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Research and Technology
University Transportation Center Grant Agreement

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Mountain-Plains Consortium, North Dakota State University
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Semi-Annual Progress Report #15-Final

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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. 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, **154 transportation and transportation-related courses** were offered this reporting period, for a **total of 1,901 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, **80 training sessions** were offered during this reporting period for a **total of 1001 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 8,106 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?

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 **85 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**
  - Joeseph Podolsky, MnRoad, Minnesota DOT
  - Larissa Young, Standing Rock Sioux Tribe, Road Department Planning
- **University of Colorado Denver**
  - Chengbo Ai, University of Massachusetts, Amherst
- **University of Utah**
  - 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 **75 peer-reviewed articles or papers** in scientific, technical, or professional journals. Since the beginning of this grant, **we have published 703** different peer-reviewed articles or papers.

B. Conference papers can be found in Appendix D

This reporting period **we have published 9 conference papers and 258 total since the grant began**.

C. Presentations can be found in Appendix D

MPC faculty and investigators **have presented at 22 different** scientific, technical, or professional conference this period. In total, we have **had 382 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: This project has allowed the development of a graduate-level class CIVE 581: The Material Point Method. This is currently being taught for the second time in the Fall of 2024. This project has allowed the development of ENGR 480A1, Engineering with Drones.

University of Utah: Analytical finite element models of the bridge deck in the as-built and repaired conditions were produced. These models are going to be shared in an upcoming journal publication, which will be submitted in October 2024. Analytical models for representing the compressive and tensile performance of GFRP bars and spirals, including the effects of bond slip and intentional debonding, were developed in OpenSees. The analytical models will be shared in an upcoming journal paper currently under review by the Journal of Composites in Construction, ASCE.

Utah State University: A preliminary release of the dataset for MPC-559 "Investigating travel behavior and air quality in Northern Utah" was made available. https://doi.org/10.5281/zenodo.11640319

A database on the previous non-proprietary UHPC mixes was developed by compiling 215 UHPC mixes extracted from 24 published manuscripts. The database is still being utilized for further studies and can be made available through email by request.

(4) Significant Outputs:

University of Colorado Denver: This period included a significant number of papers and presentations at a wide variety of outlets as well as the submission of eight final reports.

University of Utah: The development of analytical models for columns in seismic regions constructed with hybrid reinforcement in the form of glass fiber reinforced polymer bars as well as spirals and steel bars is important for adoption of such columns in areas with corrosion issues; these areas include coastal regions and regions where de-icing salts are used on bridges. A project on a microscopic approach for determining electric vehicle demand estimation is significant in that it is a precursor to electric vehicle adoption and widespread acceptance. To that end, an agent-based model has been developed to estimate daily activities of all drivers within a study region, as well as the charging demand and charging rules. A project studying the feasibility of promoting local rail vibrations using the electromechanical impedance method has been completed. This project is significant regarding the safety of the railway system. A data collection system using the electromechanical impedance method has been developed and the technology was validated using actual rail samples.

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 CSU projects will have the following outcomes: (1) improved processes and technologies for infrastructure monitoring and predictive maintenance; (2) increased understanding of social equity in transportation asset management; (3) development of more sustainable construction materials; and (4) enhanced safety and disaster resilience in transportation systems. Research efforts in unmanned aerial vehicle (UAV)-based sensing systems and non-contact measurement techniques are advancing monitoring capabilities, making structural assessments more precise and efficient. Predictive models, such as non-homogeneous Markov and Gaussian process regression models, are improving the ability to forecast infrastructure deterioration, leading to more proactive maintenance practices. The integration of 2D imaging and structure-from-motion methods further reduces inspection time and enhances the prioritization of repairs, ensuring better resource allocation for infrastructure management. Insights from the study on equity in asset management will likely shape future decision-making frameworks, leading to more inclusive practices across transportation agencies. The use of thermo-mechanical beneficiation on fly ash is expected to promote environmentally friendly construction practices by converting waste materials into valuable cementitious components. Moreover, research on hazard modeling using the material point method (MPM) will inform better design codes for infrastructure, ultimately enhancing resilience to natural disasters. Through these combined efforts, our projects are contributing to advancements in sustainability, safety, and equity in transportation systems.

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 relationships provide detail for swelling clays that would lead to robust analysis with results offering a glimpse into the mechanisms that shape the mechanical response of the hydrated aggregates.
3) Cost-effective, sensor-based improvements to railroad track inspection efficiency and safety countermeasure selection.
4) Extensive simulations and field experiments with WIM data collected via sensors, demonstrating their efficacy in enhancing pavement performance prediction and vehicle weight monitoring aimed at real-world applicability, scalability, and integration with existing infrastructure for broader adoption that led to more resilient and efficient road networks.
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 and supporting data collection technologies and supplemental methods.
7) Personnel gained information allowing them 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 of the scope of autonomous aircraft cargo logistics, prospects for adoption, deployment challenges, and the potential implications for planners and policymaking.
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.
12) Framework for local planners to use in planning and prioritizing investments on unpaved roads where the resulting model will be useful to policymakers as it can be utilized to demonstrate the benefits of investment in low-volume unpaved roads.
13) Archetypal multistate, multimodal corridor planning and simulation tool that advances the state of modeling and practice; advanced spatial analysis techniques necessary to build detailed multimodal corridor models; a food and logistics model with widespread uses beyond corridor analysis.
14) Better understanding and knowledge about the administrative requirements of the BIA Road Maintenance Program, including funding, project eligibility, right-of-way issues, and reporting requirements.
15) Increased understanding and awareness of food insecurity and food desert concepts among Native Americans living in North Dakota.

South Dakota State University

The five active projects at SDSU will have the following outcomes: adoption of sealants that delay deterioration of bridge decks, development of an appropriate methodology for traffic safety network screening, improved understanding of the effectiveness of nutrient removal from stormwater runoff using woodchips, improved understanding of over-embrittlement of asphalt mix as a result of using reclaimed asphalt pavement by application of new rejuvenators, 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 substantial progress in the last project period, leading to the publication of 11 journal papers (with one under review), seven conference presentations, and the submission of eight final reports. Additionally, the students involved gained valuable experience, honing a range of research-related skills through their participation.

University of Denver

1) Adoption of new technologies. The validation of Smartphone AlertMeter Fatigue Assessment Device for Transportation Workers has been used in several transportation settings. We hope this technology will 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 crashes and injuries in the transportation system.
2) Improved transportation practices influencing safety. Use of the Safety Culture Assessment Survey identifies how best practices are effective in reducing crashes and injuries in various transportation/transit organizations. An online safety culture assessment has been posted on our web site.
3) Improved transportation practices influencing transportation effectiveness. The development of a Safety Leadership Training Model to Improve Safety Culture 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 crashes and injuries. Previous research has not been specific to either safety organizations or transportation. Consequently, there is still an apparent 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 significant increases in 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 and their cracking tolerance, a key component in mechanistic structural pavement design, from simpler tests. This allows for a simplified method to obtain the inputs needed for the mechanistic-empirical pavement design method and improves the pavement design process.

In the geotechnical area we will have the following outcomes: (1) Make design and construction recommendations pertaining to the implementation of lightweight cellular concrete as an approach slab support system near bridges to reduce differential settlement; predictive models were suggested for preliminary engineering estimations. (2) Provide state DOTs with enhanced methods to predict the settlement or heave of approach embankments, thereby allowing them better ways to ensure that bumps at the ends of bridges are minimized; it is likely that specifications for approach embankment materials will be improved for state DOTs. (3) Improve the software used to design pavement systems bearing on soft subgrades; additional geogrid or geogrid-like materials will be identified that will be equivalent to the standard biaxial geogrid used to reinforce pavement systems bearing on soft subgrades.

In the structures area we will have the following outcomes: (1) numerical modeling tools will promote the use of light, durable and corrosion-free fiberglass materials in the construction of bridge columns in seismic regions; (2) 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) Introduce a prototype artificial intelligence algorithm based on mobile-phone-based artificial intelligence to automatically identify transportation assets of interest. This facilitates the transportation asset management practice to become automated, and UDOT is considering the method for practical implementation. (2) The ability to model the spatiotemporal distribution of public charging electric vehicle demand estimation in a bottom-up fashion and provide practical support for future public electrical vehicle supply equipment installation. (3) It is expected that the use of infrared thermography technology will improve winter roadway safety for commercial vehicles.

In the rail transport area, we will have the following outcome: through non-destructive evaluation we have improved understanding of non-propagating waves in rails using piezoelectric elements, which can improve rail inspection.

University of Wyoming

The final reports for all MPC projects—except for one—have been successfully completed and have been published. The findings of these MPC projects have been presented at professional meetings and some of the recommendations in these reports have been adopted by WYDOT. The CTIPS projects have just started. We are in the process of hiring graduate students and collecting data for these projects.

Utah State University

Outcomes and expected outcomes of USU research projects during this period include the following: (1) We expect production of an optimization framework to deploy dynamic charging lanes for plug-in hybrid electric trucks (PHETs) in an electrified road freight transportation system. The research findings will not only have theoretical significance but also offer a wide range of applications for implementing more sustainable road freight transportation systems. (2) Through our analysis of traveler behavior data, our research increases understanding and knowledge about how people and their travel patterns respond to and perceive changes in air quality. (3) We produced an optimization framework for simultaneously determining the deployment of fast-charging stations, the battery capacities of battery-electric busses (BEBs), and BEB recharging scheduling for a fast-charging BEB system. The research findings offer a wide range of applications for implementing more sustainable public transportation systems. The end product is useful to public transit agencies for the development of cost-effective and sustainable BEB systems. (4) Concrete panel modeling showed that the combined stresses from traffic loads and thermal loads did not exceed the capacity of the reinforced concrete section, leading to similar systems being deployed in pilot projects. (5) Providing pedestrian safety analysis methods have improved upon existing practices, particularly with using pedestrian exposure measures at signalized intersections. Making use of more detailed local data can generate more useful models that can consider a wider range of potential safety countermeasures and treatments. Additionally, state and local agencies could make use of pedestrian signal data for performance measures tracking pedestrian intersection crashes/fatalities at different walking activity levels: low, medium, and high pedestrian volume intersections. (6) Our work provided an increased understanding of the performance of grouted column coupler connections under static and dynamic loading with the coupler located in both the footing and column. (7) Our efforts furthered the ongoing discussions of the government's involvement in promoting autonomous driving. The end product is useful for transportation agencies evaluating their infrastructure investment of deploying automated roads. (8) We produced an advanced modeling framework for the equitable and efficient deployment of wireless charging lanes. The results may facilitate government decisions regarding the allocation of funds to equitably deploy charging lanes, thus increasing people's acceptance in transforming the transportation network into an emissions-free system. (9) We increased understanding of the current state of crash reporting, particularly in regard to the reporting of AV-involved crashes. Some indirect outcomes may be the passage of new policies in various states to account for AVs in crash reporting so as to better understand their safety impact. (10) We determined an understanding that delay time and sustainability of partial depth concrete bridge repair can be improved by increasing the number of saw-cut lines and reducing the amount of jackhammering. (11) Our research increased the understanding of how wildfire smoke and other air quality issues affect traveler behaviors. (12) We made suggestions for improvements in how polymer concrete bridge deck overlays are made. (13) We anticipated new knowledge about the influences on pedestrian safety and traffic operations around transit stops located near intersections. (14) We accomplished the first non-proprietary UHPC mix sourced with locally available materials for Utah-based transportation projects. In addition to mechanical properties such as compressive strength and modulus of elasticity, this project has ensured that these mix designs are also durable and have limited volumetric change. (15) Our research led to increased understanding of how grouted coupler connections respond to high-velocity impacts and their residual seismic capacity. The validated finite element (FE) models developed in the study have enhanced the body of knowledge by providing accurate simulations of stress distributions, failure modes, and crack development in precast columns. These models are crucial in understanding the dynamic behavior of coupler/rebar connections and their resilience after impact loading, contributing valuable insights for safer bridge design using accelerated bridge construction (ABC) techniques. The project's findings have also contributed to improved processes in evaluating the residual capacity of bridge piers after impact events. By incorporating sequential impact and seismic loading protocols, the research has demonstrated the variations in performance between different column configurations, such as those with grouted splice sleeves, compared with cast-in-place columns.

Moreover, the research described above has influenced the enlargement of the pool of trained transportation professionals. The graduate students and researchers involved in these projects have gained advanced skills in numerical modeling, the application of FE methods, data processing, and skills that will enhance their capability to address complex transportation challenges in their future careers.

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 on effectiveness of the transportation system: (1) improved durability and sustainability of transportation infrastructure; (2) enhanced safety, resilience, and equity in transportation systems; and (3) more efficient and cost-effective maintenance and management practices.

By enhancing the properties of landfilled fly ash (LFA) through thermo-mechanical beneficiation, stronger concrete infrastructure can be produced, reducing repair needs and extending service life. This will lead to more sustainable roads and bridges, improving system efficiency. Research on pedestrian safety near railways will reduce train-pedestrian conflicts through better signage and crossing infrastructure, enhancing public safety. Innovations in road maintenance tools will automate damage detection and reduce the cost of data collection, improving road safety by enabling faster repairs of potholes and other hazards.

Advanced modeling techniques, such as the material point method (MPM), will improve the design of structures to withstand real-world environmental forces. Long-term recovery planning methods will help optimize limited resources, prioritizing essential repairs after disasters to strengthen community resilience. Efforts to integrate equity into transportation asset management will promote fairer access to transportation services and more inclusive planning. Portable, non-intrusive techniques for measuring bridge displacement will streamline maintenance without disrupting traffic, while new deterioration models will improve inspection schedules and maintenance planning, ensuring long-term preservation. Additionally, co-optimization of vehicle control and traffic management systems will enhance fuel efficiency, demonstrating a 5% improvement in fuel economy while reducing emissions. These combined efforts will significantly enhance the effectiveness, sustainability, and safety of the transportation system.

North Dakota State University

The impacts of NDSU's roadway-related projects include the following: (1) Increased reliability for swelling clay predictive models. A coarse-grained model of clay that has been developed with a collaborator will be an important contribution to the geotechnical field. This technique will allow for upscaling 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, resulting in dependable designs for transportation infrastructure in areas with swelling clay. (2) Improved knowledge on how environmental effects on WIM data-assisted pavement design planning for traffic impacts on pavement conditions and greater awareness of WIM data quality issues. (3) Future transportation professionals 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 algorithms to improve understanding of the mixed environment for human factors and autonomous vehicle/smart infrastructure environment. (5) Reduced crash risk for (i) Native Nations in training and utilization of traffic safety planning tools and countermeasure implementation, and (ii) teen drivers in parental engagement in driver safety during novice driving experiences. (8) Enabling rail rolling stock within the Internet-of-Things (IoT) as relevant in connected vehicle technology and big data processing. (9) The collaborative COVID-19 traffic investigation 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. (10) Insight for addressing food security inequities as they relate to Tribal Nations transportation issues. (11) A major impact resulted from an investment assessment for improved active transport for a Tribal Nation, with a bid to be completed for a project identified in collaboration with NDSU-UGPTI and the Tribal Nation to improve community walk/bike path associated with the local wellness center. (12) Improved decision-making for very low-volume unpaved roads or potential conversion of those roads to paved surfaces as crucial routes to safe mobility and social connectivity in highly rural areas with oft-disadvantaged populations. (13) Ability to simulate of highway and railroad capacity restrictions on the cost and reliability of freight flows, trip times, trip time reliability, and other performance metrics germane to economic competitiveness. (14) The need to develop Tribe-specific policies, procedures, and standards for their Road Maintenance Program. (15) Elevated understanding of the need for curriculum and training material for Tribes on the federal regulations and standards for specific transportation program topics and activities, including right-of-way acquisition and management, financial management, project management, equipment acquisition, inventory and asset management, and procurement contract development and management for engineering planning, design, and construction services.

South Dakota State University

The five active projects at SDSU will have the following anticipated impacts: recommend guidelines on bridge deck sealant applications, develop a network screening method for an improved safety remediation measure, develop a new stormwater filtration technology using drinking water treatment residual coated woodchips, promote sustainability of pavement using reclaimed asphalt pavement, and improve the management and quality of stormwater.

University of Colorado Denver

These research projects delivered tangible benefits to society by addressing critical aspects of the transportation system. For instance, the project on optimizing route planning for ride sourcing, ridesharing, and fleet services (MPC-585) directly reduces travel times for both customers and drivers, cutting fuel consumption and lowering emissions. This not only makes trips more affordable and efficient but also contributes to environmental sustainability by shrinking the carbon footprint of these services. Along the same lines, the development of low-cost sensors for monitoring roadway conditions (MPC-612) enables quicker identification and repair of pavement issues, which minimizes traffic disruptions, enhances safety, and extends the lifespan of roadways, reducing the need for costly overhauls.

In bridge management, the research on improving bridge deterioration forecasting (MPC-616) equips transportation agencies with more accurate tools, allowing them to better prioritize maintenance, prevent failures, and reduce fatalities. This is crucial, as bridge collapses or failures can result in catastrophic economic and human losses. Moreover, the study on left-turning vehicle-pedestrian collisions (MPC-647) addresses a major safety issue at intersections, with the goal of reducing these systematic crashes. The research can lead to redesigned intersections and better signal timing, ultimately making streets safer for pedestrians and encouraging more walking and bicycling, which also supports environmental goals by promoting sustainable transportation.

The project on paratransit services (MPC-677) highlights the inefficiencies in time compared with standard automobile travel, bringing attention to the need for better transportation solutions for people with disabilities. Addressing this gap will help public transit agencies improve the quality of service, making transportation more equitable. Lastly, by assessing ADA compliance in pedestrian infrastructure (MPC-678), researchers provide cities with tools to ensure sidewalks are accessible to all, fostering more inclusive, pedestrian-friendly environments that encourage active transportation and enhance quality of life. Overall, these projects support a safer, more efficient, and equitable transportation system with wide-ranging benefits for society.

University of Denver

1) The 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. This has led 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 crashes 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. In particular has been the identification of linkages between safety culture, leadership, and fatigue in transportation operations and how best practices are effective in reducing crashes and injuries in various transportation/transit organizations. An online safety culture assessment has been posted on our web site. Ultimately, the utilization of the survey will improve the overall effectiveness of the transportation system by reducing crashes 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 crashes and injuries. Ultimately, the utilization of the survey will improve the overall effectiveness of the transportation system and lead to a reduction in crashes 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 the transportation system.

5) Impact of Rail Trespasser Fatalities & Suicide on Mental Health and Safety (MPC-691). It is expected that the results of the study will lead to increased awareness, preparedness, and prevention activities by existing transportation employees. Increased use of available resources could result in reduced absenteeism due to stress and anxiety related to experiences with railroad trespassing and fatalities.

University of Utah

The asphalt pavement projects will have the following impacts: approximating design parameters using a commonly used test that also relates to the mix design process allows for the integration of structural pavement design and materials and cost-effective analysis of designs.

The geotechnical projects will have the following impacts: (1) Lightweight cellular concrete technology will be ready for implementation by UDOT. The first phase will be a "demonstration" project where the lightweight cellular concrete will be installed and monitored. (2) A significant reduction of settlement/heave of approach embankments for bridges, thereby mitigating problems with bumps at the ends of newly constructed bridges. (3) A better understanding of the performance of pavement systems constructed on soft subgrades, both without and with geogrid reinforcement 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 bridge columns using steel and glass fiber reinforced polymer bars and spirals, constructed in seismic regions, provide bridge owners the ability to extend their life to at least 75 years since glass fiber reinforced polymer materials do not corrode. (2) Cost-effective strengthening procedures developed for partial-depth bridge decks that have suffered delamination will improve their condition, extend their lifespan, and reduce the need for bridge deck replacement.

The transportation projects will have the following impacts: (1) The algorithm developed for this project demonstrates the potential to fully automate the transportation asset collection process, including pavement conditions, striping and signing, barriers and guardrails, as well as trash and litter on the road. (2) Existing coverage of fast charging stations in the Salt Lake City metropolitan area is highly insufficient and agencies should incentivize fast-charging station deployment. Low utility efficiency is identified at several charging stations and a decentralized design can effectively augment EV drivers' accessibility to the nearest stations. Atypical activities at airports and stadiums could impact public charging demand. (3) Infrared thermography can improve the effectiveness of the transportation system with the participation of intelligent infrastructure and connected vehicles. The project leverages existing UDOT efforts on connected vehicles and extends these efforts by focusing on winter safety.

The rail transport project will have the following impact: improved effectiveness of rail and transit systems by enabling condition-based maintenance rather than time-based or age-based approaches.

University of Wyoming

The device developed in MPC-600 has been fully implemented by WYDOT and used on multiple roads to establish passing and no-passing zones on two-lane highways. MPC-633 identified the feasibility of establishing a regional road track for the dry freeze region, and it is up to WYDOT to identify the next move.

Utah State University

Projects conducted by USU researchers have and will impact the effectiveness of the transportation system by: (1) Significantly reducing petroleum consumption and local emissions, which improves the environmental sustainability of road freight transportation and the livability of communities around logistics centers. Furthermore, an electrified road freight transportation system can reduce freight transportation costs, which in turn supports the economic competitiveness of a region. (2) Providing effective strategies for travel demand management surrounding episodic air pollution events. (3) Making public transportation more cost-effective and sustainable, thereby improving its service quality and mode share, which will help to reduce traffic congestion and support regional economic competitiveness. (4) Providing systems for dynamic wireless power transfer that can accommodate high thermal loads in pavement, which is essential to efficiently operating smart highway segments. (5) Enriching the transportation planning process and contributing to improved planning outcomes, particularly for active transportation and pedestrian planning. Many planning tasks require (or would benefit from) estimates of walking activity for various locations in the multimodal transportation network: prioritizing off-street infrastructure or sidewalk infill projects, planning for Safe Routes to School, considering crossing treatments, etc.

By developing direct-demand models that use pedestrian signal data, this project creates validated methods for estimating pedestrian volumes at signalized and unsignalized intersections. These are particularly useful for state and local agencies' transportation planning efforts. (6) Helping state DOTs set their design standards for the location of grouted coupler connections in ABC bridge pier construction. The results show that impact to this type of coupler reduces its capacity to withstand future loading due to fracture of the grout in the coupler. This negative impact can be offset by locating the coupler in the footing. (7) Producing an advanced modeling framework for the planning and evaluation of an infrastructure-enabled autonomous driving system. The modeling framework can help transportation agencies mitigate traffic congestion and support regional economic competitiveness. (8) The efficient deployment of wireless charging lanes. Governments can introduce EVs as means of sustainability since they potentially incorporate renewable energy into the sources of energy used in the transportation sector. Deploying wireless charging lanes offers tremendous potential in promoting the adoption of EVs. As a result, the proposed modeling framework can help government agencies maintain a clean society while benefiting from low-cost renewable energy sources. Furthermore, the proposed project can render communities more livable by improving air quality and helping to ensure the environment is clean and emissions-free. (9) Improving the effectiveness of collecting AV crash data and conducting large-scale AV safety analyses. (10) Helping state DOTs write their construction specifications for partial depth concrete bridge deck removal. (11) Providing U.S. transportation agencies, the information necessary to manage infrastructure operations and to prepare for and mitigate any traffic impacts and mode shifts due to smoke from wildfires, wintertime inversions, and other area-wide pollution events. (12) Helping state DOTs understand the impact of vehicle fires on concrete pavements that have been treated with a polymer concrete overlay. (13) Improving our understanding of pedestrian safety and operations around transit stops near intersections. This research could inform transit agencies and local/state transportation departments about where to locate transit stops and how to operate intersections in such a way to improve safety and operations. (14) Providing an optimized non-proprietary UHPC mix developed in this study, resulting in a higher performing material for UDOT that not only saves money but performs as needed for the structure's service life. The development of a non-proprietary UHPC mix for UDOT will decrease construction costs associated with using UHPC and will also allow for UHPC to be more widely used. (15) Demonstrating a significant potential to improve the effectiveness of transportation infrastructure by enhancing the resilience of precast columns with grouted splice sleeve (GSS) connectors used in accelerated bridge construction (ABC). The FE simulations indicate that GSS-C columns experience 10% to 15% less cracking and displacement compared with CIP columns under similar impact conditions. This reduction in damage translates to fewer necessary repairs and extended service life of impacted structures. Additionally, by using GSS connectors, bridges are projected to withstand impacts from vehicles weighing up to 0.9 tons at speeds of up to 22 mph, which exceeds the performance of traditional CIP columns. These findings can have a direct positive impact on the transportation system by reducing the frequency and cost of bridge repairs following accidents or natural disasters. For example, bridges using GSS-C columns may see a 25% reduction in repair costs due to improved damage resistance, as the columns maintain better post-impact integrity. This improvement in durability will lead to fewer road closures and disruptions, enhancing the overall efficiency of the transportation system.

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 CSU projects will have the following impacts on the adoption of new practices and commercialization of technologies: (1) promoting sustainable construction materials and practices and fuel economy; (2) encouraging adoption of new technologies for infrastructure monitoring and assessment; and (3) improving decision-making regarding infrastructure maintenance and management in transportation agencies through improved tools and strategies.

Thermo-mechanical beneficiation of landfilled fly ash (LFA) is expected to promote sustainable practices by encouraging their use as cementitious materials in concrete production, with the potential to drive the development of new commercial technologies for LFA processing. Vehicle powertrain optimization methods are likely to be adopted by automotive manufacturers, contributing to better control algorithms and improved fuel economy. Automated road condition assessment tools could be adopted by CDOT and other agencies to reduce the time and cost of maintenance data collection, improving efficiency with machine learning-based assessments. New sensing technologies, such as unmanned aerial vehicle (UAV)-based displacement measurement systems, have strong potential for commercialization and practical application in structural testing. In addition, efforts to streamline imaging tools for infrastructure inspection may encourage software developers to integrate these methods into self-contained structural analysis platforms.

The development of advanced deterioration models will help agencies adopt risk-informed maintenance strategies, leading to more precise inspection schedules and cost-effective bridge management. The long-term recovery planning tools could become valuable resources for state DOTs, helping them prioritize bridge repairs more effectively after disasters.

The project outcomes shared with the Long-Term Bridge Performance Program are expected to improve data collection practices for bridges, ensuring more effective use of non-destructive evaluation data in future maintenance efforts. Research on social equity in transportation asset management will contribute to National Cooperative Highway Research Program efforts, supporting agencies in integrating equity into their decision-making frameworks. Findings from studies on aerodynamic forces on vehicles may inform travel advisories under extreme wind conditions, thereby enhancing safety.

North Dakota State University

One of the critical outcomes of this 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 affect the engineering properties of clays significantly, this work provides a new characterization technique that can be used in geotechnical engineering practice. Current soil mechanics theories, which are used to predict engineering properties, overlook the significance of clay-fluid molecular interactions, rendering them less reliable. This research will contribute to creating more robust theories that can accurately forecast engineering properties.

Sensor and drone related investigations are also underway with the state of good repair focus. Work produced a new optical sensor interrogator is capable of collecting data from 24 sensors simultaneously for an enhanced weigh-in-motion (WIM) perspective, and data collected on concrete roads are 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. Findings with the WIM sensor investigation underscore the significant impact of overweight vehicles on pavement deterioration and the superiority of advanced predictive models, which have been disseminated through journal publications and conference presentations, promoting further adoption and refinement of the technology.

Network management during crises supports TIM agencies' adoption of our prediction model developed in a collaboration between NDSU and considering the pandemic’s impact and change on traffic patterns, and to make a detour/divert operation decision when a traffic incident occurs considering the changed traffic patterns resulting from the pandemic.

Related specifically to Tribal communities, NDSU supported efforts related to driver shortages and CDL training equity. Trainings 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 is on new drivers with their CDLs and how more CDL holders can help roadways and other areas of need in Tribal communities. Recent activities have built knowledge for Tribal governments, BIA, and NDDOT to better understand the gaps in transportation to help Tribes gain better access to food that will, in many cases, have a CMV aspect. We anticipate continued opportunities to gain experience and transfer knowledge with Tribal communities for low-cost safety network screening and safety planning tools.

Work with crash factors and locations will enable decision-makers to make better-informed resource and policy decisions related to highway-rail grade crossings, rail monitoring, teen drivers, and impaired driving prevention for rural and Tribal roads. In addition, system preservation decision tools were improved with Tribes providing a template for creating a Tribal Road Maintenance Policies and Procedures document based on the BIA Manual. This work often focuses on rural roads that will benefit from a model that can be implemented to link life-cycle cost analysis with a benefit-cost framework to analyze the costs and benefits associated with unpaved roads under varying traffic levels. As traffic levels increase, a life-cycle cost analysis may justify an improvement that would upgrade roadway conditions or convert an unpaved roadway to a paved roadway, including a comparison of user costs as a result of roadway type and condition.

South Dakota State University

The five active projects at SDSU will have the following expected impacts on the adoption of new practices: reducing rapid deterioration of bridge deck sealants, codifying a methodology for traffic safety network screening, developing new filtration technology for stormwater treatment, developing new recycling practices using sustainable recycling agents, and application of E. coli removal using steel byproduct filtration for stormwater treatment.

University of Colorado Denver

These projects have significant potential for advancing new practices and technologies in transportation. The route planning methods from MPC-585 are integrated into NREL's Hive platform, offering agencies tools to optimize transportation networks, reduce emissions, and support economic growth. MPC-612 introduces low-cost sensors for automated road condition monitoring, helping municipalities reduce costs, improve road maintenance, and enhance safety.

MPC-616 and MPC-650 have developed predictive models for bridge deterioration, already available to CDOT, with plans to commercialize these tools for proactive maintenance, accident prevention, and cost reduction. MPC-647 promotes safer intersection designs to reduce pedestrian-vehicle collisions, encouraging cities to prioritize pedestrian safety and sustainable mobility.

MPC-649 applies machine learning to improve construction worker safety, offering a pilot for safety monitoring in transportation projects. MPC-675 provides new rating methods for timber bridges, helping transportation agencies manage deteriorating structures more effectively.

MPC-676 optimizes infrastructure maintenance, reducing costs and improving sustainability. MPC-677 aims to spark long-term discussions to improve paratransit services for people with disabilities. MPC-678 pushes for data-driven sidewalk management, promoting ADA compliance, safety, and accessibility while addressing equity in underserved neighborhoods.

University of Denver

1) The Smartphone AlertMeter Fatigue Assessment Device for Transportation Workers (MPC-605) has been adopted and 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) The Safety Culture Assessment Survey (MPC-532, 582, 604) 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 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 crashes and injuries.
4) The Trespasser and Suicide Prevention Training for Rail Transportation Workers (MPC-667) has been used by several different transportation agencies. It is anticipated that the training and development activities and content will be widely adopted by transportation companies throughout the country. These results may lead to improved working conditions and a more productive workforce.

University of Utah

The asphalt pavement project has developed testing and analysis methods, which can be used in the design of flexible pavements; the project resulted in a practical way to approximate inputs needed for pavement design. Due to the complexity in obtaining the actual measurements of the parameters, many highway agencies were using national averages or default values, which resulted in over-designed or under-designed pavement structures and limited innovation. This research greatly improved the process.

The geotechnical projects will assist DOT project personnel in implementing technologies that reduce differential settlement at bridge approaches. Methods to estimate the pavement’s service life sensitivity to material properties and variations, including average annual daily traffic and equivalent single axle load, could formally be evaluated. These evaluations will provide the probability of failure during the desired service life of the pavement system. It is expected that material and construction specifications for approach embankments for bridges will be revised by UDOT and other public agencies. In addition, research on geogrid-reinforced systems on soft subgrades will result in better methods of design and analysis of both unreinforced and geogrid-reinforced pavement systems within Utah and surrounding states.

The structural projects will improve seismic resilience of new bridges by using glass fiber reinforced polymer composite materials that do not corrode and have excellent structural performance during 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. The knowledge gained from this research will enable DOT personnel to design bridge columns in seismic regions that will last for more than 75 years without corrosion issues.

In another project related to strengthening of bridge decks built with partial-depth precast deck panels, the experimental and analytical methods developed have been adopted by UDOT and are being implemented in the field.

The transportation projects will improve the following areas: (1) In transportation asset management, the transportation asset information collection process has previously relied on manual efforts or equipment such as LiDAR. Artificial intelligence algorithms open up new opportunities with lightweight equipment (such as cameras and mobile phones) for UDOT to transform the way it collects transportation asset information. (2) In electric vehicle demand estimation, the developed methodology addresses the oversimplification and limitations in the literature by utilizing a high-fidelity city-scale road network, incorporating drivers' non-work-based activities, and applying real-world electrical vehicle distribution to develop a charging demand estimation model. (3) In connected vehicle winter safety, the project team worked closely with UDOT's weather group to explore different sensors and systems for improved measurement accuracy as an alternative to the existing road weather information systems.

The rail transport project has developed a rail inspection method based on ultrasound and eddy current. The ultrasonic non-propagating modes knowledge will be used for inspection and nondestructive evaluation, which has the potential for expanding to rail and transit networks.

University of Wyoming

The device developed in MPC-600 has been fully implemented by WYDOT.

Utah State University

Projects conducted by USU researchers have and will impact the adoption of new practices and facilitated technology or processes that have been commercialized by the following: (1) Developing sustainable road freight transport systems. (2) Suggesting effective strategies for travel demand management surrounding episodic air pollution events. Governments and organizations can utilize these behavior change-strategies for dealing with the negative impacts of air pollution. (3) Providing wireless power transfer solutions in the concrete, which will lead to higher adoption rates for these systems. (4) Generating innovations that are implementable by state departments of transportation or other agencies, including an online tool to visualize estimated pedestrian volumes at intersections, and pedestrian SPF and CMFs at intersections for highway safety analysis. (5) Providing relevant supporting research for the adoption of ABC grouted coupler connections providing enhanced protection of bridge piers. (6) Providing state transportation agencies and legislatures with best practices, common definitions, etc. regarding AV crash reporting found via this project. (7) Showing that more discretized saw cut lines should be used rather than large area jackhammering. (8) Providing estimates of the exposure of various road users to air pollution and any corresponding human health impacts. This project also developed several open-source data processing and analysis scripts that will be shared with the research community. (9) Showing what the footprint area of polymer concrete is like after being subjected to a vehicle fire, and discussing methods for both rehabilitation and improved usage. (10) By improving our understanding of pedestrian safety and operations around transit stops near intersections, this research could inform transit agencies and local/state transportation departments about where to locate transit stops and how to operate intersections in such a way to improve safety and operations. (11) Developing non-proprietary UHPC mix along with its characterization data that will be used to prepare a UDOT standard for the design and placement of non-proprietary UHPC mixes with locally sourced materials. (12) Significantly impacting both commercial technology and public use by informing government and industry practices. The validated finite element models for precast columns with grouted splice sleeve (GSS) connectors under impact and seismic loads provide critical data that transportation agencies, such as those in Utah and California, could adopt to enhance the resilience of bridges built using accelerated bridge construction (ABC) techniques. These insights will help standardize the evaluation of structural integrity and improve public safety. The research also opens avenues for the commercialization of enhanced GSS connectors. Industry partners, particularly in the precast construction sector, could use the findings to develop and market advanced GSS systems, leading to broader industry adoption of these resilient designs. Additionally, contractors and engineers can incorporate the study's insights into construction practices, improving durability and reducing maintenance costs for transportation infrastructure.

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

Colorado State University

The CSU projects will have the following impacts on the body of scientific knowledge: (1) advancement in sustainable construction techniques and material science; (2) contributions to equity in transportation asset management; (3)

development of new tools and frameworks for infrastructure monitoring, safety, and resilience; and (4) improvements in predictive modeling and machine learning applications.

Research on thermo-mechanical beneficiation deepens the understanding of how modified landfilled fly ash (LFA) enhances cementitious applications, offering new directions for sustainable construction. The findings provide a foundation for optimizing the use of waste materials in concrete production, helping to address environmental challenges through innovative material science. Studies on social equity in transportation asset management contribute to bridging the knowledge gap in equitable planning and resource distribution. Research on pedestrian-railway safety offers novel survey frameworks for evaluating signage, providing tools applicable across various transportation contexts. The development of dual-stereo vision systems and unmanned aerial vehicle (UAV)-based displacement measurement techniques advances the field of structural monitoring, offering new methods to capture dynamic responses with greater precision. Work on vehicle safety under extreme weather conditions provides insights that can guide policy and improve traffic management. Research on recovery planning enhances understanding of long-term resilience, with potential applications beyond earthquake recovery. The application of the material point method (MPM) contributes to structural engineering by refining analysis tools and addressing challenges related to convergence and accuracy. The combination of structure-from-motion with finite element analysis offers a forward-looking methodology that will continue to improve as imaging and computing technologies advance.

Machine learning algorithms developed for road maintenance offer new methods for damage identification by leveraging both RGB and thermal imagery, improving accuracy under challenging conditions. Gaussian process regression applications introduce new modeling approaches for bridge deterioration, contributing to predictive infrastructure management. The advanced bridge deterioration models offer more accurate predictions of individual bridge conditions, ensuring better maintenance and preservation strategies. Research on predictive uncertainty and powertrain control provides insights into the relationship between real-time prediction and fuel economy, supporting the development of more efficient vehicle control systems.

Collectively, these projects are making significant contributions to transportation research and practice by expanding knowledge, refining methodologies, and introducing innovative tools and processes.

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. Newly developed experimental techniques that 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. Specifically, 1) the nanomechanical properties of saturated swelling clays for different degrees of swelling have been reported for the first time; 2) the first clay tactoid molecular dynamic simulations have been reported; and 3) the mechanisms that affect the compressibility and shear response of swelling clays due to fluids of different polarities have been discovered through modeling.

In-pavement strain-based sensors for WIM data produced several pieces of new knowledge gained, leading to the following conclusions: 1) Support vector regression models, when integrated with axle load spectra, significantly improve the accuracy of pavement performance predictions. 2) Overweight traffic is a major contributor to pavement deterioration, particularly causing issues like alligator cracking and rutting. 3) Dynamic axle loads due to longitudinal pavement unevenness accelerate pavement fatigue and are effectively captured by advanced mechanistic-empirical models, 4) Temperature prediction models incorporating environmental factors such as solar radiation and humidity provide more accurate insights into pavement temperature variations. 5) Hybrid WIM systems that combine in-pavement sensors with computer vision technology effectively mitigate the wander effect, leading to highly accurate vehicle weight measurements. 6) Integration of machine learning and advanced sensor technologies into WIM systems enhances the ability to predict and manage pavement performance, contributing to more resilient and efficient road infrastructure.

NDSU’s safety and economic competitiveness work has produced a better understanding of the effect of considering both crash frequency and crash severity on the risk assessment or the ranking of at-grade crossings applying detailed spatial analysis. Rural road knowledge in a synthesis of models traditionally used on paved roads for use on unpaved roadways. Also, 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. Multistate corridor modeling

demonstrated travel demand modeling application in freight transportation that outlines a process to disaggregate SCTG categories 1-3, which is an improvement on existing methods.

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 primary contributions will be 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.

The NDSU Tribal technology transfer project illuminated the void of guidance and support materials for Tribal transportation programs generally. There is an absence of standard training material and resources for entry-level employees across Tribal transportation program positions and for Tribal elected officials.

South Dakota State University

The five active projects at SDSU will have the following expected impacts: adding knowledge on the effectiveness of various concrete bridge deck sealants for preventing water and chloride infiltration, expanding the knowledge of traffic safety screening methodologies, producing new data on nutrient removal by water treatment residual coated woodchips, generating a new experimental database on asphalt binders and mixes using asphalt recycling agents, and producing new knowledge on the performance of a pilot scale filter in field treatment conditions.

University of Colorado Denver

MPC-585 introduces a novel system-optimal route planning approach for ridesharing and fleet services, paving the way for broader applications in transportation optimization. MPC-612 demonstrates the use of low-cost sensors and machine learning for real-time road monitoring, offering a global tool for infrastructure management. MPC-613 enhances understanding of composite-strengthened concrete under multi-hazard loadings, enriching both engineering practice and structural resilience research.

MPC-616 and MPC-650 pioneer deep learning and physics-based models for bridge management, inspiring future predictive maintenance research. MPC-647 shifts traffic safety studies from human error to systemic factors in left-turning vehicle-pedestrian crashes, offering new insights into pedestrian safety. MPC-649 introduces machine learning for predicting cardiovascular strain in construction workers, advancing safety practices.

MPC-675 contributes to practical engineering by updating rating methods for timber bridges. MPC-676 integrates machine learning into optimization models for infrastructure maintenance, filling gaps in life-cycle cost analysis. MPC-677 explores inefficiencies in paratransit services, a previously underexamined area. MPC-678 addresses data gaps in ADA compliance and sidewalk infrastructure, advancing the study of transportation equity and accessibility.

University of Denver

Our projects will have the following impacts on the body of scientific knowledge:
1) Increasing our understanding of the role of safety culture in fatigue management, which can have a direct impact on reducing accident injuries and associated expenditures.
2) Contributing a standardized model for training leaders intending to implement and develop a safety culture in transportation organizations, 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 train people to deal with trespassers and those at risk for suicide by railroad in the best possible manner.
5) Increasing the understanding of secondary trauma or post-traumatic stress symptomatology and sequalae associated with the repeated exposure to railroad trespasser fatalities or railroad trespasser suicides.
6) The safety culture assessment tool will enhance scientific knowledge by continuing to provide a robust measurement tool for studying safety culture and thus provide additional validation of the efficacy of safety culture theory.

University of Utah

The asphalt pavement project has produced a better understanding of the relationship between different mechanical tests, which hints at the possibility of common material characterization tests; this new scientific knowledge will contribute to better pavement design practices.

One of the geotechnical projects has determined the fundamental material behavior of lightweight cellular concrete under static and cyclic loading at varying amounts of saturation. This will be used to better plan, design, and construct embankments in bridge approach areas. In another project, our understanding of the loading and wetting stress-strain characteristics of various types of soil was enhanced from the research. In a third project, the research results will likely result in a significant improvement of the knowledge regarding the design and analysis of pavement systems, both without and with 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. The project produced new analysis techniques that enable implementation of these columns in seismic regions. The project has also contributed to the development of methods for constructing such bridges using accelerated bridge construction. In a second project, a method for retrofitting partial depth prestressed concrete panels for bridge decks has been developed. 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 demonstrate their potential to facilitate transportation asset management practices and the delivered prototype AI models for practice. The project resulted in successful tests and demonstrations showing the capabilities of AI algorithms. In another project, on connected vehicles using infrared thermography, technical know-how has been developed for effective winter roadway safety practices for connected vehicles. This new scientific knowledge will contribute to better connected vehicle planning and design. A third project developed a city-scale agent-based simulation to produce daily travel profiles of electric vehicles using time-inhomogeneous Markov chain and location mapping techniques using publicly available data. Electric vehicle assignment and public charging decision modeling were specified in post-simulation analyses using socioeconomic and demographic information to produce high-resolution public charging demand.

The rail transport project has produced technical expertise on effective extraction of local resonances in rails. The results of this project will produce new knowledge on ultrasonic non-propagating modes in rails and how they can be used for inspection. This new scientific knowledge will contribute to better inspection and maintenance practices.

University of Wyoming

All UW MPC projects resulted in publications/presentations, which enhanced the scientific body of knowledge. MPC-633 developed a process to determine the cost effectiveness of building road tracks. MPC-574 established a systematic procedure to determine speed limits on mountainous roads.

Utah State University

Projects conducted by USU researchers have and will impact the body of scientific knowledge by the following: (1) Producing an optimization framework to deploy dynamic charging lanes for plug-in hybrid electric trucks in an electrified road freight transportation system. (2) Helping to increase understanding and knowledge about how people and their travel patterns respond to and perceive changes in air quality. This will provide more information to transportation researchers in civil & environmental engineering as well as planning departments. (3) Determining the deployment of fast-charging stations, the battery capacities of BEBs, and the BEB recharging scheduling for a fast-charging BEB system. The research findings will have theoretical significance as well as offer a wide range of applications for implementing more sustainable public transportation systems. (4) Providing additional data regarding concrete durability under internal heating by electric coils in pavements. (5) Improving our understanding of the built environment and how the transportation system impacts pedestrian volumes and pedestrian crashes. (6) Providing a better understanding of the load path of forces between the bridge pier and foundation as well as reliability of the couplers under vehicular impact. (7) Providing an infrastructure-based alternative solution to promote autonomous driving. (8) Providing a fair, equitable, and efficient solution to promote EVs, and to serve different user groups in a transportation network. (9) Providing a clear understanding of the current state of crash reporting, industry practices, AV expectations, etc. that are presently not readily or easily available. With the results of the state survey in particular, unpublished concerns, expectations, or plans of different states will be published in a single location for the first time. (10) Determining the effects of different concrete bridge deck removal methods on the amount of pollutant emissions are quantified, as are the methods that decrease concrete removal time. (11) Producing quantified knowledge about the magnitude, longevity, interconnectivity, and spatial variation in the impacts of wildfire smoke and other area-wide air pollution on multimodal traffic volumes. (12) Quantifying the behavior of polymer coated concrete pavements under vehicle fire loading, and prescribing methods for both rehabilitation and future usage. (12) Advancing the body of scientific knowledge around pedestrian safety at transit stops. In particular, we expect it to provide insights into the safety and operational performance of having near-side versus

far-side bus stops. (13) Producing new knowledge on which local materials are suitable for attaining a well-graded UHPC mix with enhanced strength and durability properties. This will contribute to wider use of advanced yet cost-effective material for transportation infrastructure. (14) Advancing structural engineering knowledge, particularly in the performance of precast columns with grouted splice sleeve (GSS) connectors under vehicle impacts and seismic loads. The study's finite element models showed that GSS-C columns retain up to 20% more residual seismic capacity and experience 10% to 15% less damage compared with cast-in-place columns, making them more resilient in real-world conditions. These models, with error margins of just 0.7% to 1.65%, offer engineers precise tools for assessing and improving infrastructure durability. The findings also enhance numerical modeling techniques and are expected to influence structural design and damage assessment practices.

D. What is the impact on transportation workforce development?

Colorado State University

The projects at CSU will have the following impacts on transportation workforce development: (1) providing advanced research and teaching opportunities for students and faculty; (2) equipping students with specialized skills and practical experience to prepare them for transportation careers; and (3) fostering interdisciplinary collaborations that enhance educational programs. The teaching of CIVE 581 on the material point method equips students with niche expertise in structural modeling, which will broaden the application of this powerful method within the transportation sector. Collaborations between the PI and the CSU Drone Center have resulted in a new course, Engineering with Drones, ensuring that research findings are integrated into educational programs that prepare students for transportation-related roles. Several projects supported PhD, MS, and undergraduate students, offering hands-on experience in data analysis, survey methods, machine learning, and health monitoring techniques. For example, a PhD student supported by grant funding has successfully transitioned into academia and now serves as faculty at South Dakota State University, further contributing to the transportation workforce. The projects also emphasize practical workforce development through internships and direct industry engagement. Graduate students supported have gained industry experience through internships and contributed to new course content on vehicle powertrain optimization. Through interdisciplinary projects, such as computational flow modeling and vehicle inspection using drones, students are exposed to cutting-edge technologies that enhance their readiness for transportation careers. Similarly, machine learning tools developed for pothole detection provided research experience to a graduate assistant, further enhancing their technical skills. These initiatives ensure that students are not only equipped with knowledge but also receive real-world experience, preparing them for impactful careers in the transportation field.

North Dakota State University

The projects at North Dakota State University will impact transportation workforce development with (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 students training with machine learning models in traffic safety analysis, traffic forecasting and project efficacy techniques, and 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; (7) undergraduate and graduate student experience in engineering, economics, ITS, safety, spatial analysis, and other research and technology transfer efforts; (8) Tribal and local road manager access to pragmatic and relevant safety investment data and tools, including Tribal road maintenance staff that did not previously have access to formal training.

South Dakota State University

Seven PhD, 21 MS, 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

MPC-585 trained students in system-optimal methods, with one PhD student now working at NREL. MPC-612 and MPC-616 equipped students with skills in low-cost sensors, machine learning, and data-driven techniques for infrastructure management.

MPC-613 and MPC-650 trained students in bridge engineering and deep learning models for bridge management. MPC-647 developed expertise in safety analysis and policy evaluation, while MPC-675 and MPC-676 provided practical knowledge in bridge rating and predictive maintenance.
MPC-677 employed research assistants who now work in the field, and MPC-678 trained students in GIS and ADA compliance, preparing them for roles in equitable, data-driven transportation planning. These projects collectively foster a skilled, future-ready workforce for the transportation sector.

University of Denver

Our projects have had the following impacts on workforce development:
1) Four graduate students have received training and experience in the research process, including literature review, data collection and data analysis using SPSS and Excel and report writing techniques. Another graduate student is studying the instrument and adopting it to his dissertation so it will improve his knowledge of safety and safety culture. The safety culture assessment tool has been used in two dissertations.
2) This research has supported graduate students. One, Sandra Bertran Grant, just completed the program of study and was hired as a professor.
3) Safety managers at two railroads were given information on how to improve their safety culture.
4) Presentations on the preliminary aspects of the safety culture training model have provided useful information to safety managers in planning their next organizational safety culture program.
5) As a result of this project, managers at several trucking companies received information about how to manage fatigue levels.
6) One graduate student has contributed to the final writeup and presentation by conducting a literature review, thus developing essential skills needed to work effectively in the transportation industry. She is also planning to give a presentation in November and December.

University of Utah

The asphalt pavement project will have the following impact: Two graduate students have received training in the use of mechanistic-empirical pavement design software that were supported as part of this work. They have now joined the workforce and are greatly contributing to society. 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. The research has provided exposure to many aspects of the transportation field to eight graduate students. As this research gets disseminated through workshops and publications and is incorporated into coursework, many practitioners and students will be exposed to the outcomes of this research and the importance of transportation systems to our everyday lives. In one structural project, one master's student has graduated and has joined a bridge design company in Salt Lake City. One PhD student involved in this research has graduated and joined the workforce, while another PhD student will graduate in December 2024 and join a bridge design company. In the second project, one master's student has graduated and is currently employed at a Salt Lake City structural design firm. The transportation projects will have the following impacts: Three graduate students have received research training in the project on electrical vehicle demand estimation. The students wrote code and conducted quantitative analysis based on the results. In another project, one graduate student received research training and wrote computer scripts using Python; the student also learned the theory and methods of computer vision and machine learning. In a third project, one PhD student was trained and is a potential workforce member with UDOT or a consulting company to help AI models penetrate the transportation industry. The rail transport project will have the following impacts: This research provided support for a graduate student who is studying nondestructive evaluation of transportation infrastructure. The methodologies and results of the research are being implemented in course materials for infrastructure sensing and health monitoring.

University of Wyoming

MPC project findings have been presented to WYDOT, transportation professionals at conferences, as well as students at the University of Wyoming. Several training sessions were provided to WYDOT engineers to demonstrate how to use the passing zone device developed in MPC-600. Information on the device, which is under development in MPC-686, was presented to a large WYDOT safety group to demonstrate how the developed device will reduce crashes involving snow plows.

Utah State University

Projects conducted by USU researchers have and will impact transportation workforce development by the following: (1) Provide opportunities for graduate and undergraduate students to learn about the significant and diverse opportunities in

the fields related to transportation. (2) Provide strong organizational, management, and inquiry skills that can be used by professionals in the workplace. (3) Provide opportunities for students involved in these projects to be in a position to lead companies that provide transportation services. Portions of this project interacted with construction companies. Employees were exposed to new techniques in construction for pavement in the transportation system.

E. Address any significant impacts.

University of Denver

The most significant impact has been the adoption of the AlertMeter technology. In addition, over 830 individuals have read the technical report describing the validation of the AlertMeter. Several citations of the instrument have been documented in the literature. Most recently, we learned that two private transportation companies have purchased the AlertMeter for use in their daily operations.

University of Utah

The geotechnical projects will assist DOT project personnel in implementing technologies that reduce differential settlement at bridge approaches. Methods to estimate pavement's service life sensitivity to material properties and variations, including average annual daily traffic and equivalent single axle load, could be evaluated. The structural project regarding bridge decks has developed cost-effective strengthening procedures for partial-depth bridge decks that have suffered delamination. This will improve their condition, extend their lifespan, and reduce the need for bridge deck replacement.

In the area of electric vehicle demand estimation, the developed methodology addresses the oversimplification and limitations in the literature by utilizing a high-fidelity city-scale road network, incorporating drivers' non-work-based activities, and applying real-world electrical vehicle distribution to develop a charging demand estimation model. The rail transport project has developed a rail inspection method based on ultrasound and eddy current. The knowledge of ultrasonic non-propagating modes will be used for inspection and nondestructive evaluation, which has the potential for expanding to rail and transit networks.

University of Wyoming

The passing zone equipment developed in MPC-600 will reduce crashes on two-lane highways. The equipment developed in MPC-686 will reduce crashes involving snowplows.

Utah State University

Some of the most significant impacts as detailed above are in the area surrounding electrified transportation. The impacts are in the area of transportation planning related to electrified vehicles as well as the development of electric infrastructure and what future surface transportation systems will look like in response to higher adoption of electric vehicles. These vehicles include passenger vehicles as well as freight trucks.

6. Changes/Problems:

South Dakota State University

The PI of one active project (MPC-626), Dr. Seo, passed away in Sept. 2022. Dr. Ghabchi has agreed to continue MPC-626 as the new PI. The five remaining projects will be completed in a few weeks.

University of Denver

Delays in completing the writeup were encountered due to personal and health issues faced by the PI. A request for extension was requested and granted.

University of Wyoming

There is a slight delay in MPC-686 due to the need for additional testing during the 2024/2025 snow season.

7. Special Reporting Requirements:

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