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Semi-Annual Progress Report #14

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

A. What are the major goals of the program?

The overall program 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, and (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 Competitiveness, 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-701**, which can be found on the Mountain-Plains Consortium website.

B. What was accomplished under these goals?

i. Project selection

There were 168 research projects selected, and each have undergone a rigorous peer review process, which is required to meet the requirements for selection. The projects reflect substantial input and matching resources from state departments of transportation and MPOs in the region. Collectively, this set of projects addresses all five of the secretary's strategic goals and several of USDOT's requested emphasis areas under State of Good Repair, e.g., (1) bridge condition monitoring, (2) locating critical infrastructure defects, (3) identifying tools to prevent and detect corrosion in transportation infrastructure, (4) analytical tools for infrastructure performance management, and (5) methods and criteria to measure performance of new materials and methods. Some MPC projects relate to more than one USDOT Strategic Goal and thus will be listed more than once in Appendix A.

ii. Programmatic milestones

In addition to the programmatic milestones described below, several milestones embedded within individual projects have been achieved. Most of the research projects call for literature reviews. The literature reviews for those projects with the earliest starts are substantially complete. Interim reports are not required after the literature review stage. At this time, all projects are on schedule to be completed as planned during the grant period. The program accomplishments to date are summarized in Table 1 by reference to milestones.

Table 1: Program Milestones

Milestone	Description	Start Date	End Date
Execution of Grant Agreement	The grant was received from RITA and executed by NDSU's Sponsored Programs office. All the necessary internal accounting and financial procedures were established, including subcontract agreements with consortium universities.	11/30/2016	09/30/2024
	No cost extension to end date of 09/30/2024.	10/01/2017	09/30/2023
	Mod 1, Grant No. 69A3551747108 (Year 2)	10/01/2018	09/30/2023
	Mod 2, Grant No. 69A3551747108 (Year 3)	10/01/2019	09/30/2023
	Mod 3, Grant No. 69A3551747108 (Year 4)	10/01/2020	09/30/2023
	Mod 4, Grant No. 69A3551747108 (Year 5)	10/01/2021	09/30/2023
	Mod 5, Grant No. 69A3551747108 (Year 6)	09/30/2023	09/30/2024
	No cost extension granted		
Site Visits	Site visits to all MPC universities are being conducted annually by the MPC director.	11/30/2016	09/30/2024
UTC/CUTC Meeting	The director and administrative staff attended the UTC/CUTC meeting at TRB and received guidance from RITA regarding the closeout of the FAST Act grant.	11/30/2016	09/30/2024

iii. Educational accomplishments

The transportation and transportation-related courses offered during this reporting period are in Appendix B due to the page limit constraints of this document; they are organized by major subject area. In some cases, courses with the same titles were offered at more than one MPC university. Altogether, **153 transportation and transportation-related courses** were offered this reporting period, for a **total of 1,747 transportation courses offered since the beginning of this grant**. In addition to the courses listed in Appendix B, foundational courses in engineering materials, mechanics, structural analysis, and geotechnical engineering were offered at most MPC universities.

C. What opportunities for training and professional development has the program provided?

i. Workforce development accomplishments

Altogether, **151 training sessions** were offered during this reporting period for a **total of 921 offered under this grant period.** Due to the page limits of this document, we have listed all workforce development activities in Appendix C. The Appendix C listing of workforce development activities illustrates the diversity of our workforce offerings for transportation professionals. In addition, we have had **173 online training modules** and **113 recorded sessions that 7,266 transportation professionals** utilized to strengthen their workforce skills.

D. How have the results been disseminated?

The research results are being disseminated in a variety of ways, including: (1) workshops and conferences; (2) videoconferences; (3) online modules; (4) presentations at conferences; (5) publications; (6) internet-based dissemination including broadcast emails, website postings, 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 to 18 months with dissemination of results 18 to 24 months from the start of the research. We continue to closely monitor the progress of the work plans as reported for each project in the Semi-Annual Progress Reports. Also, monthly communication, at a minimum, are made with each MPC University director to ensure the success of our investigators.

2. Participants and Collaborating Organizations: Who has been involved?

A. What organizations have been involved as partners?

As projects are selected and work plans completed within the timing of match funding, the commitments of collaborators will vary widely throughout the life of the grant. During this period, we had **86 committed collaborators**, who provided different support, such as financial, in-kind, equipment, supplies, software, or data support. In addition, many collaborators provide direct links for collaboration in research, survey mechanisms, and project activities. A list of organizations that have been involved as partners can be found in Appendix C2.

B. Have other collaborators or contacts been involved?

USDOT's continued support with the award of this grant has allowed us to encourage and support **94 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 **179 students from the U.S. and countries around the world. These include seven post-doc students, 79 doctoral students, 61 master's students, and 32 undergraduate students.**

(1) The principal investigators, faculty, administrators, and students are listed in Appendix C2, who work within the MPC Universities have participated in MPC research projects this reporting period.

(2) The following other collaborators have been identified and are working with our PIs on MPC projects that are outside of our consortium:

- **North Dakota State University**
  - Zach Hans, Iowa State University
  - Adam Larson, FHWA Tribal Safety Office
  - Larissa Young, Standing Rock Sioux Tribe, Road Department Planning
- **University of Colorado Denver**
  - Chengbo Ai, University of Massachusetts, Amherst
- **University of Utah**
  - David Steven, Utah Department of Transportation
  - John Popovics, University of Illinois at Urbana-Champaign
  - Terry Yang, University of Maryland, College Park
- **Utah State University**
  - James Corney, Utah Department of Transportation
  - Jason Richins, Utah Department of Transportation
  - David Stevens, Utah Department of Transportation

3. Outputs: What has the program produced?

Due to the length constraints of this document, a listing of conferences and workshops; publications; conference papers; and presentations from MPC principal investigators have been consolidated into Appendix D.

A. Publications can be found in Appendix D

During this period MPC faculty and investigators have published **61 peer-reviewed articles or papers** in scientific, technical, or professional journals. Since the beginning of this grant, **we have published 628** different peer-reviewed articles or papers.

B. Conference papers can be found in Appendix D

This reporting period **we have published 10 conference papers and 240 total since the grant began**.

C. Presentations can be found in Appendix D

MPC faculty and investigators **have presented at 33 different** scientific, technical, or professional conference this period. In total, we have **had 360 presentations on MPC research**, results, and outcomes.

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

(1) The MPC website is fully operational at: https://www.mountain-plains.org/
(2) The MPC Key Personnel can be found at: https://www.mountain-plains.org/personnel/
(3) Other **outputs** that are university specific:

Colorado State University

We have used the results of this work to introduce a new class at CSU titled Engineering with Drones. The SfM portion of this class is a small but extremely useful example of the type of technology that can be adapted for use in inspecting and documenting time-depending structural damage.

North Dakota State University

The Northern Tribal Technical Assistance Program (Northern TTAP) provides transportation outreach and technical assistance to tribes across the Upper Great Plains and Intermountain West. The program works with American Indian tribal governments to build tribal capacity in program management, grow the tribal workforce, cultivate and coordinate partnerships, facilitate technology transfer and the implementation of innovations, and share results of similar initiatives across the country. (https://www.northernttap.org/)

South Dakota State University

Methodologies for clustering crashes and examining crash distributions, including the use of radial methods (akin to kernel density estimation [KDE]), elliptical (along the roadway network), and standard segment and point (intersection-based). The code was developed using one year of data but rerun for five years of data and—based on this—these methodologies. Analysis of the resulting clustering and preliminary crash distributions are well underway but still currently ongoing. These methods will be disseminated via a master's thesis (perhaps multiple theses) as well as planned paper submissions concerning the methods and results.

A new course CEE 792 Experimental Geomechanics was introduced where the curriculum includes the use of suction-controlled triaxial testing where graduate students get hands-on experience of using the advanced triaxial setup (offered in Spring 2024). A new course CEE 792 Soil Behavior was introduced where the curriculum includes the reasons for the adverse effects of using cement as a stabilizer for sulfate-rich expansive soils (offered in Fall 2023).

Utah State University

Proprietary commercial UHPC mixes are expensive, which limits their applications for building high performing transportation structures. Our study aims to develop and characterize non-proprietary UHPC mixes using readily available materials. However, there are several combinations of mixture proportions that could lead to formulating UHPC. A database on the previous non-proprietary UHPC mixes was developed by compiling 215 UHPC mixes extracted from 24 published manuscripts. Thereafter, machine learning models using recursive feature elimination (RFE) were applied to identify the critical mixture components that predict key performance properties of UHPC. This resulted in a conference paper published under DOI:10.21838/uhpc.16661 in June 2023. Currently, we have casted the selected mix proportions into UHPC specimens and are optimizing end conditions to attain the characteristic strength. The database is still being utilized for further studies and can be made available over email by request. The PhD student has completed developing and validating the finite element model (FEM) necessary for parametric analysis. The FEM model includes a single grouted sleeve splice (GSS) connection under static loads, which is used to characterize energy transfer at the interface of the GSS and the surrounding concrete. The student plans to use this validated model to investigate the lateral impact resistance of precast RC circular columns and seismic response of prefabricated RC piers after collision for studying the influence of various parameters (i.e., the location of GSSs in substructure connections, vehicle velocity, engine mass, vehicle mass, dimension of the cross-section, and concrete strength).

(4) Significant Outputs:

University of Wyoming

The passing zone study is complete. It resulted in producing an advanced system which will enable WYDOT to determine accurately passing and no passing zones on two lane highways.

4. Outcomes:

A summary of significant outcomes by selected members of the consortium universities during this reporting period are as follows:

Colorado State University

The projects at Colorado State University will have the following outcomes:

(1) Enhanced techniques of transportation infrastructures inspection and monitoring. For example, our studies investigated the level of accuracy that can be obtained by SfM models for material flaws such as cracks. Our work created a unique and valuable database of geotagged and labeled trios of visible, thermal, and fused images for training pothole detection algorithms; the work also resulted in a set of procedures for integrating images from multiple types of sensors to enhance accuracy and robustness of pavement distress assessment. We also developed an advanced dynamic displacement measurement technique using unmanned aerial vehicles (UAV), allowing simultaneous measurement of three components of bridge displacements.

(2) Increased understanding and modeling of transportation system performance against aging and natural hazards. For example, we provided non-homogenous Markov deterioration models that can better predict bridge conditions and capture the impact of various important factors (explanatory variables). We improved the current practice on long-term recovery planning such as prioritizing bridge renovation following earthquakes in a region. We increased understanding of material point method (MPM) models and their ability to represent the modeling of natural hazards.

(3) Increased understanding of transportation system performance in terms of fuel economy and safety. For example, we enhanced understanding of the role those uncertain predictions have in realizing predictive fuel economy optimal control. We also improved the understanding of how various messaging strategies and sign designs affect pedestrian interpretation of safe and permissible behaviors near railroad tracks.

(4) Improved performance and sustainability of material used in transportation infrastructure through the following: Improved material properties: We successfully demonstrated that thermal and mechanical beneficiation processes could enhance the fineness and reduce the carbon content of off-spec landfilled fly ash (LFAs), making them meet the ASTM C618 requirements. Enhanced durability and performance of concrete: We found that mortar samples incorporating beneficiated LFAs exhibited comparable or superior mechanical and durability performance to traditional ASTM C618-compliant fly ash. Sustainability in construction: By showcasing the potential of using reclaimed LFAs from landfills in concrete production, our study contributes to more sustainable construction practices.

(5) Increased understanding and awareness of transportation issues such as data quality and equity. We recognized the limitations of the data about bridge conditions available through the Long-Term Bridge Performance Program. We have identified ways to improve the dataset to be more useful. We tried to produce guidance that transportation asset managers can use to incorporate equity issues into asset management decision making.

North Dakota State University

The projects at North Dakota State University will lead to:

(1) Safety measures dedicated to AVs in mixed driver environments;

(2) Molecular interactions-microstructure-property relationship details for swelling clays that would lead to robust analysis;

(3) Cost-effective, sensor-based improvement to railroad track inspection efficiency and safety countermeasure selection;

(4) Sensor-based WIM pavement design complemented by AASHTOWare ME design;

(5) Subpopulation-based and individualized intervention in impaired driving and novice teen driver crash risk;

(6) Best practices approach for tribal communities and small local road departments to encourage safety integration into ongoing planning and investment decision processes;

(7) Personnel gaining information for greater understanding and knowledge on what is needed to pass CDL testing to contribute to the pool of CDL holders on our tribal nations;

(8) Greater workforce understanding and knowledge of what is needed to pass CDL testing to contribute to the pool of CDL holders among tribal nations;

(9) DOT adoption of AI-based methodology for traffic state estimates based on proposed AI-based methodology in vehicle trajectory reconstruction;

(10) Broadened understanding of potential impacts on the scope of autonomous aircraft cargo logistics, prospects for adoption, deployment challenges, and the potential implications for planners and policymakers;

(11) Increasing the body of knowledge and technical understanding of emerging drone technologies can improve the effectiveness and reduce the cost of transportation infrastructure, such as asset inspections, and how emerging cargo drone technologies could induce a mode shift away from surface transportation modes;

(12) Enhanced freight planning ability with the development of a GIS road and railroad network of the multistate corridor that can be used in scenario and planning research applications;

(13) Increased understanding and awareness of food insecurity among Native Americans living in North Dakota;

(14) Researchers and stakeholders will get to know and adopt the emergency response model that integrates connected and autonomous vehicle features.

South Dakota State University

The 13 active projects at SDSU will have the following outcomes: (1) improved understanding of the benefits of using cellulose nano-fibers in asphalt mixes; (2) better understanding of the structure of turbulent flow and induced bed shear stress around eroding soils; (3) improved understanding of the effectiveness of steel byproducts for bacteria removal from stormwater runoff; (4) better understanding of the effects of deicing agents on the durability of asphalt mixes; (5) adoption of sealants that delay deterioration of bridge decks; (6) development of an appropriate methodology for traffic safety network screening; (7) updated testing methodologies for in-situ acceptance of the compacted granular bases; (8) improved understanding of the effectiveness of nutrient removal from stormwater runoff using woodchips; (9) improved techniques using recycled Electrospun polyethylene terephthalate microfibers for characterization the asphalt binders; (10) better understanding of the potential effects of climate change on pavement infrastructure; (11) improved understanding of the velocity distribution and bed shear stress in free-surface flows at a sudden change in bed roughness; (12) improved understanding of over-embrittlement of asphalt mixes as a result of using reclaimed asphalt pavement by application of new rejuvenators; (13) and improved understanding of the treatment efficiencies of stormwater filters using steel byproducts under field conditions.

University of Colorado Denver

All of these projects made significant progress during the last project period, resulting in the publication of 17 journal papers (with three in review), six conference papers, six conference presentations, and a final report submitted. Moreover, the students working on these projects benefited greatly from the opportunity to engage in research and develop various research-related skills.

University of Denver

The projects at the University of Denver will have the following outcomes:

(1) Adoption of new technologies – validation of the Smartphone AlertMeter Fatigue Assessment Device for Transportation Workers has been used in several transportation settings. The technology will hopefully lead to a reduction in drowsy driving and fatigue and an increase in alertness and vigilance. Ultimately, the utilization of the device could lead to a reduction in accidents and injuries in the transportation system.

(2) Improved transportation practices influencing safety – the Safety Culture Assessment Survey identifies how best practices are effective in reducing accidents and injuries in various transportation/transit organizations. An online safety culture assessment has been posted on our website.

(3) Improved transportation practices influencing transportation effectiveness – the development of a safety leadership training model to improve safety culture will help transportation organization leaders demonstrate the behaviors and best practices that will lead to the development of an effective safety culture characterized by reduced numbers of accidents and injuries. Previous research has not specified to either safety organizations or transportation. Consequently, there is still a need to develop a standard model or approach to developing a safety culture within the transportation industry.

(4) Improved safety and awareness of transportation issues – suicide and trespasser fatality intervention training has led to significantly increased awareness, self-confidence, and skill in dealing with persons who might be at risk for intentional death using a railroad, or suicide by rail.

University of Utah

In the area of asphalt pavements, the body of knowledge was increased by developing a relationship that determines the dynamic modulus of asphalt mixtures, a key component in mechanistic structural pavement design, from simpler tests. This relationship is adopted and it improves the pavement design process.

In the geotechnical area, we will have the following outcomes: (1) making design and construction recommendations pertaining to the implementation of lightweight cellular concrete as an approach slab support system near bridges to reduce differential settlement; (2) change specifications to preclude the use of native materials in fills supporting roadway pavement systems that do not meet current requirements for granular borrow; (3) allow the use of multiaxial geogrid as an alternative to currently allowed biaxial geogrid within the pavement systems for new roadways; (4) changes to the software and guidelines used to design pavement systems bearing on soft subgrades.

In the structures area, we will have the following outcomes: (1) use of light, durable and corrosion-free fiberglass materials in the construction of bridge columns of bridges built using accelerated construction methods in seismic regions that will last for at least the design life of the bridge; (2) the research improved our understanding of self-centering posttensioned concrete columns reinforced with steel and glass fiber reinforced polymer bars and glass fiber reinforced spirals; these improvements and the numerical analysis tool developed promote corrosion resistant bridges in seismic regions; (3) increased knowledge to enable DOTs to develop a design method using numerical simulations for the retrofit of bridge decks with delamination issues to prolong the life of bridge decks constructed with partial depth panels.

In the transportation area, we will have the following outcomes: (1) enable transportation agencies to quickly screen local road networks for “problematic locations” of road segments and prioritize projects to improve safety levels and provide detailed information about safety rankings at each road segment, which allows traffic engineers to address the most common safety concerns around state roadways; (2) introduce a prototype artificial intelligence (AI) algorithm based on mobile-phone-based AI to identify trash and litter on the roadway; the algorithm realizes an accuracy of 85% for automatic identification of trash and litter on the roadway; (3) estimate the queue length and queuing time estimation using video processing; this study enables transportation agencies to quickly determine the class of vehicles, the queue length, and queuing time estimation with acceptable accuracy; (4) improve understanding of the multi-lane roadway slippery condition evaluation, which usually relies on expensive sensors and covers single spots; using dual-spectrum cameras we effectively quantified the snow-coverage ratio covering three lanes on Highway I-80; (5) develop a city-scale agent-based simulation that produces daily travel profiles using time-inhomogeneous Markov chain and location mapping techniques in combination with the American Time Use Survey (ATUS).

In the air transport area, we will have the following outcomes: (1) a web-based platform, the Utah Advanced Air Mobility Simulator (UAAMS), was developed to enable researchers, planners, and practitioners to record and update assumptions about the distribution of vertiports, traffic, population, and other requirements that may affect the operation of the transportation network for determining the efficient operation of drone delivery.

In the rail transport area, we will have the following outcomes: (1) through non-destructive evaluation, we found that piezoelectric elements can effectively promote and extract local resonances, including zero-group velocity and cut-off frequency resonances. We also achieved a better understanding of wave propagation and nondestructive evaluation for rail track structures, which can improve their inspection.

University of Wyoming

The passing zone study has been fully implemented by WYDOT, and the device developed in the study is being fully utilized by WYDOT and other agencies in the state. WYDOT nominated it as a high value research project for the AASHTO high value research program.

The snowplow study will result in developing a new warning system for snow plow drivers. Such system will enable snow plow drivers in taking actions to avoid rear end crashes with other drivers. The system should reduce the number as well as the severity of crashes involving snow plows.

The GSRS study has been completed and it will be utilized by WYDOT in establishing speed limits on downgrade roads in the state. These crashes have been on the rise since some unfamiliar truck drivers are more depending on Google maps in identifying short cuts which might include mountain passes.

Utah State University

The projects at Utah State University will have the following outcomes: (1) improved planning for the deployment of charging infrastructure for electric vehicles; (2) increased knowledge of travel behavior leading to reductions in air pollution in the state of Utah; (3) increased understanding of constructability and durability issues associated with embedded wireless charging systems in pavements; (4) improved traffic operations and improved adoption by transportation agencies related to autonomous vehicles; (5) improved adoption of electric buses; (6) improved understanding and possible adoption of fiber reinforced bridge decks; (7) increased safety at and cyclist perceptions of roundabouts; (8) improved safety for pedestrians at intersections; (9) increased understanding of the post-impact behavior of bridge pier couplers; (10) increased pool of educated transportation professionals and a better trained transportation workforce; (11) improved durability of charging infrastructure for the future of electrified transportation in the US; (12) The MPC report, "Calibrating Ground Response Analyses beneath an Instrumented Bridge Using the I-15 Borehole Array and Ground Motions from the Magna Earthquake;" (13) an improved understanding of crash data; (14) improved repair times for bridge decks in need of deck replacements; and (15) improvements in the fire behavior of polymer coated bridge decks.

5. Impacts:

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

Colorado State University

The projects at Colorado State University will have the following impacts:

(1) Advancing monitoring and inspection for transportation systems. Development of image libraries facilitates objective quantification of system changes over time, aiding inspection agencies in assessing the effectiveness of transportation materials and designs. The proposed displacement measurement techniques offer a convenient and cost-effective method for measuring displacement without interrupting traffic or requiring structure instrumentation.

(2) Enhancing maintenance and management of transportation systems. The developed deterioration models allow for more accurate prediction of bridge conditions, enabling tailored maintenance plans for each bridge. This leads to better preservation of bridges, reduced inspection costs, and improved decision-making for repairs and maintenance. Automated data collection and damage identification tools decrease the cost of road condition assessments, improving road safety by enabling timely repairs and reducing damage to vehicles. Incorporating beneficiated landfilled fly ashes (LFAs) improves resistance against various factors crucial for infrastructure durability, potentially leading to less maintenance-intensive roads, bridges, and other components.

(3) Improving resilience of transportation systems. Proposed methods optimize resources for recovery planning, focusing on community resilience and providing scientific indicators for processes like bridge repairs. Better modeling of natural hazards leads to modified design strategies, reducing closure times for remediation efforts and improving protection for transportation infrastructure. The improved methodology for testing and characterizing expansive soils and treatments enhances engineering design of transportation earthworks, leading to improved transportation system longevity and resilience against expansive soil behavior.

(4) Enhancing sustainability of transportation systems. Using LFAs from active landfills in concrete production provides a sustainable use for waste materials, reducing the environmental footprint associated with transportation system construction and maintenance. Comprehensive evaluation of material performance paves the way for increased use of thermomechanical beneficiated LFAs, potentially resulting in cost savings, enhanced sustainability, and improved performance across the transportation network.

(5) Improving equity in transportation systems. Incorporating equity considerations into asset management processes addresses existing inequities in the distribution of benefits and costs across different community members.

North Dakota State University

The projects at North Dakota State University will have the following impacts: Roadway-related impacts include: (1) Increased reliability for swelling clay predictive models. A coarse-grained clay model developed with a collaborator will be an important contribution to the geotechnical field. This technique will allow for upscaling of the clay models while maintaining the effect of the clay-fluid molecular interactions. This technique will be superior to the discrete element modeling for clays. (2) Improved knowledge on how environmental effects on WIM data assisted pavement

design planning for traffic impacts on pavement condition and greater awareness of WIM data quality issues. (3) Future transportation professionals were trained in machine learning algorithms and at-grade crossing safety performance evaluation while contributing knowledge regarding highway-rail grade crossing safety and countermeasure effectiveness. (4) Improved algorithm to enhance understanding of the mixed environment for human factors and the autonomous vehicle/smart infrastructure environment. (5) Reduced crash risk for native nations in training and utilization of traffic safety planning tools and countermeasure implementation and another showing parental engagement in driver safety conversations with teens when they understand heightened crash risk. (6) Enabling of rail rolling stock within the Internet-of-Things (IoT) as relevant in connected vehicle technology and big data processing. (7) The collaborative COVID-19 traffic investigation that proposed a new streaming learning model to significantly improve physics regularized Gaussian process training time, thus reducing the computational complexity while maintaining reliable and accurate prediction performance. (8) Greater insight for addressing food security inequities related to native nations' transportation issues.

South Dakota State University

The 13 active projects at SDSU will have the following anticipated impacts: (1) promote sustainable bio-materials and agricultural byproducts for the production of bio-asphalt binders; (2) improve laboratory techniques for measuring the critical shear stress in cohesive soils to better predict bridge scour; (3) develop a new filtration technology for stormwater runoff using steel byproducts; (4) improve the selection process of deicing agents; (5) recommend guidelines on bridge deck sealant applications; (6) develop a network screening method for improved safety remediation measures; (7) reduce the possibility of insufficient field soil compaction; (8) develop a new stormwater filtration technology using drinking water treatment residual coated woodchips; (9) develop a novel technique for recycling waste PET in asphalt mixes, addressing an important environmental challenge; (10) minimize repair and rehabilitation of pavement with expansive and unsaturated soil substrates, including climate change effects; (11) enhance prediction of sediment erosion and scour; (12) promote sustainability of pavement using reclaimed asphalt pavement; (13) and improve the management and quality of stormwater.

University of Colorado Denver

The 13 projects described cover a broad range of transportation system aspects—from improvements in route planning for ride sourcing, ridesharing, and fleet services—to research on cost-effective sensing devices for roadway condition monitoring, enhancements in bridge deterioration forecasting accuracy, and innovative methods to evaluate ADA compliance in pedestrian infrastructure. Together, these initiatives aim to enhance the efficiency of transportation services, reduce their environmental footprint, and improve the safety, accessibility, and cost-effectiveness of transportation infrastructure. Expected outcomes from these projects include the development of a more skilled workforce, safety enhancements, and cost reductions for transportation agencies.

University of Denver

The projects at the University of Denver will have the following impacts:

(1) Smartphone AlertMeter Fatigue Assessment Device for Transportation Workers (MPC-605) is being used in the operational environment to assess fatigue and alertness of operators and drivers before they begin operating vehicles, leading to a reduction in drowsy driving and fatigue and an increase in alertness and vigilance. Ultimately, the utilization of the device could lead to a reduction in accidents and injuries in the transportation system.

(2) Safety Culture Assessment Survey (MPC-532, 582, 604) – The SCAS has been used to improve the safety culture of several railroads. This includes the identification of linkages between safety culture, leadership, and fatigue in transportation operations and how best practices are effective in reducing accidents and injuries in various transportation/transit organizations. An online safety culture assessment has been posted on our website. Ultimately, the utilization of the survey will improve the overall effectiveness of the transportation system and lead to a reduction in accidents and injuries in the transportation system.

(3) The Safety Leadership Training Model (MPC-604) will aid transportation organization leaders in demonstrating the behaviors and best practices that will lead to the development of an effective safety culture characterized by reduced numbers of accidents and injuries. Ultimately, the utilization of the survey will improve the overall effectiveness of the transportation system and lead to a reduction in accidents and injuries.

(4) The Suicide and Trespasser Prevention Training (MPC-667) demonstrated a significant increase in awareness, self-confidence, and skill among railroad personnel in dealing with persons who might be at risk for intentional death using a railroad, or suicide by rail. As a result, there may be a reduction in trespass fatalities associated with intentional self-harm.

Ultimately, the training will improve the overall effectiveness of the transportation system by reducing fatalities and injuries due to trespassing on transportation system property.

University of Utah

The asphalt pavement projects will have the following impacts: (1) cost-effective testing will have a significant impact in the design of asphalt pavements by relating the properties of the materials used during design and actual materials used during construction; this allows for a complete life-cycle analysis that optimizes pavement performance.

The geotechnical projects will have the following impacts: (1) lightweight cellular concrete technology (LWCC) will be ready for implementation by Utah DOT; the first phase of this implementation will be a “demonstration” project where LWCC will be installed and monitored; (2) improved understanding of the influence of native subgrade and fill materials on the performance of pavement systems constructed on soft subgrades, which will result in roadway systems that perform better and require less long-term maintenance; (3) better understanding of the performance of pavement systems constructed on soft subgrades, both without and with geogrid reinforcement, which will result in roadway systems that perform better and require less long-term maintenance.

The structural projects will have the following impacts: (1) experimental and analytical research for improved corrosion resistance of both reinforced concrete and posttensioned columns of bridges using steel and glass fiber reinforced polymer bars and spirals, constructed in seismic regions, provides bridge owners the ability to extend bridge life to at least 75 years; (2) cost-effective strengthening procedures developed for partial-depth bridge decks that have suffered delamination will reduce the need for bridge deck replacement.

The transportation projects will have the following impacts: (1) extend and improve the knowledge of safety planners by providing a cost-effective and 80% accurate safety ranking system using automated image and video analysis; this impacts the public and private sectors by reducing the number of accidents and the spending of federal tax dollars; (2) data collection and artificial intelligence to improve our capability for automatic detection of pavement marking issues and automatic identification of trash and litter on the roads, thus enhancing automation of highway maintenance; (3) cost-effective evaluation of multi-lane roadway slippery conditions, which has been a long-standing challenge; sensing technology using infrared thermography is capable of multi-lane roadway snow coverage evaluation, which improves winter safety of connected vehicles; (4) deep learning techniques for image understanding in computer vision provide transportation agencies with great opportunities to automatically determine the queue length and queuing time estimation in highway on-ramps; using these data, we will design a signal timing that would help the traffic management team maintain the flow of traffic in the mainline and ensure that no vehicle on the ramp will face more delays than the standard threshold; (5) the electric vehicle supply equipment (EVSE) allocation problem is addressed to alleviate range anxiety, the top concern for EV purchasers; by improving the operational efficiency of public charging facilities, we will increase revenue of EVSE providers and benefit government infrastructure planning.

The air transport projects will have the following impacts: (1) a web-based platform is developed that produces a statewide airspace network, delivery schedule, and truck/drone fleet mix; a greater understanding of the impact of such a model to determine whether it is more costly or more energy efficient compared with the current truck-only delivery model; this provides clarity about the energy impact of large-scale drone delivery and a viable airspace network.

The rail transport project will have the following impacts: (1) resonant frequencies of local vibrational modes, which are dependent on the geometry and mechanical properties of waveguide structures such as rails; the capability of extracting intrinsic local resonances has a strong impact on nondestructive evaluation and structural health monitoring of railway structures.

University of Wyoming

The benefit of the passing zone project can be identified through two parts.

(1) The data can be collected by two transportation professionals instead of four. This would result in reducing the labor cost by half. Assuming that the reduction in labor cost is the equivalent of one full-time position, the savings would be around $100,000 per year over the expected service life of 10 years. The total savings is around $1,000,000.

(2) The data collected with the developed device will be consistent and more accurate across the entire state, which should result in satisfying the expectations of the drivers. As a result, passing zones on two-lane highways will be safer. Even if only one fatal crash was prevented each year as a result of having accurate passing zones, the savings in crash costs would be about $4,000,000 per year. Over 10 years, the savings in crash costs would be $40,000,000. Considering that the cost of developing the passing zone device was less than $200,000, the expected benefit is significantly higher

than the cost. If other DOTs would begin implementing the developed system, then the benefit would be even higher nationwide.

The snowplow study will result in reducing rear end crashes involving snowplows. Such crashes have been on the rise in Wyoming. The developed technology will provide snow plow drivers with the warning so that they can avoid crashes in the future. The developed system will be presented in May of 2024 to the WYDOT Safety group so that they would adopt it for implementation.

The feasibility study for a pavement test track in Wyoming resulted in recommending the construction of the facility due to its cost effectiveness and potential benefits to Wyoming as well as all other states in the dry freeze region. WYDOT is looking into the potential of implementing the findings after identifying potential sources of funding.

Utah State University

The projects at Utah State University will have the following impacts on the effectiveness of the transportation system: (1) reduced petroleum consumption and reduced local emissions; (2) reduced freight transportation costs; (3) increased durability of electrified infrastructure; (4) improved transportation agency decision-making regarding data collection and management from EVs, and improved air quality through investigating and altering traveler behavior; (5) equitable deployment of both plug-in charging stations and wireless charging lanes; (6) possibly enabling the reduction of required seismic design forces; and (7) improved preparation for traveling in areas of wildfires and winter inversions. Several of these projects provide the groundwork for the increased adoption of electrified vehicles as well as the adoption of autonomous transportation in the near future. The use of fiber reinforced concrete for bridge decks will improve durability and therefore make the transportation system more effective.

B. What is the impact of your university's MPC research on the adoption of new practices and cases where a technology or process has been commercialized?

Colorado State University

The projects at Colorado State University will have the following impacts:

(1) Advancing monitoring and inspection for transportation systems. Faster assessment through structure-from-motion (SfM) technology offers a more efficient alternative to manual inspections, potentially leading to automated inspection systems, saving time and resources. UAV-based technology provides three-component displacement measurement, potentially aiding modal/load testing in practice. Airborne prototype sensing systems providing three-component displacement measurements could be commercialized and adopted by practitioners, offering new solutions for displacement measurement. Leveraging detailed bridge inspection data for predicting the condition of similar bridges enhances the cost-effectiveness of in-depth inspection methods, potentially improving bridge safety.

(2) Enhancing maintenance and management of transportation systems. Adoption of developed deterioration models enhances bridge safety and facilitates more cost-effective maintenance decisions by providing accurate deterioration predictions tailored to individual bridges. The developed automated tools will facilitate fast and cost-effective road condition assessment, replacing labor-intensive practices with machine learning-based assessments, reducing time and costs. Dissemination of research results aims to improve signage near railroad tracks, enhancing safety for pedestrians and cyclists.

(3) Improving resilience of transportation systems. New recovery planning methods help state DOTs in planning bridge repairs and recovery efforts more efficiently, optimizing resource allocation.

(4) Improving vehicle performance and traffic management. State-of-the-art vehicle powertrain optimization methods improve local vehicle control and coordination with traffic management systems (TMS), benefiting automotive manufacturers and enhancing vehicle performance. Research on turbulent wind field dynamics around high-profile vehicles informs best practices for extreme wind conditions, potentially leading to improved travel advisories.

(5) Improving design and/or modeling of transportation infrastructure. Introduction of the material point method (MPM) as an alternative to the finite element method expands practitioners' toolkits for modeling transportation infrastructure, potentially offering more accurate solutions for certain types of problems. Improved methods for analyzing expansive soils aim to mitigate the $13 billion annual damage to U.S. infrastructure, including transportation networks, by providing better data for designing engineering solutions.

North Dakota State University

One of the critical outcomes of the work at NDSU has been developing techniques to conduct nanoindentation on wet and dry clays. Experiments at this length scale on wet clays have not been previously reported. Since these experiments probe the length scale (micrometer to nanometers), which has been shown to significantly affect the engineering properties of clays, this work provides a new characterization technique that can be used in geotechnical engineering practice.

Sensor- and drone-related investigations are also underway with the state of good repair focus. Work produced a new optical sensor interrogator, which is capable of collecting data from 24 sensors simultaneously for an enhanced weigh-in-motion (WIM) perspective, and data collected on concrete roads is expected to estimate vehicle weight with high accuracy. Drone investigations promote the likelihood for industries to adopt drone-based inspection technologies based on the research findings.

Network management during a crisis supports the TIM agencies' adoption of our prediction model developed in collaboration with NDSU. Considering a pandemic's impact and resulting change in traffic patterns, the model assists the detour/divert operation's decision-making process when a traffic incident occurs.

Related specifically to tribal communities, NDSU supported efforts related to driver shortages and CDL training equity. Training sessions held in collaboration with MHA Nation and NDLTAP created awareness of what transportation training can accomplish in areas of need such as on tribal lands. The impact on new drivers with their CDL and how more CDL holders can help roadways and other areas of need in native nations. Recent activities are building knowledge for tribal governments, BIA, and NDDOT to better understand the gaps in transportation to give tribes better food access that will, in many cases, have a CMV aspect.

Work with crash factors and locations will enable decision-makers to make better-informed resource and policy decisions relating to highway-rail grade crossings, rail monitoring, teen drivers, and impaired driving prevention.

South Dakota State University

The 13 active projects at SDSU will have the following expected impacts: (1) promote the use of sustainable bio-materials and agricultural byproducts for production of bio-asphalt binders; (2) predict soil critical shear stress and erosion rates in cohesive soils; (3) reduce the bacteria contamination caused by stormwater runoff; (4) implement pavement condition-specific deicing materials; (5) reduce rapid deterioration of bridge deck sealants; (6) codify a methodology for traffic safety network screening; (7) develop a quick and efficient practice for evaluation of the field compaction quality; (8) develop a new filtration technology for stormwater treatment; (9) develop a post-processing method for waste plastic to be used as asphalt materials; (10) effective and resilient design of embankments and pavements on sulfate-rich expansive soil; (11) improve the estimation accuracy of bed shear stress, thus improving estimation of soil erosion rates; (12) develop new recycling practices using sustainable recycling agents; (13) and application of E. coli removal using steel byproduct filtration for stormwater treatment.

University of Colorado Denver

The outlined projects demonstrate significant advancements in transportation, influencing new practices and commercialization potential. MPC-585 integrates optimal route planning into NREL's Hive platform, enhancing network efficiency and supporting various agencies. MPC-612 impacts state DOT practices by adopting cost-effective roadway condition reporting, improving budget allocation. Advanced material technologies from MPC-613 and deep learning tools developed in MPC-616 and MPC-650 are utilized by CDOT, with potential wider adoption and commercialization. MPC-647 influences safer urban design, while MPC-649 aims to establish health and productivity benchmarks, potentially leading to commercial early warning systems.

University of Denver

The projects at the University of Denver will have the following impacts on adoption of new practices and new technologies:

(1) Smartphone AlertMeter Fatigue Assessment Device for Transportation Workers (MPC-605) has been adopted; it is being used in the operational environment to assess fatigue and alertness of operators and drivers before they begin operating vehicles, leading to a reduction in drowsy driving and fatigue and an increase in alertness and vigilance.

(2) Safety Culture Assessment Survey (MPC-532, 582, 605) – The SCAS has been adopted and used by several railroad and transit agencies to improve the safety culture of several railroads.

(3) The Safety Leadership Training Model (MPC-604) has been adopted by three different agencies and will aid leaders of transportation organizations in demonstrating the behaviors and best practices that will lead to the development of an effective safety culture characterized by reduced numbers of accidents and injuries.

University of Utah

The asphalt pavement project has developed testing and analysis methods which can be used by both material and pavement engineers in the design of flexible pavements. Currently, these professionals do not share existing methods, however, this research should enable system optimization.

The geotechnical projects will assist DOT project personnel in implementing technologies that reduce differential settlement at bridge approaches; this will improve the safety and transport of people and goods on roadways. In addition, better design and construction guidelines for both unreinforced and geogrid-supported pavement systems will result in wider use of this technology within roadway systems as designed by all pavement designers.

The structural projects will improve seismic resilience of new bridges by using fiberglass materials that do not corrode and have excellent structural performance during strong earthquakes; the research has shown that the seismic performance of bridge columns constructed with a combination of steel and glass fiber reinforced polymer bars and spirals is equivalent to that of all-steel reinforced columns. In another project related to strengthening of bridge decks built with partial-depth precast deck panels, the experimental and analytical methods developed in the research will be implemented in an actual bridge by the Utah DOT in the near future.

One transportation project has developed a method that provides a multi-lane snow coverage ratio by combining both optical and thermal images that convert the roadway snow coverage ratio to a recommended safe driving speed; the safety message is communicated with local infrastructure for improved winter roadway safety. The Utah DOT is interested in mobile-phone-based artificial intelligence for maintenance asset management; a computer-vision-based system for safety ranking of rural roadways has been developed and it is anticipated that safety planners will adopt the developed technology for the safety evaluation of rural roadways. This technique could transform existing highway maintenance practices, which rely on manual efforts by maintenance workers, to automatic identification using artificial intelligence, which will alleviate the burden in daily maintenance. In a project regarding safety assessments of rural roadways using automated image and video analysis, automatic detection and rating of unsafe conditions have been developed; this is cost-effective and efficient compared with manual inspection or LiDAR technology. The process of automatically detecting and tracking the vehicle class, queuing time, and queue length on access ramps is developed in another project. The final product is a Python script that applies image processing and computer vision to obtain data for ramp meter signal design; this economical approach that uses existing traffic cameras to estimate the system's performance and is able to count and track vehicles and detect the speed, exit rate, and entry rate of vehicles. Another project builds a pipeline of data preparation and leverages Multi-agent Transport Simulation, an open-source framework for implementing large-scale agent-based transport simulation, together with road networks, to return optimal travel plans for all drivers.

The air transport project has implemented and deployed the Utah Advanced Air Mobility Simulator successfully; this tool incorporates the latest software and infrastructure techniques and has demonstrated the impacts of advanced air mobility on communities (e.g., environmental) by using micro-simulation technology.

The rail transport project has developed rail inspection based on ultrasound and eddy current; this inspection will be conducted once a year at Utah Transit Authority (UTA) sites, where fractured rails were detected between annual inspections; this will contribute to cost-effective full rail cross-section rail inspection and enable condition-based maintenance.

Utah State University

The projects at Utah State University will have the following impacts on the adoption of new practices and process commercialization: (1) the use of electrified infrastructure will change the way electricity is delivered into vehicles; (2) development of effective strategies for travel demand management surrounding episodic air pollution events; and (3) adoption of proposed partial depth bridge deck replacements, which will speed up and simplify bridge repairs. Governments and organizations can utilize these behavior change strategies for dealing with the negative impacts of air pollution.

C. What is the impact on the body of scientific knowledge?

Colorado State University

The projects at Colorado State University will have the following impacts:

(1) Advancing monitoring, inspection, maintenance, and management for transportation systems. While imaging technology itself is well-developed, the study focuses on refining and combining it with other methods to enhance infrastructure inspection, contributing to ongoing advancements in imaging applications. The project innovates by leveraging machine learning to automate road inspection and maintenance tasks, particularly enhancing damage identification accuracy through novel algorithms. The study introduces a new experimental methodology for measuring moisture-dependent behavior in expansive soils, enhancing understanding and aiding in the development of stabilization technologies. The proposed technique for three-component displacement measurement using UAVs advances existing methods, offering more comprehensive dynamic response data for structures. The proposed technique advances dynamic displacement measurement by simultaneously measuring structure displacement and UAV motion in a mathematically elegant manner. The study advances bridge deterioration modeling by accounting for variations in bridge conditions, environment, and deterioration rates, leading to more accurate predictions and better bridge management and preservation.

(2) Improving resilience of transportation systems. Investigating the impacts of long-term recovery efforts broadens understanding, which is potentially applicable beyond earthquakes, and enhances resilience planning.

(3) Improving vehicle performance and traffic management. The study identifies the role of uncertainty in predictive vehicle trajectory on powertrain control efficacy, providing insights crucial for optimizing fuel economy. The project contributes to safety assessment and policy guidance for managing traffic during adverse weather, addressing a critical gap in transportation management. The project framework enhances understanding of the public's traffic sign perceptions, applicable beyond railroad signage, contributing to improved signage design and communication strategies.

(4) Improving analysis and/or modeling of transportation infrastructure. Exploring multi-fidelity modeling barriers in bridge engineering contributes to understanding its applicability in this context, enriching knowledge in structural modeling methodologies. By applying analysis methods to various natural hazard effects on transportation infrastructure, the study explores both known and understudied phenomena, enriching understanding in this domain.

(5) Enhancing sustainability of transportation systems. Detailed insights into beneficiation processes improve understanding of how they enhance material properties, contributing to sustainable construction practices. Comprehensive assessment of concrete incorporating beneficiated LFAs contributes valuable data to the scientific literature, informing future engineering practices for more durable and sustainable infrastructure.

(6) Improving equity in transportation systems. This study addresses the underexplored aspect of equity in transportation asset management, enriching knowledge in transportation planning and management.

North Dakota State University

NDSU's state of good repair research outcomes thus far indicate that interactions between clays and fluids control mechanical properties and need to be incorporated in the analysis and design of transportation systems built on swelling clays. New experimental techniques developed to target swelling clays will help better characterize swelling clays. In addition, new findings regarding sensor technology and drone use will enhance asset monitoring and planning activities.

Safety and economic competitiveness work by NDSU have produced a better understanding of the effect of considering both crash frequency and crash severity on the risk assessment or ranking of at-grade crossings applying detailed spatial analysis. Freight modeling methods employed advanced freight modeling techniques above the assignment of observed flows, allowing researchers to forecast impacts into the future. In addition, linking freight flows to specific segments allows for further research into the impacts of changes in modal shares on existing infrastructure.

Increased understanding of drone capabilities such as freight delivery, asset monitoring, and driverless vehicle function in rural and tribal environments is anticipated. The use of AI in data collection and processing is featured in several projects. The contribution will be primarily in efficiently gathering data, processing information streams, and producing AI-assisted decision support related to rural transportation environments and issues. A model to consider the impacts of evolving vehicle technology in emergency response was created and shared with researchers and practitioners for adoption and future research.

South Dakota State University

The 13 active projects at SDSU will have the following expected impacts: (1) added knowledge in the field of biomaterials and the use of environmentally friendly and renewable fuel resources; (2) better understanding of the critical shear stress and erosion rates in different clay soils and sand-clay mixtures; (3) added new knowledge on bacteria adsorption by steel byproducts and the long-term bacteria removal from stormwater; (4) addition of new knowledge on the effects of chemicals used in deicing agents on asphalt; (5) added knowledge on the effectiveness of various concrete bridge deck sealants for preventing water and chloride infiltration; (6) expanded the knowledge on traffic safety screening methodologies; (7) expanded the knowledge on soil compaction testing methodologies; (8) added new data on nutrient removal by water treatment residual coated woodchips; (9) characterization of Electrospun PET microfiber used in asphalt binder; (10) highlighting the impacts of climate change on the transportation infrastructure in this region with sulfate-rich expansive soil substrates; (11) generation of new experimental data on flow velocity profile and bed shear stress at smooth-to-rough and rough-to-smooth bed transitions in subcritical and supercritical flows; (12) generation of a new experimental database on asphalt binders and mixes using asphalt recycling agents; (13) and added knowledge on the performance of a pilot scale filter in field treatment conditions.

University of Colorado Denver

Our projects are making significant contributions to the body of scientific knowledge across various transportation domains. MPC-585, for example, pioneers a system-optimal route planning approach, setting new pathways for transportation problem-solving. MPC-612 and MPC-613 advance infrastructure monitoring and structural engineering through innovative datasets and composite material studies. MPC-614, MPC-647, and MPC-678 reveal critical insights into infrastructure navigation challenges, systemic factors in vehicle-pedestrian crashes, and gaps in ADA compliance, respectively, influencing design and policy improvements. MPC-616 and MPC-650 introduce groundbreaking deep learning techniques for predictive bridge management, potentially revolutionizing infrastructure maintenance. MPC-649, MPC-675, and MPC-676 develop methods to optimize construction worker health and infrastructure life-cycle costs, enhancing economic efficiency. MPC-677 provides a systematic analysis of paratransit inefficiencies, suggesting significant overhauls.

University of Denver

The projects at the University of Denver will have the following impacts on the body of scientific knowledge by:

(1) Increasing our understanding of safety culture's role in fatigue management, which can have a is a direct impact on reducing accidents, injuries, and associated expenditures.

(2) Contributing a standardized model for the training of leaders intending to implement and develop a safety culture in a transportation organization, which will provide a basis for testing the most effective approaches for undertaking organizational change.

(3) Contributing to the concurrent and predictive validity and accuracy of a mobile-based assessment tool for detecting fatigue in vehicle operators.

(4) Increasing our understanding of how-to best train people to deal with trespassers and those at risk for suicide by railroad.

(5) Increasing the understanding of secondary trauma or post-traumatic stress symptomatology and sequalae associated with the repeated exposure to railroad trespass fatalities or railroad trespasser suicides.

University of Utah

The asphalt pavement project has produced a better understanding of the relationship between different tests of asphalt mixtures; this insight, based on conservation of energy, could change the way structural pavement design is conducted by incorporating actual materials rather than default values or national averages.

One of the geotechnical projects has determined the fundamental material behavior of lightweight cellular concrete (LWCC) under static and cyclic loading at varying amounts of saturation; this will be used to better plan, design, and construct LWCC embankments in bridge approach areas. Two geotechnical projects will likely improve the base of knowledge within the civil engineering field with respect to the economical design of pavement systems both with and without geogrid reinforcement.

The structural projects will improve seismic resilience of bridges by increasing the body of knowledge regarding seismic performance of concrete columns reinforced with a combination of steel and glass fiber reinforced polymer bars and spirals; in addition, the projects have contributed to the development of materials and methods for constructing such

bridges using accelerated bridge construction. A method for strengthening partial depth prestressed concrete panels for bridge decks has been developed in another structural project; the numerical models for the original deck and the strengthened deck improved the body of knowledge in determining the performance of actual bridge decks.

The transportation projects advance the use of artificial intelligence (AI) algorithms to support automated infrastructure management, especially for auto-identification of trash and litter; although the development is not fully complete, the customized AI algorithm shows promising results in automatic identification of trash and litter under practical situations. In another project, new knowledge on connected vehicles using infrared thermography has produced the technical expertise on effective winter roadway safety using a low-cost dual-spectrum imager; this will contribute to new knowledge on winter roadway safety for connected vehicles. In addition, a computer-vision-based system for the safety ranking of rural roadways has been developed; by leveraging computer vision and machine learning, transportation agencies can efficiently and accurately identify and address safety concerns on rural roadways, ultimately leading to safer roads and fewer crashes. Another project will inform UDOT's long-range transportation plans regarding efforts by the auto industry, coupled with initiatives at federal and state levels, to promote EV adoption; the research will result in greater certainty surrounding infrastructure planning for such aggressive EV adoption and could be used to understand future capacity needs. Better understanding of computer vision techniques and their application in traffic management were developed in another project; simulation-based models were used to estimate the ramp performance; this is an efficient approach that uses computer vision and video-based processing models, which provide a complete framework to extract and analyze data, determine the exit rate, and provide signal phase suggestions to the traffic management team.

University of Wyoming

The passing zone study resulted in a one-of-a-kind device, which has been described in technical papers.

Utah State University

The projects at Utah State University will have the following impacts on the body of scientific knowledge: (1) Many of the projects at USU have as their goal to determine ways to improve the transportation system and the environment. Much of the work is directed at improving our living environment. (2) The project which is profiling the sub-surface soil beneath an I-15 structure will be used to generate the only known large-scale, 3D shear wave velocity model beneath an instrumented bridge in the U.S. When combined with the ground motions and dynamic response recorded by the Magna earthquake, this will be a unique and invaluable resource for seismic site response and soil-structure interaction studies. (3) The knowledge gained about the performance of polymer under high temperatures will add to the body of scientific knowledge. (4) Another project will provide an infrastructure-based alternative solution to promote autonomous driving.

D. What is the impact on transportation workforce development?

Colorado State University

The projects at Colorado State University will have the following impacts:

(1) Graduate student support and educational enhancement. The projects provide support for graduate students to develop expertise in transportation-related fields, enhancing their academic and practical skills. Involvement in cutting-edge research projects enhances graduate students' educational experience, providing practical skills and knowledge beyond traditional classroom learning. The research findings support students in expanding their dissertation work, contributing to their academic and research development. Students receive training in specialized techniques such as computational fluid dynamics, material point method, and data handling, expanding their skill set and knowledge base.

(2) Undergraduate exposure to emerging technologies. Undergraduate students are exposed to emerging technologies like structure-from-motion (SfM) methodologies and drones, providing them with valuable experience and potentially inspiring further exploration in these areas.

(3) University course offerings. The project contributes to workforce development by offering specialized engineering courses, such as the Material Point Method Engineering with Drones, providing students with unique learning opportunities.

(4) Preparation for diverse career paths. The comprehensive training prepares students for diverse career paths within the transportation sector, including roles in civil engineering, materials science, environmental sustainability, and infrastructure management. Participation in the project offers graduate students the opportunities for internships, research training, and specialization in areas like bridge inspection techniques, vehicle powertrain optimization, and traffic safety, enhancing their readiness for future careers in the transportation sector.

(5) Enhanced expertise in asset management and equity. The project supports students in gaining expertise in asset management and equity in transportation, enriching their understanding of these critical aspects of the field.

North Dakota State University

The projects at North Dakota State University will impact transportation workforce development with the following: (1) workforce trained in AV, smart infrastructure, and mixed-driver environment safety; (2) course development and new workforce training in swelling clay research experiments; (3) new workforce development with graduate student training in machine learning models in traffic safety analysis. Traffic forecasting techniques and project efficacy techniques related to evolving vehicle technology; (4) existing workforce contributions with improved tribal and local road manager access to pragmatic and relevant safety investment data and tools; (5) increased awareness of individualized driver improvement countermeasures and their integration as data-driven approaches among traffic safety workforce professionals; (6) support to tribal communities in heavy equipment and CMV driver workforce attraction, development and retention, and community accessibility challenges; and (7) graduate student experience with GIS modeling, including TransCAD© and TransModeler© software applications.

South Dakota State University

Seven PhD, 21 master's, and three undergraduate students have been trained through transportation-related research activities planned in the SDSU projects. The students have been encouraged to work in transportation agencies or private firms working on transportation projects.

University of Colorado Denver

The CU Denver projects significantly impact transportation workforce development by providing extensive training and research opportunities across various aspects of transportation engineering and management. MPC-585, MPC-612, MPC-613, and MPC-616 focus on training students in data-driven techniques, system-optimal route planning, and the use of sensing technologies. These students are equipped to handle advanced transportation system challenges, contributing to workforce development in system optimization and infrastructure monitoring.

University of Denver

The projects at the University of Denver will have the following impacts on the transportation workforce development:

(1) Training four graduates in the research process, including literature review, data collection and analysis, Using Excel and SPSS, and report writing.

(2) Assisting safety managers at two railroads, who were given information on how to improve their safety culture.

(3) Providing useful information and training models to transportation organization leaders and managers for improving their safety culture and leadership development.

(4) Managers at several trucking companies received information about how to manage fatigue levels as a result of this project.

University of Utah

The asphalt pavement project will have the following impacts: Two graduate students have received training in the use of mechanistic-empirical pavement design software; one of them joined the workforce during this period.

The geotechnical projects will have the following impacts: The research provides support for graduate student researchers who study geotechnologies applied to transportation systems; the research methodologies and results are being used in course materials. Moreover, the research has provided exposure to many aspects of the transportation field to five graduate students who have worked on the geotechnical projects; as this research gets disseminated through workshops and publications and incorporated into coursework, many practitioners and students will be exposed to the outcomes and the importance of transportation systems to our everyday lives.

In one structural project, the research has provided opportunities to improve the skills of a doctoral student from an underrepresented group in transportation and expose a master's student to transportation-related research in the structure's laboratory. In another project, two doctoral students and one master's student developed analytical skills that will enable them to find employment in the transportation industry. Another structural project improved the skills of one master's and one doctoral student in the structures laboratory by getting them involved in bridge-related research; the experimental portion of the research was developed in collaboration with the Utah DOT, and the numerical analysis portion was developed to expand the applicability of the retrofit technique to different scenarios.

The transportation projects will have the following impacts: One project involved two doctoral students in research regarding automated identification of trash and litter on roadways; it prepared graduate students with hand-on experience in developing computer vision and machine learning algorithms, and closely collaborating with industry partners (Utah DOT) in the development process. In another project, students took an active role in advancing transportation safety through hands-on involvement; graduate students developed software to support model development, while undergraduates were responsible for data labeling; the potential for collaboration between academia and industry in advancing transportation safety is evident, and engaging students in real-world safety evaluation tasks can help develop the next generation of transportation safety professionals while making meaningful progress toward safer roads for everyone. Two doctoral students were heavily involved in another project, which will serve as the basis for their dissertation work; the principal investigator is offering a graduate course on "Traffic Operations Analysis," and the agent-based modeling technique developed in the project is incorporated in the course to teach students practical skills on agent-based simulation. In another project, graduate students received research training, wrote computer scripts using MATLAB, and learned the theory and methods of machine learning and computer vision. Another project involved a group of graduate and undergraduate students for data collection purposes; the graduate students were involved in model development software packages, and undergraduate students were mostly involved with data labeling; this increases their knowledge and the opportunity to find good well-paying jobs in the transportation industry; moreover, the disseminated educational materials will be significantly useful for both skilled and novice engineers when performing traffic management and analysis.

University of Wyoming

All research studies performed at UW have been presented to WYDOT professionals and some local transportation professionals, enhancing their understanding of our work. In addition, some of the findings of UW studies have been incorporated into undergraduate and graduate courses.

Utah State University

The projects at Utah State University will have the following impacts on transportation workforce development: (1) inform the many students involved in performing the research; (2) influence many undergraduates to study transportation as a career due to the exposure to so many interesting projects. USU's projects are having a broad impact on students as well as those who learn about the projects. Additionally, the transportation workforce is impacted by the many short courses and training modules provided by Utah's LTAP center located at USU. The number of people involved in these events is presented in the section on workforce development.

E. Address any significant impacts.

University of Denver

The projects at the University of Denver have had the most significant impact in the adoption of the AlertMeter (MPC-605) and also in the utilization and adoption of the Safety Culture assessment survey (MPC-532, 582, 604).

University of Utah

The asphalt pavement project has produced a better understanding of the relationship between different tests of asphalt mixtures; this insight could change the way structural pavement design is conducted by incorporating actual materials rather than default values or national averages. The structural projects improve seismic resilience of bridges by increasing the body of knowledge regarding seismic performance of concrete columns reinforced with a combination of steel and glass fiber reinforced polymer bars and spirals; in addition, the projects have contributed to the development of materials and methods for constructing such bridges using accelerated bridge construction. In a transportation project, new knowledge on connected vehicles using infrared thermography has produced the technical expertise on effective winter roadway safety using a low-cost dual-spectrum imager; this will contribute to new knowledge on winter roadway safety for connected vehicles. In addition, a computer-vision-based system for the safety ranking of rural roadways has been developed; by leveraging computer vision and machine learning, transportation agencies can efficiently and accurately identify and address safety concerns on rural roadways, ultimately leading to safer roads and fewer crashes.

Utah State University

USU's work in electrified transportation spans many disciplines of transportation. Many researchers are working in this area including from the perspective of system optimization, infrastructure durability, and the sub-surface characterization of soil. Also, the work on pedestrian safety at roundabouts will inform future transportation officials about design and utilization.

6. Changes/Problems:

Colorado State University

Only one project reported changes, as described below.

MPC-538: In March 2020, long duration testing was terminated before the end of the experiments due to the COVID-19 pandemic and the mandatory ceasing of all non-essential laboratory tests at Colorado State University on March 23, 2020. Given their size, rerunning all tests was not possible with the project's budget. Unfortunately, analysis of the test data from terminated tests revealed that the initial iteration of the testing methodology was unsuccessful at generating necessary data for model calibration and validation.

South Dakota State University

The PI of one active project (MPC-626), Dr. Seo, passed away in September 2022. Dr. Ghabchi has agreed to continue MPC-626 as the new PI. Some changes have been reported in four projects due to material shortages, test setup limitations, and/or global supply chain issues. However, all PIs have reported reasonable progress and with no significant delays. All projects will be completed in this reporting period.

Utah State University

Lingering problems related to delays in projects can still be attributed to laboratory delays due to the covid shutdowns. Some difficulties in finishing projects are related to the support of personnel and students during the covid shutdown that now results in lack of funding to support additional students to complete the delayed work.

7. Special Reporting Requirements:

T2 Performance Measures and Targets are listed in Appendix E.