vehicle (UAV) Bridge Inspection Procedures - This project provided opportunities for research and mentoring in transportation-related disciplines and has trained a master's student with state-of- the-art knowledge in bridge inspection and robotics sensing.

**MPC-536** — Development of Age and State Dependent Stochastic Model for Improved Bridge Deterioration Prediction - The research will help provide exposure of students and practitioners to the idea of probabilistic analysis and how to use data to information modeling and decision making.

**MPC-537** — Quantifying Mountain Basin Runoff Mechanisms for Better Hydrologic Design of Bridges and Culverts - The MPC funds were used to support a graduate student during his studies for his master's degree. This student performed all the hands-on modeling and analysis conducted in this project. The student is expected to become a member of the transportation workforce in the future.

**MPC-538** — Representative Testing of Expansive Soil Treatment Technologies for Transportation Earthworks - Project has provided opportunity for research in transportation related challenges (expansive soils), and development of innovative testing methods and apparatus. Specifically, project has supported a PhD student in the Department of Civil and Environmental Engineering at Colorado State University. Through the research, this project provides valuable training in geotechnical engineering of expansive soils. This student is expected to become part of the transportation workforce as a geotechnical engineer.

**MPC-568** — Mitigation of Flooding-Related Traffic Disruptions with Green Infrastructure Stormwater Management - This research has provided opportunities for research and training for two graduate students at CSU including improving their performance and skills in transportation related work as it intersects with water resources and hydrologic hazards.

**MPC-569** — Traffic Performance Modeling and Planning of Emergency Medical Response in Rural Areas - The study will be incorporated in CIVE 303 Infrastructure and Transportation system to train undergraduate students and future engineers.
**MPC-570** — Experiments and Modeling for Infrastructure Data-Derived Fuel Economy and Safety Improvements - This project is expecting to have developed a number of students with skillsets in modern transportation topics such as big-data, transportation system optimization, environmental assessment, and transportation policy. These students will be able to build careers in the transportation workforce.
**MPC-571** — Monitoring Transportation Structure Integrity Loss and Risk with Structure-From-Motion - The best use of this technology would be to determine if damaged systems need repair, and to what order. Costs are always an issue, and if a structure looks bad but is still at 90 percent of capacity, limited resources could be used elsewhere for a structure at 50 percent.
**MPC-591** — Reliability-Based Traffic Safety Risk Function of Traffic System in Hazardous Driving Conditions to Promote Community Resilience - It will help train graduate students and future engineers through research.
**MPC-592** — Development of an Autonomous Transportation Infrastructure Inspection System Based on Unmanned Aerial Vehicle - This project has improved the performance and skill of young professionals through graduate students advising.
**MPC-593** — Probabilistic Modeling of Landslide Hazards to Improve the Resilience of Transportation Infrastructure - This research has, and will continue to, provide opportunities to expose graduate students to issues related to transportation infrastructure through class projects and research activities.
**MPC-594** — Transferring Research Innovations in Bridge Inspection Planning to Bridge Inspection Practice - A Ph.D. student was hired to assist the PIs in conducting this research project; and it is anticipated that this research will form a foundation for their dissertation. Furthermore, Dr. Atadero has recently developed a graduate level course titled: Inspection, Management and Repair of Structures; and the findings of this research project may be introduced in that course.

**North Dakota State University**

The MPC research has extensive student involvement in field experiments, data collection and ITS applications. Students will take this working knowledge into classroom application and eventually into the workforce. In addition, these students gain valuable experience in disseminating their research to peers and professionals through paper and presentations. In addition, the MPC projects have extended research and outreach opportunities with Native Nations in attracting new students and developing local capacity of transportation practitioners.

**South Dakota State University**

The expected impacts include: educating and training graduate students and engineers on the design of new structural system for transportation dynamic messaging signs, field inspection/testing and simulation of bridges, fundamental experimental methods in bridge engineering, structural performance of the CLT bridge systems, modern laboratory techniques of flow measurements and the theory and methods used to predict pier and contraction scour in cohesive soils, and application of a new technology to improve stormwater treatment.

**University of Colorado Denver**

The seven 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 results of the project will have a positive impact by increasing the understanding and knowledge of safety professionals on how the introduction of autonomous vehicle technology can affect safety and safety culture. Additionally, by improving safety culture the management of fatigue risk will also be improved. Finally, the results of the research will lead to the development of education materials and course content that can be used by educators throughout the US.

**University of Utah**

Modeling and analysis of automated vehicles provided an opportunity to create modules in transportation planning with autonomous vehicle updates for research and teaching including detailed adjustment procedures for trip generation and mode choice modules. The research on big transportation data analytics provided data and case examples in machine learning applications in transportation for research and teaching. In the remaining projects, the expected impact on transportation workforce development is to increase the educational material available thus allowing future practitioners to specify better systems and practices.

**University of Wyoming**

Several workshops were presented by the University of Wyoming and the Wyoming LTAP to transportation professionals across the state. Some of these workshops are required for transportation professionals to do their daily jobs. This would include certifications in aggregate, asphalt, and concrete. In addition, the knowledge learned from the ongoing projects is being incorporated into the classes taught at UW for graduate and undergraduate students.

**Utah State University**

Each of the project funding support is used to support at least one student. These are primarily graduate students. In addition, many projects also fund an undergraduate student. In all there are more that fourteen students that have been supported with this funding. Each student represents an investment in the workforce development in the transportation sector.

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

**University of Denver -** Development of a new measure of Safety Culture for transportation agencies normed on transportation professionals for use by transportation professionals.

**University of Utah** - Research carried out in several transportation projects has the potential to advance the body of scientific knowledge by addressing concerns in lifecycle assessment through machine learning techniques. The project on connected vehicles will develop simulation models under the connected vehicle environment, which fully account for the impact of geometric features of intersections. The project on asphalt pavements at low and intermediate temperatures will improve performance of the materials and enable the design of longer lasting transportation systems. The research on Geogrids in pavement systems will result in the economical design of pavement systems. Research on self-centering and hybrid bridge bents will result in innovative energy dissipation systems for bridges thus improving infrastructure resilience.

**Utah State University** - I believe that our two impact areas are in the electric and autonomous vehicle areas. We have a lot of synergy in that area. I would also not be surprise if the bicycle safety project did not result in policy changes. Bicycle safety has become an important topic as round about are being used more and more frequently.

**6. Changes/Problems**

**Colorado State University** - Two projects have made some changes:

**MPC-568** — Mitigation of Flooding-Related Traffic Disruptions with Green Infrastructure Stormwater Management - Our original study location did not have adequately detailed information on the stormwater network characteristics for stormwater modeling. Therefore, we have moved to another watershed within Denver, Colorado: Harvard Gulch. Harvard Gulch has a rich stream of data available for hydrologic and stormwater modeling including previously developed stormwater models and multiple rain gages and stream gages.

**MPC-593** — Probabilistic Modeling of Landslide Hazards to Improve the Resilience of Transportation Infrastructure - The student who is taking the lead in this work is a new M.S. student at CSU and did not arrive on campus until August, so the project is slightly delayed from its original timeline.

**7. SPECIAL REPORTING REQUIREMENTS:**

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