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

Reporting Period End Date: March 31, 2019
UTC-Semi-Annual Progress Report #4

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North Dakota State University

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

a. What are the major goals of the program?

The overall objectives are to: (1) conduct basic and applied research, the products of which are judged by peers or other experts in the field of transportation to advance the body of knowledge in transportation; (2) offer educational programs in transportation that includes multidisciplinary course work and participation in research; (3) conduct workforce development activities and programs to expand the workforce of transportation professionals; and (4) provide an ongoing program of technology transfer to make transportation research results available to potential users in a form that can be readily used. Other program goals are to select projects and activities using peer review principles and procedures and client input that: (1) address the Secretary's five strategic goals (2) leverage UTC funds with matching funds from state and local governments and private industry. The chief operational goals are to make important contributions to research and technology transfer in key areas related to the Secretary's goals of State of Good Repair, Safety, Economic Competiveness, Environmental Sustainability, and Livable Communities while addressing critical issues of the region and stakeholder groups. The MPC research program theme, "Preserving the Existing Transportation System" will focus on: (1) cost-effective preservation and maintenance practices for highways and freight rail lines; (2) tools to evaluate the effects of tolling and highway investments; (3) inspecting, evaluating, and designing bridges to promote longevity and cost-effective maintenance; (4) the resilience of highway infrastructure to wildfires, floods, earthquakes, and other natural disasters; and (5) workforce development and capacity building. In addition, some related safety research will be conducted to address regional needs.

MPC projects that have been selected since the award of this grant include MPC-533 through MPC-602 which can be found on the Mountain-Plains Consortium website

b. What was accomplished under these goals?

i. Project Selection

Sixty-two 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 Goals. These projects will be listed more than once. Due to space constraints of this document, Table 1 through 5 listing MPC research projects by strategic category can be found in Appendix A.

ii. Project Status Updates

Colorado State University – The projects at CSU are making good progress, out of the twelve projects, two are delayed and the rest are on schedule.

North Dakota State University - NDSU had seven projects active during the grant-reporting period. Three projects were focused on the rail industry with of two asset management projects designed to pilot implementation and test economic viability. Rail is also in the spotlight in a safety project that will investigate the potential to predict crashes at rail-highway grade crossing based on existing data that has been geographically transformed to model infrastructure, traffic and crash factors. Other safety studies focus on high-risk groups. The first, a tribal transportation safety management and planning is on schedule but has had a slight delay to due personnel changes. A second focused on teens and a new program to engage parents in notice driver safety is moving forward as scheduled in a collaboration with the NDDOT. The final study, asset management program in materials, is an experiment into improving prediction techniques for clay swelling. Student researchers were actively participating in data collection or analysis in five of the seven projects. The remaining two projects do have student activities in later phases of the projects. All active projects are on schedule for timely delivery. Early findings from this research has being shared with researchers presenting at eight events with local to international audiences. In addition, eight publications and two conference papers were published during the reporting period. Human capital development is also evident with students involved in six of the seven projects. All expectations are for continued success in completing projects and disseminating results to peers and practitioners in various platforms.

South Dakota State University - The MPC program at SDSU maintains a strong partnership with SDDOT to address transportation-related issues in the state and the region through research. The research projects portfolio under this grant consists of 5 projects in transportation safety, pavement, and bridge engineering. Of the 5 projects was completed in this reporting period and 4 are underway. The completed project in this reporting period developed a Monte Carlo simulation based tool for predicting the performance of steel fibers reinforced concrete. Workforce development continues to be one of the main goals. Four graduate students (3 M.S. and 1 Ph.D.), one post-doctoral researcher, and two undergraduate students were supported through this grant. We plan to complete all outstanding projects, publish final reports, and disseminate research findings through peer-reviewed journal papers and technical presentations.

University of Colorado Denver - The major goals for our UTC revolve around improving and preserving the existing transportation system. Our university has several projects intended to enhance the efficiency, effectiveness, and safety of the current infrastructure. Our projects are progressing well, and we completed one final report during this reporting period.

University of Denver - The major accomplishments have been in promoting and educating the transportation industry about the importance of Safety Culture as a method to improve safety. Several presentations, additional data to further validate a measure of safety culture and other activities have all contributed to our success of our mission. Other work by out center included presentations to several national and one international organization on the methods that would be helpful to improve safety for trespassers. Increasing awareness of the problems of intentional death associated with railroads was also a major accomplishment. Our center staff also contributed to leadership development and workforce training activities of a number of transportation organizations. Building on our work in safety culture, and the associated leadership and management techniques necessary to achieve a positive safety culture, several presentations on the importance of effective leadership were offered. These presentations helped emphasize the importance of effective leadership and the contribution to transportation efficiency and safety.

University of Utah -A project on exploratory modeling and analysis for automated vehicles in Utah is currently under way. Another project seeks to determine whether statistical modeling and/or machine learning can be applied for estimating/predicting traffic conditions. A project seeks to assess the lifecycle performance using snowplow ruck automatic vehicle location data. Crash scenarios with connected vehicle technology applications are mapped to discuss connected vehicle benefits on mitigating crash severity and reducing crash rates. Another project has made progress regarding intermediate temperature properties of representative asphalt mixtures produced in the state of Utah. A project seeks to determine whether a geogrid adds any benefit to the long-term performance of the pavement system and the project is well on its way. Another project seeks to develop potential methods or best practices to mitigate bridge abutment differential settlement. Progress has been made in using alternative methods for constructing bridge bents in high seismic regions using self-centering in terms of post-tensioning of bridge columns and external energy dissipation devices such as buckling restrained braces.

University of Wyoming - All UW studies are on schedule. Some of the studies have hard match from WYDOT which will make the implementation of the findings easier.

Utah State University - There have been a blend of accomplishments that were achieved during this reporting period as the time on the grants have varied. For some of the newer grants the major accomplishment has been to get them approved and the index set up so the PI can hire a student and start to work on the research. This has been particularly important for our new faculty members in the transportation area. The existing grants I think have made significant progress. We have students that are being funded on each of the grants. These students will receive their graduate degrees in transportation related fields. Providing students opportunities is one of our major goals of the center and university. A second goal that is right along those lines is to support faculty, particularly new faculty, in their careers. The hope is that if we can get them to look at transportation research early in their careers then they will continue to do research in this area throughout the remainder of their careers. Publications and research that impacts the state of practice is also very important and I believe that we have selected projects that will accomplish this goal.

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 OST-R 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. Mod 1 Executed Oct 1, 2017 (Year 2) Mod 2 Executed Oct 1, 2018 (Year 3)	11/30/2016	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 the annual summer meeting to received guidance from OST-R 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 listed in Table 7, organized by major subject area. In some cases, courses with the same titles were offered at more than one MPC university.

Table 7: Transportation and Transportation-Related Courses Offered This Period

Major Subject Area	Course Title
Engineering & Design	1. CIVE 508 Bridge Engineering 2. CIVE 566 Intermediate Structure Analysis 3. CEE 216/216L Materials and Lab 4. CEE 282 Civil Engineering Computer-Aided Design 5. CEE 346/346L Geotechnical Engineering and Lab 6. CEE 353 Structural Theory 7. CEE 443 Matrix Structural Analysis 8. CEE 432 Hydraulic Engineering 9. CEE 455 Steel Design 10. CEE 436/536 Advanced Hydraulic Engineering

	11. CEE 458/558 Design of Timber Structures 12. CEE 492/592 S01 Soil and Subgrade Stabilization 13. CEE 755 Advanced Reinforced Concrete 14. CVEN 4602 Highway Engineering 15. CVEN 5602 Advanced Street & Highway Design 16. CVEN 5682 Pavement Design 17. URPL 3000 Planning the Built Environment 18. CVEEN 3520 Transportation Engineering 19. CVEEN 3510 Civil Engineering Materials 20. CVEEN 5500 Materials Sustainability 21. CVEEN 5510 Highway Design 22. CVEEN 5570 Pavement Design 23. CVEEN 5305 Introduction to Foundation Engineering 24. CVEEN 7310 Advanced Foundation Engineering 25. CVEEN 3310 Geotechnical Engineering 26. CVEEN 6310 Foundation Engineering 27. CVEEN 5220/6220 Concrete II 28. CVEEN 7260 Seismic Rehabilitation 29. CVEEN 5560/6560 Transportation Planning 30. CVEEN 7545 Traffic Network Modeling 31. CE 3500 Transportation Engineering 32. CE 3600 Soil Mechanics 33. CE 4510 Pavement Design 34. CE 5510 Pavement Design 35. CE 5660 Soils and Rock Slope Engineering 36. CE 4555 Geometric Design of Highways 37. CE 5555 Geometric Design of Highways 38. CE 4970 Design Squad Coop 39. CE 5585 Pavement Management System 40. CEE 2240 Engineering Surveying 41. CEE 3160 Civil Engineering Materials 42. CEE 5010 Matrix Analysis/Finite element 43. CEE 5070 Structural Steel Design 44. CEE 5350 Foundation Analysis and Design 45. CEE 6130 Structural Dynamics and Seismic Design 46. CEE 6930 Structural Design Loads 47. TL 715 Introduction to ERP 48. TL 725 ERP Configuration
Freight & Logistics	1. TRAN 4010 Introduction to Transportation Systems 2. TRAN 4330 Principles of Supply Chain: Management and Technologies 3. TRAN 4080 Transportation Law and Regulation: Domestic and International 4. CVEEN 6920 Optimization in Transportation 5. TL 711 Logistics Systems 6. TL 788 Research in Transportation and Logistics 7. TL 811 Modeling for Logistics Research 8. TL 733 Case Studies in Logistics 9. TL 721 International Logistics Management 10. TL 831 Modeling for Transportation and Logistics Decision Analysis
Planning & Environment	1. URPL 5050 Urban Development 2. URPL 6350 Form and Formation of Cities 3. URPL 6355 Urban Redevelopment Strategies 4. URPL 6365 Parks and Public Spaces 5. URPL 6400 Community Development 6. URPL 6399 Introduction to Sustainable Urban Infrastructure

	7. URPL 6410 Social Justice in Planning 8. URPL 6600 Regional Planning 9. TRAN 4710 Transportation Finance 10. TRAN 4020 Transportation Economics 11. TRAN 4060 Transportation Marketing and Sales Tools 12. TRAN 4330 Principles of Supply Chain Management and Technologies 13. CVEEN 3520 Transportation Engineering 14. CVEEN 5560 Transportation Planning 15. CVEEN 6560 Transportation Planning 16. CVEEN 7545 Traffic Network Modeling 17. CEE 4200 Engineering Economics 18. CEE 6930 Green Infrastructure 19. TL 754 Urban Transportation Systems Analysis 20. TL 782 Highway Planning and Logistics 21. TL 756 Transportation and Land Use Integration
Public Transportation	1. CVEN 5800 Transit Design 2. URPL 6560 Transit, Bicycle & Pedestrian Planning 3. TRAN 4080 Transportation Law and Regulation: Domestic and International 4. TRAN 4320 Transportation Management, Leadership, and Values 5. TRAN 4800 Analysis of Freight & Passenger Transportation Business Segments 6. TRAN 4840 Multimodal Passenger-Freight Transportation Systems 7. CVEEN 5560/6560 Transportation Planning 8. TL 786 Public Transportation 9. TL 757 Public Transportation II
Traffic & Operations	1. CEE 363 Highway and Traffic Engineering 2. CVEN 4612 Traffic Impact Assessment 3. CVEN 5612 Traffic Impact Assessment 4. CVEEN 3520 Transportation Engineering 5. CVEEN 7545 Traffic Network Modeling 6. CE 5700 Traffic Flow 7. CE 5540 Traffic Control 8. CEE 5220/6220 Traffic Engineering
Transportation Safety	1. CEE 691 S01 Transportation Analysis and Safety 2. CVEN 5611 Transportation Engineering Statistics 3. CVEN 5662 Transportation System Safety 4. CEE 5230/6230 Geometric Highway Design 5. CEE 5255 Transportation Safety 6. TL 789 Leadership, Ethics and Academic Conduct in Transportation
Transportation Systems	1. CIVE 303 Infrastructure and Transportation System 2. CVEN 5633 Sustainable Transportation Systems 3. URPL 6555 Transportation, Land Use, and the Environment 4. TRAN 4010 Introduction to Transportation Systems 5. TRAN 4050 Intermodal Transportation Systems 6. TRAN 4850 International Transportation & Supply Chain Management Analysis 7. CVEEN 7545 Traffic Network Modeling 8. CEE 6210 Transportation Systems Analysis 9. TL 855 Geospatial Information Systems for Transportation 10. TL 757 Intelligent Transportation Solutions 11. TL 783 Transportation Systems II

Altogether, 113 transportation and transportation-related courses were offered this reporting period, for a total of 307 transportation courses offered since the beginning of this grant. In addition to the courses listed in Table 7, 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, 87 training sessions were offered this reporting period, for a total of 212 offered under this grant period. Multiple training sessions are annotated by () and the appropriate number of sessions.

- Blockchain in the Transportation Industry: Plain Talk and Progress
- Concrete Training
- WYDOT Asphalt Certification
- WYDOT Concrete Certification
- WYDOT Aggregate Certification
- WorkZone Training
- ATSSA Certification
- Asphalt treatments
- OSHA 10 - Workplace, Equipment and Jobsite Safety
- Heavy Equipment Safety Operations
- Retroreflectivity for Signs
- Fork Lift Certification
- ATSSA Flagger Certification
- ATSSA Traffic Control Technician
- ATSSA Traffic Control Supervisor
- ADA Ramp Design
- Confined Space Training
- Employee Motivation
- Asphalt Paving Maintenance 1
- Asphalt Paving Maintenance 2
- Registered Storm Water Inspector
- Pedestrian and Bicycle Safety
- Bridge Evaluation, Repair, Load Rating
- EDC Exchange
- Registered SWPPP Writer
- Basics of a Good Road
- Roadway Materials
- Roadway Drainage
- Winter Road Maintenance
- Heavy Equipment Operation
- Autonomous Truck Mounted Attenuator
- Autonomous Vehicle Strategies for Transportation Agencies
- Building Trust & Respect
- Communicating with Diplomacy and Tact
- Concrete Manholes & Inlets: Design, Production & Installation
- Cracking & Debonding of a Thin Reinforced Concrete Overlay
- Dewatering (Environmental Series
- Digital Signatures & E-Construction
- Evaluation of Asphalt Patching & Crack Sealing Methods & Best Practices Manual
- Fiber-Reinforced Concrete for Structure Components
- Fraud Awareness
- I Am a Leader - On-Site – Bismarck
- Implementation Guidance for Accelerated Bridge Construction in SD
- Interpersonal Competence - Enhance Teamwork
- Job Safety Analysis
- Knowing the Rules and Doing Your Homework
- Lean Mental Models and Problem Solving: Turning Organizational Deficiency to Efficiency
- Local Road Surface Selection Tool
- Mobile & Terrestrial LiDAR & Advancements in Mobile Imaging
- Motor Grader One on One Advanced Training - On Site - Bottineau County
- Motor Grader One on One Advanced Training - On Site - Burleigh County
- Motor Grader Training - One on One - On Site – Bottineau
- Motor Grader Training - One on One - On Site - Burke County
- Motor Grader Training - One on One - On Site - Burleigh County
- Motor Grader Training - One on One - On Site - Cavalier County
- Motor Grader Training - One on One - On Site - Divide County
- Motor Grader Training - One on One - On Site - Grand Forks County
- MPC Research-Optimization of Pavement Marking Performance
- Non-Destructive Testing of Concrete
- Pavement Preservation Peer Review (EDC-4)

- Personnel & Equipment Detection on Construction Projects – Webinar
- Planning & Delivering Presentations
- Positive Motivation Equals Positive Performance
- Preventing Runovers & Backovers - On Site - City of Bismarck
- Ramsey County Bridge Demo - On Site - Devils Lake
- Regional Local Roads Conference
- Road Safety & Temp Traffic Control - On Site - Burleigh County
- Roundabouts - Operational Analysis & Lane Configuration
- Roundabouts - Single Lane High Speed
- Rural Solutions for High Crash Locations – Webinar
- Rumble Strips - Permanent & Temp Measures & State of Practice
- Safety 365 - On site - Emmons County
- Safety 365 - On site - Foster County
- Self-Consolidating Concrete for Prestressed Bridge Girders
- Signing 201 - On Site - Morton County Snow Fences
- Structural Fibers in Thin Concrete Overlays
- Temporary Measures during Construction (Environmental)
- The Art & Science of Communication
- Transcending Challenges with a Relentless Focus on Workplace Experience Innovation
- Truck Summit - On Site - Manning - Dunn County
- Truck Summit - On Site - Valley City - Barnes County
- Vampires at Work: Handling Difficult People and Conflict
- WDEA Roundtable Meeting - On Site –
- Watford City
- Wildlife & Roads Part 1
- Wildlife & Roads Part 2
- Wildlife & Roads Part 3

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 48 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
- CHARISM, Fargo, ND, in-kind support and outreach program
- 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
- CMA-CGM Maritime, Inc., Washington, D.C., 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
- Denver Regional Council of Governments, Denver, CO (in-kind support in the form of data)
- 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
- Keolis Commuter Services, Boston, MA, in-kind support
- Mineta Transportation Institute, San Jose, CA, in-kind support
- MnROAD facility, Minnesota Department of Transportation, Monticello, MN, in-kind support and collaborative research
- Mountainland Association of Governments, Orem, UT, subject matter experts
- 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 Department of Health, Bismarck, ND, in-kind support
- North Dakota Highway Patrol, Bismarck, ND, in-kind support
- Olympus Precast, Bluffdale, UT, in-kind support
- Owens Corning, USA, Seward, NE, in-kind support
- Port of Oakland, Oakland, CA, 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 & in-kind support
- South Dakota Department of Transportation, Pierre, SD, field testing collaboration.
- South Dakota State University, Brookings, SD, in-kind support
- Spirit Lake Nation, Fort Totten, ND, subject matter experts
- 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 and in-kind support
- University of New Mexico, Albuquerque, NM (personal exchanges; the former student working on this project garnered a tenure-track job at UNM last year and helped finished off the project from there).
- University of Sydney, Sydney, Australia, in-kind use of facilities
- 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, (financial support & subject matter experts)
- Wasatch Front Regional Council, Salt Lake City, UT, subject matter experts
- Wyoming Department of Transportation, Cheyenne, WY, (facilities, financial support & in-kind support)
- Wyoming Safety Coalition, Worland, WY, in-kind support
- Wyoming Technology Transfer Center, Laramie, WY, collaborative research

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

b. Have other collaborators or contacts been involved?
USDOT's continued support with the award of this grant has allowed us to encourage and support 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.

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, Douglas Woolridge, Joseph Scalia, Chris Bareither, Aditi Bhaskar, Thomas Bradley, Paul Heyliger, Peter A. Nelson and Mehmet E. Ozbek. In addition, fourteen 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, and Chao Jiang. In addition, 11 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, NeTia Bauman, Sharma Kshitij, Kenneth Davis and Laurel Benson. In addition, thirteen students are working on MPC project: Mu'ath Al-Tarawneh, Mohanad Alshandah, Xinyuan Yang, Xinyi Yang, Hafiz Usman Ahmed, Keshab Thapa, H M Nasrullah Faisal, Neeraj Dhingra, Amin Keramati, Xiaoyi Zhou, Leonard Chia, Bhavana Bhardwaj, and Bukola Bakare. Another four principal investigators, faculty, and administrators are participating in MPC projects at **South Dakota State University** are: Junwon Seo, Ahmad Ghadban, Nadim Wehbe, and Rouzbeh Ghabchi. In addition, seven students are working in MPC research projects: Euiseok Jong, Ibin Amatya, Marco Paulo Pereira Castro, Maria Laura Velazco Fasce, Prateek Rai, 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, fourteen students are working on MPC research projects: Shahryar Monghasemi, Ahmed Ibrahim, Mallory Redmon, Shalini Mahanthege, Alayna Truong, Ricardo Gonzalez, Brady Heath, Molly North, Ghazal Batouli, Nick Ferenchak, Nick Coppola, Yaneev Golomber, Shahryar Monghasemi, and Robert Fitzgerald.

Nine 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, Chris Pantelides, Tiffany Hortin, Mark Bryant, and Xianfeng Terry Yang. In addition, twenty 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, Shuanli Bao, Swastik Pohkrel, Emad Ghodrati, Henrik Burns, Nadereh Adham, Kaden Harris, Ijan Dangol, Dipendra Thapa, Faramarz Safazadeh, Abi Sufian Mohammed Asib, Bahar Azin, and Qinzheng Wang.

Five principal investigators, faculty, and administrators are participating in MPC projects at the **University of Wyoming** are: Jennifer Tanner, Khaled Ksaibati, Promothes Saha, Er Yue, and Amirarsalan Mehrara Molan.. In addition, eleven 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, Milhan Moomen, Sahima Nazneen, 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, and Marc Maguire. In addition, fifteen students are working on MPC research projects: Zhaocai Liu, Prasanna Humagain, Ferdousy Runa, Kevin Brown, Michael Ruiz-Leon, Seth Thompson, Joshua Ward, Nicholas Markosian, Brad Davis, Pilaiwan Vaikasi, Ashikur Rahman, Zhcaocai Liu, Yi He, Pilaiwan Vikasi, and Jared McRory.

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

c. Were there any collaborators from outside the UTC?

Nothing to report at this time.

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 B through D.

a. Publications can be found in Appendix B.

i. During this period MPC faculty and investigators have published 30 peer-reviewed articles or papers in scientific, technical, or professional journals. Since the beginning of this grant, we have published 76 different peer-reviewed articles or papers.

b. Conference Papers can be found in Appendix C.

i. This reporting period we have published 11 conference papers and 33 total since the grant began.

c. Presentations can be found in Appendix D.

i. MPC faculty and investigators have presented at 36 different scientific, technical, or professional conference this period. In total, we have had 85 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:

The outcomes of research that is underway and has been completed at **Colorado State University** are increasing practitioners' understandings of inspection techniques, traffic performance assessment, bridge deterioration prediction, hydrologic design, soil treatment, and UAVs and autonomous techniques. New methodologies have been developed in these fields that will help industry, government and the research community. For example, by considering the cost implications and timing of both infrastructure inspection and maintenance activities, MPC-533 provides transportation agencies with the tools and knowledge to realize long term life-cycle cost savings. MPC-534 increases practitioners understanding of traffic system performance following hazards, as well as recovery and repair planning following earthquakes. MPC-535 has proven the feasibility of UAV-based data acquisition for bridge inspection, which could revolutionize inspection practices. The improved bridge condition deterioration model developed in MPC-536 allows better use of existing inspection data and takes into account both accurate data and incomplete/censored data. The computational models developed in MPC-537 have been used to analyze runoff production mechanisms for several basins in the Colorado Front Range for both historical and design storms, quantifying the effects of longer duration storms in producing saturation-excess runoff. The enhanced understanding of expansive soil issues and a standard methodology for testing expansive soil treatment technologies (e.g., the use of different recycled materials and compaction of claystone backfills) being developed in MPC-538 will lead to new techniques for the prediction and engineering of expansive soils for transportation earthworks. Through engagement with Colorado Association of Geotechnical Engineers (CAGE), this work will enlarge the pool of professionals that have exposure to treatment of expansive soils for transportation earthworks. MPC-568 is advancing our understanding of where and when street flooding conditions and related transportation issues occur in the Denver, Colorado metropolitan area, thus improving the management of stormwater infrastructure in metropolitan areas. MPC-569 is providing new knowledge on traffic performance modeling and the planning of emergency medical response services in rural arears. MPC-570 is disseminating new knowledge of fuel-economy and safety to local and national stakeholders (including the City of Fort Collins) from infrastructure/vehicle datasets. MPC-571 (Monitoring Transportation Structure Integrity Loss and Risk with Structure-From-Motion) allows for transient investigation of the degradation of transportation structures using imaging technology that captures damage over time.

MPC-591 is expected to improve the understanding of traffic safety under adverse conditions. MPC-592 has improved the data analytics of UAV-based bridge inspection. MPC-593 will improve engineers' abilities to predict landslide hazards to infrastructure, including road networks and allow transportation professionals to make better decisions about where to direct resources for the management and development of transportation systems. MPC-594 is expected to produce a thorough accounting of the factors that limit the capacity for change within transportation agencies. 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.

The infrastructure safety support system for smart cities developed in MPC-547 at **North Dakota State University** has identified an infrastructure embedded sensor network that can provide real-time traffic information such as volume, vehicle classification, vehicle speed, and dynamic axle weights via weigh-in-motion (WIM). In addition, algorithms are being designed to process the sensor-based real-time traffic data to support the decision making processes of autonomous vehicles. An outreach program to first generation American elementary and middle school kids is introducing them to transportation related hand-on projects. In terms of swelling clay, the major finding from MPC-548 this reporting period is that fluids with different polarities affect the magnitude of swelling and compressibility behavior of clays. This outcome could influence the design and maintenance approaches for roads built in swelling clay areas. MPC-549 introduced several students to statistical software tools including SAS, R, MATLAB, and Python in machine learning and data mining techniques in pursuit of the rail track monitoring and benefit-cost analysis studies. Students became familiar with the Federal Railroad Administration's train accident database and learned about patterns and causes of railroad accidents and their impact in terms of financial losses, injuries, and fatalities. Students also learned risk management and security theories for the quantification of benefits and costs of technology deployment in the railroad industry. MPC-550 is increasing understanding and awareness of highway rail grade crossing safety issues and the body of working knowledge, especially with respect to countermeasure effectiveness. Researchers are getting real-world feedback from NDDOT and Colorado crossing safety managers. The automated track geometry monitoring project (MPC-551) will increase understanding and awareness of smart phone based geometry monitoring systems and applications. Moreover, the tribal and teen projects (MPC-556 and MPC-567) will contribute to road safety by: (1) increasing awareness of tribal traffic safety issues and improving communication and collaboration with tribal partners, (2) a better understanding of the parent letter outcomes in terms of parents' receptiveness to the letters, (3) parental practices with regard to monitoring teen drivers, and (4) parental interactions with teens, in terms of discussion and/or training, based on the advisory letter.

The research that is underway and has been competed at **South Dakota State University** has led to (1) the evaluation of mechanical performance of newly developed adhesively bonded joints in highway dynamic messaging signs, (2) the development of an incremental step towards better prediction of flexural performance of FRC structural members, (3) the calibration of live load distribution and dynamic load allowance factors in double-tee bridges, (4) the identification of limitations and advantages of designing mixes using bio-asphalt binders and additives, and (5) the development of novel cross-laminated timber bridge systems for local roads.

Research that is underway and/or has been completed at the **University of Denver** has resulted many identifiable outcomes including (1) contributions to the scientific understanding of safety culture, (2) further contributions to the development and validation of a measure of safety culture, (3) contributions to workforce development through discussions of safety culture, (4) contributions to the knowledge and expertise of transportation professionals' leadership skills, and (5) enlargement of the pool of qualified and competent transportation professionals through our educational efforts. Further anticipated outcomes include: (1) contributions to the further understanding of the role of Safety Culture on the safety of transportation employees and the public at large; (2) contributions to improvements in transportation professionals understanding of how to improve safety culture; (3) contributions to scientific knowledge by continued refinement and development of a measure of safety culture, as accurate measurements are needed to be able to benchmark, manage and improve safety culture; (4) improvements in safety and a reduction of accidents and injuries in the transportation system as a result of improvements in safety culture; (5) improvements in efficiency and quality in transportation organizations that address safety culture; and (6) improved customer/user/rider satisfaction due to improved safety culture.

The projects at **University of Utah** will have the following outcomes: (1) increased understanding of how automated vehicles would impact the region-wide traffic conditions; and (2) improved techniques for big transportation data processing and archiving. The selection of the optimal replacement year for snowplow trucks can help DOTs efficiently allocate resources and reduce overall costs. Another project will increase the understanding of connected automated vehicle benefits in improving traffic safety, under the impact of different road geometric designs. In the area of roadways, new policies and specifications will be developed to allow state departments of transportation to characterize the intermediate temperature properties of asphalt mixtures. The use of geogrid in pavement systems will be studied to provide longer service life and reduced maintenance including better design methods and improved construction techniques. Mitigation of differential settlement at bridge approaches is another project which is expected to be implemented to remediate the "bump on the bridge" problem. Another research effort seeks to create bridges that will remain operational after a strong earthquake. This will enable bridge engineers to design resilient bridges in high seismic regions including external energy dissipation devices.

The research that is underway and has been completed at **the University of Wyoming** has led to a new procedure for determining speed limits on mountain passes (MPC-574); estimates of traffic volumes on all low volume roads in the state, which will help planners/engineers in conducting safety/planning studies (MPC-572); and identification of better alternatives to interchanges so that they are more efficient and safer for the driving public (MPC-573).

The research projects at the **University of Colorado Denver** have all progressed over the last project period, with four journal papers published and one final report. This work has also had an impact on the students working on them in terms of providing an opportunity for research and the various research-related skill development. The research projects being conducted at the **Utah State University** are increasing the pool of trained transportation professionals. A lengthy list of students is working on MPC projects. Moreover, new faculty members are making substantial contributions. The projects, the faculty, and the students are increasing understanding and awareness of transportation issues of various kinds, with projects that are in the transportation and structural fields. Some of these projects will result in improved design methodologies and others will provide skills that help in the planning of better transportation systems for the future.

5. Impacts

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

Research underway at **Colorado State University** will impact the effectiveness of the transportation system through new techniques and methodologies and processes to conduct bridge inspection, post-hazard recovery, bridge sustainability, flood prevention, land slide hazard, infrastructure resilience, traffic safety and connected and autonomous vehicles (CAV). The long term expected impact of MPC-533 is that inspections and maintenance will be carried out at more cost-effective times and decisions about inspection and maintenance will be based on bridge specific conditions. These factors will promote a state of good repair, while respecting the limited budgets available to transportation agencies. MPC-534 will help practitioners conduct better post-hazard recovery and repair planning using the findings of this study. It will make post-hazard repair more cost-effective and keep resilience of the transportation system at a high level. MPC-535 has provided proof-of-concept regarding the adoption of new UAV technology in transportation infrastructure inspection. The insights and experiences gained from the project may guide the application of UAV-based inspections by bridge owners and managers. The findings from MPC-536 will likely impact the risk, cost-informed inspection and maintenance planning of transportation systems, especially regarding bridges. The results from MPC-537 demonstrate that the possibility of saturation-excess runoff needs to be included in hydrologic analysis and design in the Colorado Front Range to prevent planners from missing runoff that might occur. Effective testing of innovative expansive soil treatment technologies from MPC-538 will allow for increased effectiveness in the adoption of new soil treatment technologies for transportation infrastructure in the mountain plains region (and nationally). MPC-568 will reduce traffic delays related to street flooding by better cataloging and managing the traffic consequences of street flooding. MPC-569 is expected to help EMS planning in the future and help save more lives by optimizing existing resources. MPC-570 will improve understanding of the role of ATMS (and other infrastructure) sensors, information, and infrastructure in advancing the safety and environmental benefits of CAVs and the value (in terms of the metrics of safety and fuel economy) of integrating the datasets available from transportation system infrastructure into the control of CAVs. By monitoring the damage levels and loss of stiffness and strength using information from MPC-571, repairs can be directed to where they are needed while ensuring that damaged structures still possess the necessary strength and stiffness so they can be used without loss of integrity. MPC-591 will help develop safer traffic systems even under adverse conditions by providing quantitative measures to assess traffic safety performance considering a range of uncertainties. MPC-592 will improve the efficiency and effectiveness of adopting UAV-based bridge inspection technologies. MPC-593 will provide insights into what constitutes high-hazard locations for roads and highways—which will ultimately lead to the development of a safer transportation system through improved landslide hazard assessments of existing roads. MPC-594 will identify how large-scale changes are made to engineering practice at DOTs and how to engage with transportation agencies to promote the adoption (or adaptation) of research advances into routine practice.

Work continues at **North Dakota State University** in asset management. For example, the computational modeling from MPC-548 (along with the understanding of key mechanisms) will help improve prediction capabilities of the strengths of swelling clays and contribute toward more reliable design of transportation infrastructure in swelling clay areas. The likely impacts of deploying an autonomous rail track geometry monitoring system (MPC-551) is to screen the network for faults during normal train operations which will lead to a significant reduction in the risk of accidents due to track and roadbed infrastructure issues. Besides, enhanced situational awareness from real-time condition monitoring will motivate improvements in railroad asset management, maintenance, and safety practices. More efficient maintenance practices will improve infrastructure quality, which in turn will enhance railroad capacity, reduce accidents, and improve service reliability. Improvements in business efficiencies and services could potentially encourage mode shifts from trucks, which will have a net positive benefit in the reduction of congestion and harmful emissions. The rail network research could enhance knowledge of inertial data transformation to track geometry measurements. The tool developed in the research could increase the efficiency of track geometry monitoring and maintenance operations, leading to less track down time but higher rail revenue in-service time. The expected impacts from the highway-rail grade crossing safety system project (MPC-550) will inform crossing safety agencies and assist them to allocate budget dollars more effectively. The safety system for smart cities with automated vehicles (MPC547) will develop an infrastructure embedded sensor network that can provide real-time traffic information for traffic management. With the detected real-time traffic information, the developed I2V (infrastructure to vehicle) algorithms from this research can support the decision making processes of autonomous vehicles in mixed traffic conditions to improve the safety of all vehicles. The tribal crash project (MPC-566) will improve tribal transportation safety related to special studies and expand tribal community participation in grant opportunities. The teen parent advisory letter project (MPC-567) will explore communication between novice teen drivers and their parents. It is anticipated to produce long-term safety improvements for novice teen drivers and an improved understanding of parents' roles in relation to graduated driver licensing requirements.

As a result of research at **South Dakota State University**, the feasibility and structural performance of lighter and water-tight joints will be developed for the structural frames of highway dynamic messaging signs. Engineers will be able to better predict the flexural performance of steel-fibers reinforced concrete. Use of bio-asphalt binders may result in environmental benefits and reduced asphalt cost. The use of cross-laminated timber will promote environmentally sustainable and diversified bridge construction materials.

MPC projects at **University of Colorado Denver** will help lay the foundation for improving the built environment and extending the longevity of the existing infrastructure. In addition, the intent is to help make roads safer and more efficient. The impact of **University of Denver**’s research on the effectiveness of the transportation system will be seen in the form of improved safety culture and fewer accidents and injuries among transportation organization employees. Many of the projects at **Utah State University** focus on improving the effectiveness of the transportation system. It could be in terms of cost of construction, cost of utilization (daily user costs) or the long-term costs that are associated with maintenance and replacement. These projects all improve the effectiveness of the transportation system. Meanwhile, one project at the **University of Utah** will investigate how automated vehicles impact traffic conditions. The impact of connected automated vehicle technology on traffic safety under different geometric designs will be investigated. MPC research will also investigate how machine learning can be applied at predicting and estimating traffic volumes. Models for predicting snowplow truck performance using vehicle locator data will also be developed. Asphalt pavements at low and intermediate temperatures will be evaluated based on a new test and on field performance. Geogrids in pavements will be assessed for longer service life and reduced maintenance. In the area of bridges, mitigation of differential settlement at highway bridge approaches will be investigated. Bridge bents will be developed with self-centering capability after moderate or strong earthquakes. A hybrid bridge bent system will be developed using post-tensioned columns and buckling restrained braces for accelerated bridge construction in seismic regions.

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

The projects being conducted at **Colorado State University** are expected to transfer technology to government, industry and other interested stakeholders. In MPC-533 (Use of Life Cycle Cost Analysis to Enhance Inspection Planning for Transportation Infrastructure) the costs associated with different inspection scenarios could help facilitate the movement to one of the newly proposed inspection schemes. The techniques developed in MPC-534 are being transferred to government for traffic management and repair prioritization. MPC-535 focuses on the feasibility of adopting UAV technology in bridge inspection practices. A positive outcome might be to promote more research and development activities on the application of this new technology by government and industry. MPC-536 has led to improved understanding of the impact of bridge inspection data on calibrated deterioration models, which could lead to changes in bridge inspection and maintenance practices. In MPC-537 researchers are actively collaborating with Colorado Dam Safety and expect the results of the study to be considered in an upcoming update to their guidelines for evaluating dam safety. MPC-538 is expected to impact the development of future commercial expansive soil treatment technologies and identify best practices for the preparation of re-compacted claystone backfills. The results of MPC-568 will be transferred to the City of Westminster and the Urban Drainage and Flood Control District, which could lead to more informed adoption of green infrastructure stormwater practices. MPC-569 could help government entities enforce new planning tools. The information developed in MPC-570 is being disseminated to numerous stakeholders including the Colorado Department of transportation, the City of Fort Collins, Denver Clean Cities Coalition, and the Northern Colorado Clean Cities Coalitions; who have been briefed on the interim results and are seeking ways to collect, organize, and monetize the datasets derived from infrastructure and connected vehicles. The automated methods emerging from MPC-571 (Monitoring Transportation Structure Integrity Loss and Risk with Structure-From-Motion) can free human personnel from routine assessments and allow them to work on higher-priority activities that require human skills.

MPC-591 (Reliability-Based Traffic Safety Risk Function of Traffic System in Hazardous Driving Conditions to Promote Community Resilience) provides suggestions to communities and practitioners in terms of traffic safety advice. The developed data and analytical tools from MPC-592 may be adopted by bridge management sectors, such as state DOTs, city, and county engineering departments. The technology might also be transferred to industry—e.g., bridge inspection companies. The modeling results from MPC-593 will provide transportation officials with additional tools to manage landslide hazards across road networks. MPC-594 is expected to provide general and important information to DOT professionals who want to implement changes in their organizations.

The results of research underway and completed at **North Dakota State University** are being transferred to entities in government and industry. MPC-548 is providing insights into molecular interactions-microstructure-property relationships for swelling clays that could lead to robust analysis procedures and accurate predictability of the behavior of swelling clay that can be utilized by government and industry. IT applications resulting from the safety support system for highway-rail grade crossings (MPC-550) and the automated track geometry monitoring system (MPC-551) projects will produce easy-to-use tools for grade crossing and track condition monitoring safety for public agencies. Moreover, the machine learning approach to track geometry monitoring could lead to possible adoption by the industry. The project on safety systems for smart cities with AV (MPC-547) may introduce new sensor networks and algorithms for safer driving of autonomous vehicles in traffic conditions with human drivers mixed with autonomous vehicles. Because of MPC-556, it is expected that tribes will have new opportunities to apply and receive grants to support traffic safety initiatives. Moreover, (MPC-567) is providing insights to improve teen driver safety in the long run. The teen parent advisory letter program created by the project can be easily transferable to other states and/or communities with access to traffic records and license information.

Findings from the testing and simulation of adhesively bonded joints in dynamic messaging signs at **South Dakota State University** can be transferred to structural engineers. The findings may be used by existing or startup companies to efficiently use adhesive joints in DMS. The outcome of quantifying the range of variability in the flexural strength of fiber reinforced concrete could potentially serve as a first step towards adopting a new designing procedure of FRC structural members. Bridge engineers will be able to determine with higher certainty the live load distribution in double tee bridge girders. Bridge owners will be able to specify new sustainable alternative to structurally deficient existing bridges.

While Safety Culture is not a new concept, the use of a standardized instrument developed by the **University of Denver** will improve organizational culture and practice. Previously, non-standardized, individualize, and anecdotally based instruments have been used. This has led to confusion and the lack of common benchmarks for improving safety culture. An example of the impact of research being conducted at **University of Wyoming** is the adoption of a new technique to determine speed limits of mountain passes. While there have been no new startup companies at **Utah State University** the results of MPC research have clearly impacted new practices. For example, some of the research on the electrified roadway is part of a potential larger grant to electrify a section of roadway in Illinois, which may have widespread impacts on practices in this field.

The impact of automated vehicles on travel demand is being investigated at the **University of Utah** and will be reported to DOTs and metropolitan planning organizations. Big transportation data analytics will be used to estimate traffic and reduce the burden on UDOT's annual traffic count program. In addition, data-driven methods will be developed for use by UDOT in evaluating the life cycle of snowplow trucks and identifying service continuity/termination. The research on connected automated vehicle technology and its effects on traffic safety under different highway geometric designs will be useful to DOTs for implementation. Mitigation of differential settlement at bridge approaches may change Utah DOTs Manual of Construction for bridge approaches located on soft ground. The research on performance of asphalt pavements at low and intermediate temperatures will have an immediate application at UDOT and other DOTs. The research on geogrid reinforce pavements will result in improved design procedures and ultimately lower costs of roadway pavement systems and will be transferred to DOTs. The projects on self-centering and hybrid bridges will allow designers to build resilient bridges after strong earthquakes.

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

Research that is underway and completed at **Colorado State University** is expected to have important contributions to the body of scientific knowledge, such as new methodologies of life cycle cost estimation, traffic performance assessment, bridge inspection using UAVs, post-hazard resilience, horological impacts on bridges, traffic safety etc. For example, the potential costs associated with early or missed maintenance identified in MPC-533 will contribute to infrastructure management using LCCA. The network recovery planning method following earthquakes developed in MPC-534 includes an innovative repair prioritization algorithm for transportation infrastructure. The feasibility of adopting the UAV-based bridge inspection methods from MPC-535 has enhanced the body of scientific knowledge in the field of bridge engineering/inspection. The Bayesian approach to bridge deterioration prediction developed in MPC-536 allows the incorporation of both accurate and incomplete inspection data and, thus, will improve the common approach (which cannot take into account censored inspection data when calibrating condition deterioration models). The models and saturation-excess runoff predictions from MPC-537 are important in understanding large events (both historical and design storms) in the Colorado Front Range. The new testing methods for evaluation of expansive soil treatment technologies developed in MPC-538 will improve how new treatments are used by civil engineers. The causes and solutions of street flooding explored in MPC-568 are expected to lead to better understandings of which green infrastructure solutions are most appropriate. A new methodology to prioritize EMS planning introduced in MPC-569 will lead to better traffic performance assessment and improve the interactions between transportation engineering and public health officials. New publications regarding the use of infrastructure data to improve the safety and fuel efficiency of transportation from MPC-570 have resulted in new additional funding from the U.S. Department of Energy. This speaks to the novelty and importance of the study. MPC-571 has led to improve monitoring of transportation structure integrity loss and risk. A new approach to assess traffic safety has been introduced in MPC-591. Methods to use UAV-collected bridge inspection data and the automation of data analytics from MPC 592 will bridge the research gap between the data collected and knowledge needed for bridge condition assessment. MPC-593 (Probabilistic Modeling of Landslide Hazards to Improve the Resilience of Transportation Infrastructure) is expected to improve overall understanding of how and where landslides initiate. Linkage of model-predicted landslide initiation to new methods of predicting landslide runout areas will provide a better understanding of landslide dynamics and potential hazard to infrastructure. MPC-594 (Transferring Research Innovations in Bridge Inspection Planning to Bridge Inspection Practice) is expected to provide general and important information to other researchers who might want to propose large scale changes to departments of transportation.

Railroads traditionally analyze the benefits and costs of projects in terms of financial returns from investments in infrastructure and equipment. Rarely does a benefit-cost analysis (BCA) involve the quantification of risk reduction from the deployment of technology that can enhance situational awareness. The rail track geometry benefit/cost project being conducted at **North Dakota State University** (MPC-549) will quantify benefits to a sensor approach in terms of risk reduction and will develop a statistical machine learning model to predict the savings from avoiding financial losses due to railroad accidents. NDSU’s highway-rail grade crossing project (MPC-550) will lead to improved knowledge of highway rail grade crossings and integrated hazard indexes for forecasting and rankings. The major outcome of the swelling clay basic research being conducted in MPC-548 will be a multiscale computational framework for swelling clays to evaluate the mechanical response of swelling clay to external loading. The models incorporate the molecular scale clay-fluid interactions and the evolution of microstructure during swelling, the two critical factors that influence the mechanical properties of swelling clays. These simulation testbeds will provide insight into the key mechanisms that affect the mechanics of swelling clays during swelling. The innovative experiments and experimental techniques developed in this research would not only serve as model development and verification tools but also could lead to the introduction of new experimental techniques for swelling clays. The automated track monitoring project (MPC-551) will improve knowledge of signaling data processing and geometry measurement estimation from multiple sensors. The developed infrastructure embedded sensor network in the safety system for smart cities with AVs (MPC-547) will help understand how autonomous vehicles behave in a mixed traffic condition and how changes in traffic would impact the safety of the traffic flow.

Data from experimental testing and computational simulation of adhesively bonded joints of highway dynamic messaging signs from MPC-563 at **South Dakota State University** will add to the literature and body of knowledge in this area. Knowledge on quantifying the variability of the flexural performance of FRC from MPC-564 can be incorporated in bridge codes. Evaluation of asphalt mixes containing bio-asphalt binders and additives (MPC-575) will add to the body of knowledge and will increase industry confidence in using bio-materials, reduce asphalt material cost, and promote sustainability. Moreover, the cross-laminated timbers for bridge systems from MPC-595 will promote sustainability of bridge construction material.

MPC projects being conducted at the **University of Colorado Denver** are successfully adding to the scientific body of knowledge on several transportation-related fronts, including: road safety, travel behavior, smart cities, and advanced infrastructure composites. As we continue to publish, we expect to see these results have broader, multi-disciplinary impacts with the business community, the bridge construction industry, and the Vision Zero community. Research being conducted at the **University of Denver** is contributing to the scientific understanding of safety culture and the development and validation of a measure of safety culture. Moreover, the expected impacts of the research being conducted at the **University of Utah** on scientific knowledge encompass computer science and big data, machine learning methods and their applications to civil engineering. Asphalt and geogrid materials and geotechnical engineering will be enriched by MPC research, as will earthquake and structural engineering. MPC research being conducted at **Utah State University** is contributing substantially to the body of scientific knowledge especially in the electrified roadway area, where Civil Engineering is working collaboratively with Electrical Engineering to improve and create the system.

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

All the MPC projects at **Colorado State University** provide training opportunities for graduate students. Some of the studies have generated new teaching information which will be included in new and existing courses related to transportation and help undergraduate and graduate classroom education. In addition, many studies provide insights and new information to help in general engineering and community development to study new knowledge from academic research. One Ph.D. student will be partially supported by MPC-533. MPC-534 will help train a new generation of engineers through conducting research and potentially incorporating the findings in the future teaching of graduate students. MPC-535 offers opportunities to train a new generation of professionals who can adopt cutting-edge technologies to improve practices in traditional civil engineering fields. The outputs of the project have been disseminated to research communities and practitioners through conference presentations, meetings with the engineering departments of Larimer County and City of Fort Collins, as well as the Colorado Department of Transportation. MPC-536 provides opportunity for promoting the idea of using risk-informed inspection planning for transportation workforce. MPC-537 is supporting an M.S. student in the Department of Civil and Environmental Engineering. Through the research, this project provides valuable training in hydrologic aspects of surface transportation system design. This student is expected to become part of the transportation workforce as a hydrologist. MPC-538 has supported a Ph.D. student in the

Department of Civil and Environmental Engineering at Colorado State University. Through the research, the 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 has provided opportunities for two students in research and training. MPC-569 helps train future traffic engineers as emergency responders. The findings of MPC-570 will be included in the education of future DOT and transportation workers. MPC-591 will help train new generations of engineers. MPC-592 offers opportunities to train a new generation of professionals who can adopt cutting-edge technologies to improve practices in traditional civil engineering fields. The outputs of the project have been disseminated to research communities and practitioners through conference presentations, meetings with engineering departments of Larimer County and City of Fort Collins, as well as the Colorado Department of Transportation. MPC-593 will provide opportunities for research and teaching in landslide mechanics and risk assessment to transportation systems. This project will support a graduate student in their pursuit of a Master of Science in Civil and Environmental Engineering at Colorado State University. Additionally, this project will be used as an example study in a course taught by the PI, CIVE 513: Morphodynamic Modeling. The curriculum for this course will be adapted to include material on models of landslide initiation. The data and model used in the 2013 Colorado test case will provide material for a class project or assignment. In MPC-594, a Ph.D. student has been hired to assist the PIs in conducting the project. It is anticipated that the research will form a foundation for his 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.

MPC projects at **North Dakota State University** have provided opportunities for research and teaching in transportation and related disciplines. The automated track geometry monitoring system project has provided knowledge exposure to researchers, graduate, and undergraduate students in advanced signal data processing algorithms. Geometry measurement methods introduced in the research provide knowledge and new modeling options for researchers in track condition monitoring and related disciplines. Students involved in the B/C analysis of sensors for track monitoring will develop skills in data science that include machine learning, data mining, and artificial intelligence. Such skills are currently in high demand but are scarce. The transportation sector is becoming more connected and infused with sensors that will generate huge amounts of data. There is a lack of workforce with the knowledge to mine such data for knowledge gain and actionable information. This project will produce data science techniques that the researchers will incorporate into new courses in the future, such as intelligent transportation solutions. Doctoral students are heavily involved in the swelling clay project and portions of the research conducted will go towards their dissertation. The students and PIs will present seminars at NDSU and papers at meetings and conferences for wider dissemination of results to students, researchers and professionals. The students will also author journal and conference manuscripts. Research results will be incorporated into the advanced soil mechanics course in the department of civil and environmental engineering. The highway-rail grade crossing safety system project support student research and provides exposure to advanced data mining algorithms. These are relatively new modeling options for researchers in transportation safety and related disciplines. The tribal crash safety work is expected to bring about a more diversified approach through the special projects and grant support efforts in the project. The safety system for smart cities with AV project develops a new outreach program which works with CHARISM to promote transportation engineering to elementary school and middle school kids. The program works with three elementary schools and one middle school (around 25 kids each school) and implements four after-school activities each Thursday for four weeks to introduce transportation related hand-on projects including pavement, tunnel, highway, and bridge to first generation American young kids.

Five graduate students at **South Dakota State University** will be mentored to develop new methods and materials for enhancing transportation infrastructure. Many of the research results can be incorporated into bridge engineering and asphalt pavement courses. The seven MPC projects at the **University of Colorado Denver** have been instrumental in providing opportunities for several graduate students. They are all gaining experience in research methods, paper writing, and presenting, as well as developing new skills. The work has provided them with opportunities to attend conferences and interact with and share their work with other researchers and the broader transportation community. One of the Ph.D. students working on this grant also garnered a tenure-track academic position at the University of New Mexico. The present research at **University of Denver** will make a contribution to workforce development through the increased knowledge of transportation safety professionals. In turn, this should lead to improved performance in safety. Models developed at **University of Utah** will be incorporated into teaching modules to be used in transportation planning courses. Computational techniques will be developed for transportation analysis. Research on seismically resilient bridges will benefit bridge design courses and will be disseminated to other States and transportation professionals through presentations at scientific conferences.

Workforce development is an area of special emphasis **Utah State University**. Each project supports at least one student with the goal that the student will graduate and enter the work. We have also been working with other individuals as part of these projects. Some are engineers which life-long learning is important and others are not engineers but the opportunity to learn about research in the transportation areas is a significant contribution to the workforce development. I am thinking specifically of the political side of things. The cooperation between MPC and the Wyoming LTAP resulted in providing lots of training to transportation professionals at the **University of Wyoming.**

6. Changes/Problems

Nothing to report at this time.

7. SPECIAL REPORTING REQUIREMENTS:

a. Technology Transfer Plan for the Mountain –Plains Consortium (MPC)

i. MPC T2 performance measurers and performance targets are listed in Appendix E.