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Research and Innovative Technology Administration
University Transportation Center Grant Agreement

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Center for Transformative Infrastructure Preservation and Sustainability (CTIPS)
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North Dakota State University
Upper Great Plains Transportation Institute
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SAPR#2

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

a. What are the major goals of the program?

The Center for Transformative Infrastructure Preservation and Sustainability (CTIPS) aims to revolutionize the preservation of existing transportation systems through the integration of advanced sensing technologies and automation in data collection and analysis. Our research aligns with the statutory priority area of Preserving the Existing Transportation System and USDOT's non-exclusive candidate topic area of "asset management – techniques and cost-effective inspection, preservation, and maintenance practices." In addition, CTIPS research will address systemic equity issues in the region, especially inequities stemming from the relatively poor quality of Tribal and rural roads. Infrastructure Preservation through Autonomous Inspection and Artificial Intelligence and Infrastructure Preservation through Pavement Resilience and Bridge Management form the two focus areas of the research portfolio. Overall, the proposed research portfolio represents a transformative approach to preserving the existing transportation system. By integrating advanced technologies, automation, IoT, and AI, the research will revolutionize infrastructure condition monitoring and assessment, leading to safer, more reliable, and more sustainable transportation infrastructure. The research aligns with the statutory priority of Preserving the Existing Transportation System and with USDOT's goal of innovation by expanding current practices and introducing transformative technologies into the transportation sector. By setting a new benchmark for the industry, the expected impacts of CTIPS research will benefit the transportation system and its users.

The overall objectives are to: (1) conduct basic and applied research, the products of which are judged by peers or other experts in the field of transportation to advance the body of knowledge in transportation; (2) offer an education program 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) support the statutory priority area of Preserving the Existing Transportation System and USDOT's research priorities of Asset Management and Resilience to include techniques and cost-effective inspection, preservation, and maintenance practices and (2) leverage UTC funds with matching funds from state and local governments and private industry. The chief operational goal is a comprehensive approach to address the aforementioned research priorities and systemic equity issues. The proposal is targeted at a future vision of system preservation and asset management. and other supporting objectives while addressing critical issues of the region and stakeholder groups.

b. What was accomplished under these goals?

i. Project Selection

Research projects selection for year 1 and 2 year are undergoing a peer review process for possible selection. The projects reflect substantial input and matching resources from state departments of transportation, MPOs in the region, and industry. Collectively, this set of projects addresses all seven 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. Other research projects are related to the Secretary's strategic goals of Safety, Economic Strength and Global Competitiveness, Equity, Climate and Sustainability, and Transformation and other supporting objectives.

CTIPS projects CTIPS-001 through CTIPS-038 have been selected, peer reviewed, and posted to the CTIPS website and are listed in Appendix A.

ii. Programmatic Milestones

In addition to the programmatic milestones described below, several milestones embedded within individual projects will be achieved as projects get selected. Most of the research projects call for literature reviews. The literature reviews for those projects with the earliest starts are being completed. Interim reports are not required after the literature review stage. So, no publications have been produced at this time. At this time, all projects are on schedule to be completed as planned during the program period.

The accomplishments to date are summarized in Table 1 by reference to milestones.

Table 1: Program Milestones

Milestone Event	Description	Start Date	End Date
Development of Proposal Guidelines	Proposal guidelines were developed by the director, in consultation with other consortium members, to ensure a consistent solicitation and project selection process that facilitates peer review and links program activities to the Secretary's strategic goals. The research proposals guidelines are shown in Table 2. Similar but different guidelines were developed for education, workforce development, and technology transfer projects, to reflect the differences in tasks and outcomes associated with these projects. The proposal guidelines and related information have been posted on the Center's website.	12/01/2023	03/01/2024
Call for Proposals	The solicitation of proposals occurred on each university campus, using proposal guidelines developed by the director.	12/01/2023	11/30/2025
Execution of Grant Agreement	The grant was received from RD&T and executed by NDSU's Sponsored Programs office. All of the necessary internal accounting and financial procedures were established, including subcontract agreements with consortium universities.	12/01/2023	12/01/2024
Center Directory	A directory of key center personnel was completed and published on the center's website.	12/01/2023	02/02/2024
Center Website	The CTIPS website was updated and is fully functional for the current grant period.	12/01/2023	02/02/2024
CTIPS Kick-Off Meeting	The director and administrative staff attended the UTC/CUTC meeting at TRB and received guidance from RD&T regarding the forthcoming grant.	04/09/2023	04/09/2024
Peer Review of Proposals	All project proposals were subjected to external and internal peer review.	03/01/2024	11/30/2025

Primary Focus	Our research aligns with the statutory priority area of Preserving the Existing Transportation System and USDOT's non-exclusive candidate topic area of "asset management – techniques and cost-effective inspection, preservation, and maintenance practices." In addition, CTIPS research will address systemic equity issues in the region, especially inequities stemming from the relatively poor quality of Tribal and rural roads. Infrastructure Preservation through Autonomous Inspection and Artificial Intelligence and Infrastructure Preservation through Pavement Resilience and Bridge Management form the two focus areas of the research portfolio. The research aligns with the statutory priority of Preserving the Existing Transportation System and with USDOT's goal of innovation by expanding current practices and introducing transformative technologies into the transportation sector. **USDOT Strategic Goals:** • **Safety** – Make our transportation system safer for all people. Advance a future without transportation-related serious injuries and fatalities. • **Economic Strength and Global Competitiveness** – Grow an inclusive and sustainable economy. Invest in our transportation system to provide American workers and businesses reliable and efficient access to resources, markets, and good-paying jobs. • **Equity** – Reduce inequities across our transportation systems and the communities they affect. Support and engage people and communities to promote safe, affordable, accessible, and multimodal access to opportunities and services while reducing transportation-related disparities, adverse community impacts, and health effects. • **Climate and Sustainability** – Tackle the climate crisis by ensuring that transportation plays a central role in the solution. Substantially reduce greenhouse gas emissions and transportation-related pollution and build more resilient and sustainable transportation systems to benefit and protect communities. • **Transformation** – Design for the future. Invest in purpose-driven research and innovation to meet the challenges of the present and modernize a transportation system of the future that serves everyone today, and in the decades to come.	12/01/2023	11/30/2030

Selection of Projects	Projects are being selected from the proposals received and awards were made to principal investigators, based on the peer reviews of proposals, stakeholder commitments, and the overall availability of funds.	04/01/2024	11/30/2025
Posting of Projects	The selected projects will be posted on the CTIPS website and added to the Research in Progress database.	04/01/2024	11/30/2025
Site Visit	A site visit to all CTIPS Universities will be conducted annually.	12/01/2023	11/30/2030
UTC/CUTC Summer Meeting	The center director and other key staff will attend the 2024 summer UTC/CUTC meeting in South Padre Island, Texas.	06/10/2024	06/13/2024
UTC/CUTC Winter Meeting	The director and administrative staff will attend the UTC/CUTC meeting at TRB and received guidance from RD&T regarding the forthcoming grant.	01/05/2025	01/09/2025

Table 2: CTIPS Research Proposal Guidelines

Title	Provide a title that is descriptive of the project and includes key terms. Titles should be written in title case and limited to 20 words.
Universities	List CTIPS universities involved in the proposed project. It is highly encouraged to collaborate with other universities in the consortium (CTIPS) on project proposals.
Principal Investigators	If the project is a multi-university proposal, list a principal investigator from each university. For each principal investigator, include name, ORCID number, university affiliation, title, email address, and phone number.
Research Needs	Provide a statement of the important issues and problems that give rise to the need for the project, including a brief literature review (if appropriate) that summarizes the state of knowledge in the subject area and identifies the knowledge gaps the project seeks to fill. It must be clear from the description that there are compelling needs for the study and it will address issues of national and regional importance.
Research Objectives	Provide a clear statement of the research objectives, including any hypotheses to be tested. At least some of the objectives must be measurable—i.e., at the conclusion of the project, it must be possible to ascertain whether the stated objectives have been achieved.
Research Methods	Provide a sufficient description so that reviewers can assess the appropriateness of the research approach and methods and the quality and reliability of data, including descriptions of any mathematical, statistical, operations research, and simulation techniques to be used, as well as surveys, lab tests, and field data.
Relevance to Strategic Goals	Select one (1) USDOT strategic goal (Safety; Economic Strength and Global Competitiveness; Equity; Climate and Sustainability; Transformation) that is primarily addressed by the proposed project. You also have the option to select one (1) secondary strategic goal related to the project. Describe how the project and expected outcomes/impacts relate to the selected goal(s). Also, describe how the project engages in breakthrough, advanced, or transformative research.
Educational Benefits	Describe how students will be involved in the project and any expected classroom or instructional uses of procedures, examples, or discoveries derived from the project. If not applicable, state Not Applicable below Educational Benefits.

Outputs through Technology Transfer	Describe the results of the work performed including new research, technology or process that the project will produce. Outputs could include processes and methods; data, hardware, software, and databases; invention disclosures, patent filings, inventions, etc. Also describe any new partnerships outside of CTIPS that will be established through the project. Provide a technology transfer (T2) plan for your project. Describe the process you will use for transferring your findings/outputs to other researchers, professionals and practitioners. The goal should be further development, commercialization, and practical applications from the results of your research. Ultimately, technology transfer should sustain economic growth and improve efficiency, safety, and/or cost effectiveness through the development and commercialization of new technologies and practices. Technology transfer may occur through (but is not limited to): peer-reviewed research reports, peer-reviewed journal articles, peer-reviewed conference papers, newsletters, workshops, webinars, web pages, social media, YouTube clips, seminars, the CTIPS website, your university/department website, and other distance learning events. CTIPS T2 programs will primarily utilize three forms of engaging clients and disseminating research results: (1) virtual delivery via live webinars, recorded online modules, videoconferences; (2) in-person seminars or presentations; (3) conferences or workshops that organize related T2 topics into day-long or multi-day events. Please list how you intend to fulfill this requirement and remember to report your technology transfer activities in the SAPR (Semi-Annual Progress Report) for this project.
Expected Outcomes and Impacts	Provide a description of the expected outcomes in terms of potential findings and impacts, including advances in modeling, practices, and procedures and implications for future research. Describe the application of the output and any changes this output has or will make to the transportation system, or its regulatory, legislative, or policy framework, including a description of products or patents, or a change in practice, or instances of research results informing policy decisions. Discuss how this research output will positively impact the transportation system in terms of safety, reliability, durability, costs, etc. Describe any tangible products beyond the research report, including prototype software, equipment, guidebooks, or instructional manuals that may emanate from the project. Journal papers, other publications, and presentations are not sufficient to show impact.
Work Plan	Provide a description of the major tasks or steps in the project, along with an expected timeline. The tasks should be numbered with an expected completion date assigned to each one. Instead of calendar dates, the timeline should be expressed in months from the starting date. Typically, a work plan includes steps such as the completion (and testing) of questionnaires, lab tests, field tests or data collection efforts, input or focus group meetings, and critical steps such as the initial runs and calibrations of models. A draft report and other milestone events should be included, as well as a technology transfer plan that includes a research seminar via the Transportation Learning Network (TLN) and/or plans to collaborate with an LTAP or TTAP center (if appropriate). If the research is basic

	in nature, other dissemination methods may be substituted for the TLN, LTAP, or TTAP distribution channels.
Project Cost	List the amount of CTIPS funds requested, the amount of the expected matching contributions, and the sources of the matching resources, including all agencies expected to contribute funds or in-kind resources to the project. CTIPS projects require at least a dollar-for-dollar match. Note that other federal funds (e.g., federal funds other than UTC funds) cannot be used as match, except for state planning and research funds and LTAP funds, which are eligible under exclusionary provisions of the authorizing legislation. The definition of "non-federal funds" is based on the original source of funds.
Potential Peer Reviewers	Provide the complete contact information of at least three persons who are qualified to review and critically assess the proposal, including the person's name, position title, organization, and email address. Peer reviewers cannot have conflicts of interests, such as possibly benefiting, personally or professionally, from the proposed project. Peer reviewers may include professionals at federal, state, metropolitan, or local agencies, as well as university and private-sector researchers. At least three completed reviews are required for a proposal to move forward in the assessment process. Consequently, submitting more than three names may expedite the time frame for approval in the event of one or more nonresponsive reviewers. For select projects (e.g., those conducted for your state's DOT), that have already been peer-reviewed (by DOT personnel), indicate the organization/committee that peer-reviewed the proposal. Include organization name, committee name, and provide information (name, title, and email) for at least 3 people who performed the peer review from that committee.
Data Management Plan	The data management plan for CTIPS is posted online (view data management plan). The plan describes our strategies for developing, describing, and archiving digital data sets resulting from DOT-funded research to facilitate public access and sharing of data resources. If your project requires an additional or a different data management plan (including those from other funders), you will be asked to upload your plan.
TRB Keywords	List applicable TRB keywords
References	List the major references cited in the proposal and other seminal work in the field.

iii. Educational Accomplishments

The transportation and transportation-related courses offered during Spring, Summer, and Fall 2024 are listed In Appendix B, organized by major subject area. In some cases, courses with the same titles were offered at more than one CTIPS university. In these cases, the number of courses offered is shown in parenthesis.

Altogether, **166 transportation and transportation-related courses** have been offered this reporting period, for a total of **319 total transportation courses** offered this grant period. In addition to the courses listed above, foundational courses in engineering materials, mechanics, structural analysis, and geotechnical engineering were offered at most CTIPS universities.

iv. Workforce Development Accomplishments

Training: A list of **80 training events** were provided for transportation professionals during this reporting period and are listed in Appendix C. Dates following training, are development dates. In addition, we have had **173 online training modules** and **113 recorded sessions that 8,106 transportation professionals** utilized to strengthen their workforce skills.

c. How have the results been disseminated?

The results will be disseminated in a variety of ways, including: (1) workshops and conferences, (2) videoconferences, (3) online modules, (4) presentations at conferences, (5) publications, (6) website postings and displays, (7) Internet-based dissemination media, including broadcast emails and webinars, and (8) YouTube delivery.

d. What progress has been made this reporting period and also what do you plan to do during the next reporting period to accomplish the goals?

Projects will be selected and research will begin, along with implementation of plan and grant schedule.

Colorado State University

During this reporting period, we have accomplished work within four projects by testing measurement accuracy, creating technical strategies, understanding key functions within the research scope, and developing assessment frameworks. During the next reporting period, all seven projects will have work underway, ranging from finalizing experimental designs (two projects) to lab experimentation and testing (two projects), and data collection (one project).

North Dakota State University

NDSU stood up two CTIPS projects that were aimed at contributing to transportation transformation and innovation in Region 8. The project, Advanced Air Mobility (AAM) to Enhance Freight Logistics and Preserve Road Condition (CTIPS-001), centers on USDOT's strategic goal of economic strength and global competitiveness. The project, Assessing Condition of Rehabilitated Concrete Pavement with Slab Fracturing and Asphalt Overlay Using Distributed Fiber Optic Sensors (CTIPS-002), has important implications for safety enhancement related to cracking penetration patterns in asphalt overlaid concrete pavement after surface rehabilitation. Several early journal publications were published for CTIPS-001, producing timely information for the burgeoning air freight in multimodal delivery, including several highly ranked international publications. The air mobility project also strengthens a research bond between NDSU and UND with a key regional strategy to deliver a pragmatic guide for AAM integration in rural regions. Both projects are on time and within budget.

South Dakota State University

The SDSU research project portfolio under this grant currently includes two projects in line with the strategic goal of "transformation" (two projects). Both projects are reporting normal progress without any delays. A unique aspect of this grant at SDSU is the collaboration and partnership with transportation agencies within and outside of the region (e.g., SDDOT, Alaska DOT&PF).

University of Colorado Denver

The priority area of our UTC is to preserve the current transportation system. Our primary USDOT strategic plan goal is to enhance economic strength and global competitiveness; our second strategic goal is equity and transformation. With respect to these priorities and goals, we are under contract and have launched several relevant projects.

University of Denver
The University of Denver continues to make progress in the areas of research, education, and workforce development. The education programs have continued with the successful graduation of another cohort of master's students, bringing the number of students who have graduated from the program to over 155 since being started with UTC funds under SAFETE-LU. Established in 1997, the DU Master's in Transportation and Supply Chain was founded in part with UTC program funding. Since 2020, undergraduate students have been enrolled in transportation and supply chain courses in the undergraduate program of the DU School of Business under the direction of Professor Jack Buffington.

In terms of workforce development, we have conducted several outstanding workforce development activities in the form of webinars and presentations as well as involving graduate students in data collection and analysis, which will prepare them for working in transportation research roles.

The successful validation of the AlertMeter technology (MPC-605) continues to contribute to the improvement of safety and effectiveness of the transportation system by targeting the time, effort, and resources, of transportation organizations during a period of reduced resources. Interestingly, the MPC-605 research report project description has received over 832 reads or downloads since being posted.

Ongoing research being conducted in the areas of fatigue and safety leadership training continues to contribute to the overall goal of improving transportation system safety. Our work developing training and resource materials to assist transportation workers in identifying and intervening with individuals at risk for trespass and suicide on the right of way will hopefully provide enhanced workforce development and increased competence among transportation rail workers. Lastly, our work on leadership training and safety culture (MPC-582 & 604) is gaining more interest. Plans for the coming reporting period include continuing our data collection, report writing, and workforce development.

University of Utah
In the planning area, for a project on data-driven inspection planning for Utah culverts using federated learning (FL), an assessment FL's feasibility for culvert condition prediction with limited data has been completed; the evaluation of FL model performance compared with traditional centralized machine learning (ML) models is currently underway.

In the geotechnical area, for a project on subsurface seismic imaging using full-waveform inversion and physics-informed neural networks, two tasks are underway: (1) generating a set of synthetic wavefields for shallow buried anomalies through the numerical solver of the elastic wave equation to train our networks; (2) combining physics-informed neural networks with full-waveform inversion to retrieve both primary (P-wave) and secondary (S-wave) velocity profiles.

In the transportation area, for a project focused on a transportation infrastructure electrification certificate program, the design of four new courses that represent an entirely new direction and concept of education is currently underway. For another project focused on artificial intelligence (AI) and mobile phone-based pavement marking condition assessment and litter identification, a task on summarizing existing approaches for automated pavement marking assessment and litter identification is complete. In a third project on optimizing guardrail placements along highways in Utah to enhance road safety and mitigate road departure crashes, a task on extracting the roadside features from pathway images for five state roads in Utah is complete, and a second task on analyzing the impact of roadside features on road departure crashes is underway. For a fourth project on the development and validation of a methodology and tools to estimate retro-reflectivity of pavement markings using LiDAR, several tasks are underway: (1) development of a method implemented by a tool suitable to monitor pavement retro-reflectivity using LiDAR data using traditional statistical analysis and machine learning; (2) development of a computer tool implementing the proposed methodology such that data ingestion,

processing, and outputs are largely automated; and (3) provide an estimate of retro-reflectivity using the methodology and computer tool to generate reports that support federal mandates.

University of Wyoming
We are in the process of hiring graduate students for all CTIPS projects. CTIPS-013 is off to a very good start. An advisory board has been formed and the data have been collected.

Utah State University
USU has just recently selected projects for the new reporting period. No work has been done at this time.

Fort Lewis College
During Year 1 of this project, the team used a surface vehicle to verify the sonar system and the software to be deployed to an underwater vehicle in year 2. The sonar boat project uses off-the-shelf components and some 3D-printed parts to create a low-cost solution for gathering information around the pier. In the second half of Year 1, the team will create a LIDAR distance measurement system to help the surface vehicle navigate around the pier. The data from the LIDAR sensor will be integrated with the boat motor's control modules to ensure precise positioning. The accuracy of the mapping relies heavily on the positioning system, which operates as a closed-loop control system in conjunction with the thrust modules. This enhancement to the boat will facilitate accurate mapping, which is the primary objective for Year 2's project.

United Tribes Technical College
We have had some meetings with the other Tribal Schools in North Dakota and have met with our local LTAP. Our intent is to get more aggressive with the other schools in the Spring, so we have a plan for next fall.

University of North Dakota
The PI reports reflect our progress. Some tasks are underway, and it is expected that the other objectives and tasks will be completed gradually.

2. PARTICIPANTS AND OTHER COLLABORATING ORGANIZATIONS: Who has been involved?

a. What organizations have been involved as partners?

- Agricultural Research Service, Fort Collins, CO, financial support
- Alaska Department of Transportation and Public Facility, Juneau, AK, financial support
- Cankdeska Cikana Community College, Fort Totten, ND, collaborative workforce development
- City of Durango, Durango, CO, facilities
- Colorado State University, College of Engineering, Fort Collins, CO, financial support, educational support
- Colorado State University, Department of Civil and Environmental Engineering, Fort Collins, CO, financial support, educational support
- Colorado State University, Drone Center, Fort Collins, CO, in-kind support
- Colorado State University, Fort Collins, CO, facilities, subject matter experts
- Durango Community Recreation Center, Durango, CO, facilities
- North Dakota State University, Fargo, ND, facilities, subject matter experts
- Nueta Hidatsa Sahnish College, New Town, ND, collaborative workforce development
- Sitting Bull Community College, Fort Yates, ND, collaborative workforce development
- South Dakota Department of Transportation, Aberdeen, SD, in-kind support
- Truck Load Carrier Association, Alexandria, VA, financial support, in-kind support
- Turtle Mountain Community College, Belcourt, ND, collaborative workforce development

- UDOT Maintenance & Facility Management Division, Salt Lake City, UT, subject matter experts, personnel exchanges
- Utah Department of Transportation, Salt Lake City, UT, financial support, subject matter experts
- Utah Systems of Higher Education, Salt Lake City, UT, financial support
- Wyoming Department of Transportation, Cheyenne, WY, provide data, subject matter experts

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 **49 principal investigators, faculty, and administrators at eleven universities in Region 8.** In addition, we have been able to support, mentor, and develop research skills and knowledge in transportation for **32 students from the U.S. and countries around the world. These includes 15 doctoral students, 10 master's students, and 7 undergraduate students.**

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

- **University of Utah**
  - Jimmy McDonough, Utah Systems of Higher Education

3. OUTPUTS: What new research, technology or process has the program produced?

a. Publications can be found in Appendix D

During this period CTIPS faculty and investigators have published **11 peer-reviewed articles or papers** in scientific, technical, or professional journals. Since the beginning of this grant, **we have published 11** different peer-reviewed articles or papers.

b. Conference papers can be found in Appendix D

This reporting period **we have published 5 conference papers and 5 total since the grant began**.

c. Presentations can be found in Appendix D

CTIPS faculty and investigators **have presented at 9 different** scientific, technical, or professional conference this period. In total, we have **had 9 presentations on CTIPS research**, results, and outcomes.

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

i. The CTIPS website is fully operational with additional information added as needed at https://www.ctips.org/

ii. The CTIPS Key Personnel Directory can be found at https://www.ctips.org/personnel/executive-committee.php

iii. CTIPS project descriptions can be found at https://www.ctips.org/projects/

iv. Other outputs that are University specific:

South Dakota State University

The following project websites were developed to disseminate the findings with researchers and the public. The websites are frequently updated to show project progress.
https://sites.google.com/view/mostafa-tazarv/research/computer-vision-for-bridge-inspection
https://sites.google.com/view/mostafa-tazarv/research/computer-vision-bridge-measurements

University of Utah

Together with University Connected Learning, we have conducted a market analysis to assess the potential success of the certificate program. Here is a brief summary of findings:

This program is indeed niche, with very few universities offering the exact same curriculum. Our search under the CIP code 14.4801 revealed only two programs, and none were found under CIP code 47.0614. We have identified a few similar, yet different, programs. The average cost-per-credit for similar programs across the United States is $1,248, with the average program requiring 13 credits. For well-established, nationally recognized R1 level master's programs delivered via distance learning, our enrollment projection tool estimates an enrollment range of 33 to 95 students. Typically, certificate programs enroll about 25% to 50% of the number of students in related master's programs. Accordingly, we can predict an enrollment range of eight to 24 students for this certificate program.

University of Wyoming
We have developed a methodology to calculate the percentage deviation between the awarded contractor's bid amount and the engineer's estimated amount for WYDOT projects. This analysis will then be compared with similar data from other state departments of transportation (DOTs) to evaluate how WYDOT's cost estimation practices align with or differ from those in other states. This comparison aims to identify factors influencing the accuracy of WYDOT's cost estimates and could inform future improvements in estimation techniques. The results will be shared through detailed statistical reports and comparative analyses.

Fort Lewis College
The team developed software that interconnects the sonar system, GPS, and the central control unit for the surface boat. To facilitate primary data collection, they modified a low-cost surface RC boat, establishing the necessary hardware connections during the first half of the project.

4. OUTCOMES: What outcomes has the program produced? How are the research outputs described in section (3) above being used to create outcomes?

a. **Increased understanding and awareness of transportation issues.**
    - Nothing to Report.
b. **Passage of new policy, regulation, rulemaking, or legislation.**
    - Nothing to Report.
c. **Increased in the body of knowledge.**
    - Nothing to Report.
d. **Improved processes, technologies, techniques and skills in addressing transportation issues.**
    - Nothing to Report.
e. **Enlargement of the pool of trained transportation professionals.**
    - Nothing to Report.
f. **Adoption of new technologies or practices.**
    - Nothing to Report.

5. IMPACTS: What is the impact of the program? How has it contributed to improve the transportation system; enhance safety, reliability, durability, improve transportation education, and/or strengthen the workforce, etc.?

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

Colorado State University
The CSU projects will have the following impacts: (1) enhanced preparation of future transportation professionals to address social equity issues; (2) more efficient and accurate infrastructure inspection processes; (3) improved timeliness and coverage of pavement condition assessments; (4) optimized maintenance practices for gravel roads, leading to safer conditions and better air quality; (5) reductions in emissions through the

identification of vehicle characteristics contributing to air contamination; and (6) increased durability and sustainability of concrete infrastructure. Specifically, the development of course modules focused on equity will ensure that transportation professionals are better equipped to serve diverse communities fairly. The use of unmanned aerial system (UAS) technology will allow for quicker identification of damage, improving resource allocation for repairs. Integrating robotics and AI into bridge inspection will allow for more precise damage predictions and proactive maintenance, increasing safety and reducing costs over the long term. Crowdsourced data from electric vehicles will provide real-time insights into pavement conditions, reducing the time lag between issue identification and repair. Additionally, real-time moisture monitoring on unpaved roads will enhance maintenance scheduling, preserving road quality and mitigating dust emissions that affect residents' health. Research into resuspension emissions will help mitigate air quality concerns for communities near busy roads by informing policies targeting vehicle emissions. Finally, the use of graphene-enhanced concrete aims to create more sustainable and longer-lasting infrastructure, reducing the frequency of maintenance and promoting environmental sustainability. These impacts collectively contribute to a more efficient, sustainable, and equitable transportation system.

North Dakota State University
NDSU project, AAM to Enhance Freight Logistics and Preserve Road Condition (CTIPS-001), will fill a knowledge gap in the propensity to shift certain types of cargo flows away from surface transportation modes, such as roads and rail, and can help to reduce congestion, emissions, and infrastructure deterioration. Data mining and machine learning models will help to predict the magnitude of potential mode shifts. Knowledge transfer could trigger policies to adopt electrified cargo drones because of potential benefits to the environment and increased effectiveness of surface transportation systems.
In another project, overall maintenance costs will be lowered by extended pavement lifespan. Anticipated impacts of Assessing Condition of Rehabilitated Concrete Pavement with Slab Fracturing and Asphalt Overlay Using Distributed Fiber Optic Sensors (CTIPS-002) will produce more accurate simulations and experimental validations of bottom-up crack propagation in pavement structures to enable timelier and more effective pavement maintenance. Additionally, the use of distributed fiber optic sensing (DFOS) technology to monitor crack propagation in real time will allow for more precise assessments of pavement conditions, saving valuable staff monitoring time.

South Dakota State University
The two active projects at SDSU will have the following anticipated impacts: a substantial time and cost reduction for bridge deck inspection and automation in inspection data processing and reporting; and a substantial reduction of bridge field testing time, effort, and cost by eliminating conventional sensors and data acquisition systems.

University of Colorado Denver
CTIPS-026 leverages 311 complaint reports to identify gaps in transportation asset maintenance, particularly in underserved communities, helping us push toward more equitable infrastructure improvements. CTIPS-027 develops a standardized approach to identifying high-injury road networks, allowing cities to more effectively target safety improvements and reduce fatalities through consistent, data-driven strategies. CTIPS-028 focuses on extending the lifespan of bridge decks by using ultra-high-performance concrete (UHPC) overlays, offering a sustainable solution for long-term bridge maintenance. CTIPS-029 creates a maintenance optimization system utilizing machine learning to predict bridge conditions and optimize maintenance schedules, helping maximize bridge performance within budget constraints.

University of Denver
The expected impact of this study will be to improve the experience of drivers in the transportation industry. This will further enhance workforce diversity and lead to the inclusion of more drivers from diverse

backgrounds. Lastly, this study may inform the transportation industry of factors that will increase the quality of life, job satisfaction, and retention of drivers from diverse backgrounds.

University of Utah

In the planning area, for a project on data-driven inspection planning for Utah culverts using federated learning (FL), the implementation of FL is expected to play a pivotal role in addressing data scarcity and privacy challenges faced by DOTs in managing critical infrastructure such as culverts. By enabling UDOT to leverage data from other state DOTs while ensuring data privacy, FL has the potential to enhance the accuracy and robustness of culvert condition predictions and contribute to a more resilient and cost-effective transportation system.

In the geotechnical area, for a project on subsurface seismic imaging using full-waveform inversion and physics-informed neural networks, the research introduces a seismic inversion technique to accurately detect small-scale subsurface anomalies within transportation infrastructure while reducing data acquisition costs. This early detection capability enables timely implementation of corrective measures, thus preventing damage and mitigating the risk of catastrophic roadway failure.

In the transportation area, for a project focused on a transportation infrastructure electrification certificate program, the program's vision is to create entirely new thinking on how city and highway electric grid infrastructures are designed, how vehicles and operators interact with those systems, and how to integrate private sector partners and public resources into the human interface of planning, economics, and policy. For another project focused on AI and mobile phone-based pavement marking condition assessment and litter identification, the project will facilitate the automation of transportation asset collection practices, significantly reducing UDOT maintenance costs in daily management. Since pavement markings and road litter affect driver safety, timely information collection enabled by this project will enhance transportation safety. In a third project on optimizing guardrail placements along Utah highways to enhance road safety and mitigate road departure crashes, preprocessing images and training a model on the image set enhances our ability to analyze roadside environments, which leads to efficient maintenance and safety improvements and allows transportation agencies to assess and prioritize areas needing intervention, improving pathway safety and usability. Merging roadside features with the crash database enables a comprehensive analysis of the relationship between specific roadside characteristics and crash occurrences, and integration of these data allows transportation agencies to make data-driven decisions that optimize safety and operational efficiency.

For a fourth project on the development and validation of a methodology and tool to estimate retro-reflectivity of pavement markings using LiDAR, the methodology has been implemented to a wide range of datasets from multiple freeways, where the resulting models have demonstrated the potential to obtain reliable assessments of retro-reflectivity that can serve as a primary outcome to comply with new FHWA regulations.

Fort Lewis College

This project is crucial for preserving and enhancing transportation infrastructure, particularly bridges. By addressing scour, a significant threat to bridge foundations, we aim to improve the structural integrity of essential transportation components. Focusing on the 158 scour-critical bridges identified by the Colorado Department of Transportation (CDOT), the project will help identify vulnerable structures and facilitate prioritized maintenance.

University of North Dakota

The projects at University of North Dakota (UND) aim to increase the use of two technologies in the transportation system to 1) improve the inspection of steel structures, and 2) to properly integrate CAVs on rural roadways. The PIs have experience and expertise in the subject. They have been successful in hiring the required workforce to successfully complete the projects. Several tasks are already underway toward completion.

b. What is the impact of technology transfer on industry and government entities, on the adoption of new practices, or on research outcomes which have led to initiating a start-up company?

Colorado State University

The CSU projects will have the following impacts: (1) support for the adoption of equity-based practices in transportation education; (2) improved standards for unmanned aerial system (UAS)-assisted infrastructure inspections; (3) transfer of automated pavement monitoring tools to state maintenance teams; (4) operational use of cosmic ray neutron sensing methods for gravel road maintenance; (5) development of policy recommendations targeting emissions based on vehicle characteristics; (6) promotion of sustainable practices in material engineering; and (7) adoption of advanced technologies for infrastructure inspection.

The development of course modules focused on equity will equip future professionals with the tools to implement inclusive transportation practices. By standardizing the use of UAS technologies, the research aims to provide practical guidance to inspection agencies, fostering consistency and efficiency. Automated tools for road condition monitoring will be introduced to CDOT, enhancing the timeliness of pavement maintenance decisions. In another project, real-time road moisture estimates using cosmic ray neutron sensing will empower road managers to optimize maintenance schedules and dust suppression efforts. The ReACh project will contribute to new regulations by identifying vehicle characteristics that affect resuspension emissions, influencing both electric and combustion vehicle policies. Additionally, advancements in snow-melting geopolymer concrete using graphene nanoplatelets and recycled fly ash are expected to encourage sustainable material practices. Finally, the integration of a robotic arm and AI-powered sensing in UAS inspections will offer more precise bridge assessments, enabling early defect detection and optimized maintenance strategies. These projects collectively promote the adoption of innovative technologies and processes across public and commercial transportation sectors.

North Dakota State University

NDSU impacts from the AAM to Enhance Freight Logistics and Preserve Road Condition (CTIPS-001) project is an enhanced awareness of the research and its objectives. Continued surveys of literature and industry will be used to quantify the performance and capacities of drones, architecture types, and applications. Our publications will promote the positive benefits of moving cargo to electrified aircraft as well as the potential downsides and how those could be mitigated. Increased awareness of both the benefits and challenges will likely trigger new policies to encourage adoption.

Leaning more into maintenance innovations, the anticipated impact of Assessing Condition of Rehabilitated Concrete Pavement with Slab Fracturing and Asphalt Overlay Using Distributed Fiber Optic Sensors (CTIPS-002) is technology transformation for advanced crack propagation simulations and the integration of DFOS technology, which are likely to influence future practices in both government and industry. These innovations are expected to be adopted by transportation agencies and infrastructure firms for improved pavement monitoring and maintenance using DFOS technology. They will provide a reliable, real-time method for detecting cracks, offering a superior alternative to traditional inspection methods for broad adoption by agencies responsible for road infrastructure.

South Dakota State University

The two active projects at SDSU will have the following expected impacts: collecting information on bridge deck defects quickly and safely using cutting-edge technologies; and non-contact measurements of bridge displacements without the need for conventional sensors.

University of Colorado Denver

These projects are expected to drive the adoption of new practices in transportation. For instance, CTIPS-026 will encourage more equitable infrastructure maintenance by highlighting gaps in 311 complaint reports from underserved areas, prompting public agencies to prioritize neglected regions. CTIPS-027 aims to standardize

high-injury network analysis, allowing cities to adopt a consistent, data-driven approach to road safety, improving the effectiveness of safety interventions. CTIPS-028 promotes the use of UHPC overlays to extend bridge lifespans, encouraging sustainable practices in bridge management. CTIPS-029 introduces a machine learning-based maintenance optimization system for bridges, helping agencies move from reactive to proactive maintenance, thereby improving efficiency and extending infrastructure life while staying within budget constraints.

University of Denver
It is anticipated that the study will lead to the adoption of new and better processes and methods for selecting drivers from diverse backgrounds.

University of Utah
In the planning area, for a project on data-driven inspection planning for Utah culverts using federated learning (FL), a new paradigm of machine learning (ML), this project has enabled the adoption of innovative data-driven practices, particularly for predicting and pinpointing culverts in poor conditions. By showcasing how FL can address both data privacy and scarcity challenges, the project encourages state DOTs to consider this approach for their own asset management needs, and this paves the way for commercial opportunities.
In the geotechnical area, for a project on subsurface seismic imaging by integrating full-waveform inversion and physics-informed neural networks, the project has introduced a more efficient and accurate method for detecting subsurface anomalies in transportation infrastructure. This approach has gained attention for its potential to reduce data acquisition costs and improve the resolution of seismic imaging in complex geological settings.
In the transportation area, the transportation infrastructure electrification certificate program will be a collaborative effort by engaging domain experts from multiple disciplines to train graduate students by applying cross-domain knowledge to prepare them to adapt to an increasingly interdisciplinary world. Another project, focused on AI and mobile phone-based pavement marking condition assessment and litter identification, will develop new practices with automated and timely collection of information related to pavement marking and road litter. This will transform UDOT practices for pavement marking maintenance in a timely manner since maintenance crew members could easily carry cameras or mobile phones to identify and mark faded markings and litter when driving. In a third project on optimizing guardrail placements along highways in Utah to enhance road safety and mitigate road departure crashes, the research has led to identifying crash hotspots and safety measures, including the deployment of guardrails. By merging crash data with roadside features, the project has provided insights guiding UDOT’s decisions for guardrail installations and other safety improvements, helping to reduce crash risks in high-priority areas. This work enhances UDOT’s ability to implement data-driven safety interventions. For a fourth project on the development and validation of a methodology and tool to estimate retro-reflectivity of pavement markings using LiDAR, the team anticipates developing models to produce reliable estimates of retro-reflectivity from LiDAR measurements for maintenance scheduling purposes and FHWA reporting requirements. These guidelines will reduce contracting needs and reliance on retro-reflectivity field data collection using specialized equipment, and instead leveraging existing LiDAR datasets the state already owns.

University of Wyoming
The developed procedure will help in making cost-effective decisions when maintaining infrastructures.

Fort Lewis College
Our innovative, cost-effective unmanned underwater drone (UUD) solution allows for scalable monitoring of multiple bridges while alleviating financial burdens associated with traditional systems. Equipped with sonar and distance sensors, the UUD will provide real-time assessments of riverbed conditions around bridge piers, ensuring timely identification of scour concerns and enabling prompt maintenance actions. The open-source nature of our hardware and software promotes collaboration within the engineering community, accelerating

effective scour monitoring technologies. The documentation of our methods and educational resources will serve as valuable tools for transportation authorities, engineers, and researchers aiming to improve infrastructure preservation. Through collaboration with CDOT, we will help allocate resources efficiently, identifying bridges in urgent need of repair while advancing the use of cutting-edge technologies in infrastructure preservation.

University of North Dakota
The UND projects have the potential for commercialization; however, more research is required to increase both spectral sensing and CAV technology readiness levels as both are being developed under controlled environments. In the case of spectral sensing, the technology can be integrated into a smart payload. The CAV for rural roads is being developed with simulations but, upon completion, can encourage stakeholders in North Dakota to invest in implementation of this technology. The level of future adaptation is too early to assess and without the dissemination of findings and technology transfer.

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

Colorado State University
The CSU projects will have the following impacts on scientific knowledge: (1) new insights into teaching methods for equity-based education in transportation courses; (2) contributions to the understanding of drone inspection methods for infrastructure assessment; (3) advancements in the use of crowdsourced electric vehicle data and machine learning for road condition monitoring; (4) development of techniques to accurately estimate road moisture using remote sensing; (5) groundbreaking research into resuspension emissions based on individual vehicle characteristics; (6) deeper understanding of sustainable construction materials through the study of graphene-enhanced concrete; and (7) novel contributions to robotics and structural health monitoring through the integration of advanced sensing technologies.
The course on social equity in transportation will generate data from its pilot phase, potentially advancing pedagogical methods for equity-focused education. Comparative studies of UAS methods will fill a gap in the literature, offering specific guidance on their use for infrastructure inspection. Research leveraging electric vehicle data will enhance understanding of the feasibility and accuracy of crowdsourced road condition monitoring. New techniques to disentangle landscape moisture from road moisture using cosmic ray neutron rovers will provide a unique solution to challenges in road maintenance. Additionally, the study of resuspension emissions will significantly shift the focus from fleet averages to individual vehicle contributions, enabling more targeted and effective environmental regulations. The work on graphene-enhanced geopolymer concrete will provide valuable data for future construction material innovations, promoting sustainability and durability. Finally, the introduction of tensegrity-based robotic arms and the integration of multiple sensing modalities in UAS systems will advance the fields of robotics and structural health monitoring, influencing future research and practice. Collectively, these projects will expand the body of knowledge across transportation, engineering, and environmental science disciplines.

North Dakota State University
The projects at NDSU will contribute to the scientific body of knowledge by contributing to a knowledge foundation for AAM in freight delivery and real-time monitoring for improved infrastructure longevity and service conditions. AAM to Enhance Freight Logistics and Preserve Road Condition (CTIPS-001) includes econometric models to rank the types of cargo for initial mode shifts and the locations for those deployments that can maximize the positive benefit in informing decision-making about the potential payback period from incremental investments and continued deployments. We anticipate that Assessing the Condition of Rehabilitated Concrete Pavement with Slab Fracturing and Asphalt Overlay Using Distributed Fiber Optic Sensors (CTIPS-002) will contribute to a deeper understanding of crack propagation in pavements and improve detection methods using DFOS technology in real-time pavement monitoring and maintenance. Knowledge

generated could also inform pedagogical methods, enhancing the training of future engineers in advanced crack detection technologies and simulation techniques.

South Dakota State University
The two active projects at SDSU will have the following expected impacts on scientific knowledge: generating a comprehensive inspection database, including RGB, thermal, and LiDAR data from various devices; and building software using open-source Python libraries.

University of Colorado Denver
These projects are expected to contribute significantly to the body of scientific knowledge in their respective areas. For example, CTIPS-026 will provide new insights into how transportation infrastructure maintenance can be impacted by socioeconomic factors through the analysis of 311 complaints, offering a framework for understanding equity gaps in public services. CTIPS-027 will establish a standardized, generalizable method for high-injury network analysis, enabling broader comparative studies across cities and advancing the field of road safety by identifying design elements contributing to fatalities. CTIPS-028 will contribute to structural engineering by exploring the use of UHPC overlays to extend the lifespan of bridge decks, providing valuable guidelines for sustainable bridge management. CTIPS-029 will introduce machine learning-based predictive models and optimization systems for bridge maintenance, transforming current practices by offering data-driven solutions for efficient resource allocation and infrastructure longevity, enhancing both safety and cost-effectiveness in bridge management.

University of Denver
The projects at the University of Denver will have the following impact on the body of scientific knowledge: The study identifies factors that contribute to truck driver turnover and retention in a diverse population of drivers. Driver attitudes and beliefs and perceptions related to these factors will be surveyed to identify important information related to an understanding of these factors. Results should show the extent to which various factors studied contribute to the retention, satisfaction, and longevity of drivers from diverse backgrounds.

University of Utah
In the planning area, for a project on data-driven inspection planning for Utah culverts using federated learning (FL), the project demonstrates how organizations can adopt data-driven approaches while adhering to privacy regulations, even when they lack comprehensive asset inventories. This project enables a comparative analysis of FL and traditional centralized models on the same dataset, highlighting the potential performance advantages of FL.
In the geotechnical area, for a project on subsurface seismic imaging by integrating full-waveform inversion and physics-informed neural networks, the project has demonstrated the potential of this approach in handling small-scale subsurface anomalies and improving computational efficiency. These findings will influence future research in geophysics, machine learning applications in earth sciences, and subsurface imaging techniques.
In the transportation area, the transportation infrastructure electrification certificate program is timely under the BIL grant and the vast investment in clean energy and vehicle electrification. It is perceived that several well-paying jobs will become available in this area to those who understand systems operations and possess skills in AI, mixed modeling, programming, and open science with transdisciplinary backgrounds for electrification. For another project focused on AI and mobile phone-based pavement marking condition assessment and litter identification, the research team has summarized the current advancements in computer vision, establishing the foundation for full-scale development and validation of AI algorithms for automated pavement marking assessment and litter identification and will develop an algorithm to achieve this. In a third project on optimizing guardrail placements along Utah highways to enhance road safety and mitigate road departure crashes, the project has advanced our understanding of the relationship between roadside features and crash

occurrences. This research will impact the field of transportation safety by offering a more data-driven approach to identifying high-risk areas and recommending targeted safety interventions such as guardrail installations. These findings enhance the theoretical and practical understanding of crash prevention and are expected to influence future research and policy in transportation safety. For a fourth project on the development and validation of a methodology and tool to estimate retro-reflectivity of pavement markings using LiDAR, the models are still in the final development stages, but the evidence suggests reliable estimates of retro-reflectivity can be obtained from LiDAR datasets, particularly to develop classification methodologies leading to maintenance decisions.

Fort Lewis College
The project aims to establish a positioning system for both the remote boat and an underwater drone for bridge monitoring. In Year 1, the control system will be developed and tested on the boat, with deployment to the underwater drone planned for Years 2 and 3. We expect to develop and test an optimized control algorithm using the boat.

University of North Dakota
The UND projects are novel and will contribute to the development of advanced non-contact sensing for corrosion detection and evaluation of steel infrastructure, and to generate the required fundamental data to make informed decisions regarding CAV implementation on rural roadways. The first project generated impressive results, which were used in a submitted manuscript in a reputable journal on nondestructive evaluation and testing.

d. What is the impact on transportation workforce development?

Colorado State University
The CSU projects will have the following impacts on workforce development: (1) development of equity-oriented professionals in transportation through new educational modules; (2) enhanced workforce development via specialized training in drone technology; (3) expanded research opportunities in transportation-related disciplines; (4) practical fieldwork experience for students in road moisture measurement; (5) interdisciplinary research opportunities for students connecting transportation systems and environmental engineering; (6) hands-on training in advanced materials research for transportation infrastructure; and (7) practical experience in robotics and engineering applications for infrastructure inspection.
Specifically, the equity-focused modules will prepare future transportation professionals by introducing social responsibility into the curriculum for engineering and construction management students. The new course, Engineering with Drones, will immediately transfer unmanned aerial system (UAS) technology skills to students, enhancing their readiness for transportation careers. The use of rideshare EV data for research also provides a platform for students to engage in innovative transportation research. Fieldwork experience with cosmic ray neutron rovers will offer graduate students specialized knowledge in soil and road moisture measurement techniques. Additionally, the ReACh project supports a graduate student in applying systems engineering to transportation challenges, bridging environmental and transportation fields. Advanced materials research with snow-melting geopolymer concrete provides graduate students with hands-on experience in sustainable infrastructure development. Finally, the integration of robotics training in UAS inspection not only imparts technical skills but also offers valuable problem-solving experience, ensuring students are well prepared for future roles in transportation industries. Collectively, these efforts contribute to building a skilled, well-rounded transportation workforce.

North Dakota State University
A wide spectrum of workforce development is associated with the NDSU CTIPS projects, ranging from student to seasoned practitioner. With AAM to Enhance Freight Logistics and Preserve Road Condition (CTIPS-001), undergraduate and graduate students developed Python scripting and literature review skills to write computer

code in Python to create machine learning models that can identify and rank societal benefits from freight innovation and cost-effectiveness. The products will be valuable to practitioners modeling multimodal impacts in the freight industry. Assessing Condition of Rehabilitated Concrete Pavement with Slab Fracturing and Asphalt Overlay Using Distributed Fiber Optic Sensors (CTIPS-002) is expected to provide valuable research opportunities for students, enhancing their skills in crack propagation simulations and DFOS technology, and may also offer opportunities for underrepresented groups to increase access to transportation careers.

South Dakota State University
Three PhD 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 including software developing companies related to transportation projects.

University of Colorado Denver
These projects will enhance transportation workforce development by equipping students with key skills. CTIPS-026 will train students in data analysis and equity-focused infrastructure planning. CTIPS-027 will develop expertise in standardized, data-driven road safety analysis. CTIPS-028 will provide hands-on experience in sustainable bridge maintenance using advanced materials like UHPC. CTIPS-029 will teach students machine learning and optimization techniques for proactive bridge maintenance. Together, these projects will prepare students for leadership roles in transportation engineering and planning.

University of Denver
The impact of this project on transportation workforce development will be to provide graduate students with experience in data collection and analysis. The project will also provide existing transportation managers with additional information on how to improve their workplace practices and increase the recruitment and retention of drivers from diverse backgrounds.

University of Utah
In the planning area, for a project on data-driven inspection planning for Utah culverts using federated learning (FL), students involved in this project gained hands-on experience in advanced machine learning (ML) techniques and their application in transportation asset management. Students learned to analyze data, develop models in Python, and address challenges related to data privacy and collaboration among agencies.
In the geotechnical area, a project's findings on subsurface seismic imaging by integrating full-waveform inversion and physics-informed neural networks will be incorporated into a graduate course "Signal Processing and Inverse Problems." By integrating the methodologies and results from this research into the course, the project is educating students with the latest tools and techniques used in the field, thus bridging the gap between research and practice.
In the transportation area, for the transportation infrastructure electrification certificate program, we expect a steady-state graduate class of 10 to 50 graduates per year to provide a workforce that not only possesses the needed technical skillsets in the domain but also has a leadership vision. Another project, focused on AI and mobile phone-based pavement marking condition assessment and litter identification, supports graduate students studying automation and enhancing transportation asset management practices. A presentation to UDOT's technical committee offers opportunities for UDOT practitioners to attain relevant knowledge about AI applications in transportation. A third project, optimizing guardrail placements along Utah highways to enhance road safety and mitigate road departure crashes, has contributed to transportation workforce development by providing research experience to one graduate student. The student has gained hands-on experience in data analysis, model development, and collaboration with industry professionals, which has enhanced his skills. UDOT has also benefited from related meetings by gaining access to research findings that support their decision-making efforts. For a fourth project on the development and validation of a methodology and tool to estimate retro-reflectivity of pavement markings using LiDAR, one doctorate student has enhanced

his skills by processing large datasets and developing automated scripts to extract, model, and apply outcomes, mainly using Python. The student is also developing a stand-alone executable application for external users, where the application contains pre-loaded models, allows the updating of existing models, and produces assessments on retro-reflectivity.

Fort Lewis College
This project offers substantial educational benefits by preparing the workforce for transportation, aligning with key areas of student learning and professional development. Through hands-on experiences, undergraduate students will confront practical challenges related to engineering in the transportation field.
The project fosters interdisciplinary collaboration by uniting students and faculty from civil engineering and computer engineering disciplines. This teamwork cultivates a learning environment that exposes students to a variety of perspectives and skill sets within the engineering field.

University of North Dakota
The UND projects provide research opportunities for both undergraduate and graduate students to improve the transportation system in North Dakota. They are also expected to develop learning modules such as lectures, PDHs, and other formats to educate students, train the current workforce, and serve as K-12 outreach to increase the transportation workforce. The existing outreach of college-level programs at the College of Engineering and Mines, our PIs' connections with professional organizations such as ASCE, and their commitment to include the generated knowledge in these projects in course work are promising aspects of our projects to reach their expected workforce development goals.

6. CHANGES/PROBLEMS:

a. **Changes in approach and reasons for change.**
    - Nothing to Report.
b. **Actual or anticipated problems or delays and actions or plans to resolve them.**
    - Nothing to Report.
c. **Changes that have a significant impact on expenditures.**
    - Nothing to Report.
d. **Significant changes in use or car of human subjects, vertebrate animals, and/or biohazards.**
    - Nothing to Report.
e. **Changes in primary performance site location from that originally proposed.**
    - Nothing to Report.

7. SPECIAL REPORTING REQUIREMENTS:

Nothing to Report.