U.S. Department of Transportation
Office of Research, Development and Technology
University Transportation Center Grant Agreement

Grant No. 69A3552348308
Center for Transformative Infrastructure Preservation and Sustainability (CTIPS)
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April 30, 2025

DUNS: 803882299 and EIN: 45-6002439

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Grant period: December 1, 2023 – November 30, 2029

Reporting Period End Date: March 31, 2025
SAPR#3

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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 addresses systemic equity issues in the region stemming from the relatively poor quality of rural and Tribal 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 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. CTIPS strategic plan 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 proposals from all universities are undergoing a peer review process for possible selection. The projects reflect substantial input and matching resources from state departments of transportation and other clients. Collectively, this set of projects addresses the Secretary's strategic goals and several of USDOT's requested emphasis areas—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 goals of Safety, Economic Strength and Global Competitiveness, and Transformation, as well as to other supporting objectives. CTIPS projects CTIPS-001 through CTIPS-040 have been selected, peer reviewed, and posted to the CTIPS website and are listed in Appendix A. The approved research selection process is also shown in Appendix A as *CTIPS Research Proposal Guidelines*.

ii. Programmatic Milestones

In addition to the programmatic milestones described below, several milestones embedded within individual projects will be achieved as projects are selected and tasks are completed. Most of the research projects call for literature reviews. The literature reviews for those projects with the earliest starts are

being completed and several peer-reviewed journal articles have been published. Most projects are scheduled to be completed as planned during the program period. The accomplishments to date are summarized in Table 1 by references to milestones.

Table 1: Program Milestones

Milestone Event	Description	Start Date	End Date
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 necessary internal accounting and financial procedures were established, including subcontract agreements with consortium universities. Grant No. 69A3552348308. Modification No. 1	12/01/2023 06/01/2024	11/30/2029 11/30/2029
Center Directory	A directory of key center personnel was completed and published on the center's website.	12/01/2023	11/30/2029
Center Website	The CTIPS website was updated and is fully functional for the current grant period	12/01/2023	11/30/2029
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 addresses systemic inequities stemming from the relatively poor quality of rural and Tribal 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.	12/01/2023	11/30/2029
Selection of Projects	Projects are being selected from the proposals received and awards have been 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	Site visits to all CTIPS Universities will be conducted periodically.	12/01/2023	11/30/2030
UTC/CUTC Summer Meeting	The center director and other key staff will attend the 2025 summer UTC/CUTC meeting in Northwest Arkansas at MarTREC.	06/24/2025	06/26/2025
UTC/CUTC Winter Meeting	The director and administrative staff will attend the UTC/CUTC meeting at TRB and receive guidance from RD&T regarding the forthcoming grant.	01/07/2026	01/07/2026

iii. Educational Accomplishments

The transportation and transportation-related courses offered during Fall 2024 and Spring 2025 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, **156 transportation and transportation-related courses** have been offered this reporting period, for a total of **475 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 **39 training events** were provided for transportation professionals during this reporting period and are listed in Appendix C. The dates following training are the development dates. In addition, we have had **201 online training modules** and **149 recorded sessions** that **7,450 transportation professionals have** utilized to strengthen their workforce skills.

c. How have the results been disseminated?

The 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) website postings and displays, (7) Internet-based dissemination media, including broadcast emails and webinars, and (8) You Tube 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?

Considerable progress has been made during this period. Altogether, 40 research projects have been selected, started, and are moving toward completion. Several reports on first-year projects are in the final stages of preparation. Moreover, a robust reporting workflow has been established to ensure the timely publishing of final project reports and an internal compliance review of all Year 1 and 2 projects has been launched. Several highlights from the reporting period are presented next.

Several early journal articles have been published from CTIPS-001 (Advanced Air Mobility (AAM) to Enhance Freight Logistics and Preserve Road Condition), yielding timely information about air freight in multimodal delivery, including several highly ranked international publications. In addition, NDSU has added a rural safety project (CTIPS-040) which focuses on innovative technologies and tools for safety enhancement in highly rural and persistently impoverished communities.

University of Colorado Denver's projects aimed at transportation asset maintenance are focusing on assembling geo-spatial datasets and cleaning records to highlight transportation-sector issues, while the investigation of high-injury networks has moved from conceptual groundwork to creating a comprehensive data framework and applying it to major U.S. metropolitan areas. The University of Denver's education programs have successfully graduated another cohort of master's students, bringing the number of students who have graduated from the program to over 165 since it was started with UTC funds under SAFETE-LU. In addition, a driver retention and success study (CTIPS-004) has been started that will improve transportation safety and effectiveness by targeting the time, effort, and resources of transportation organizations in a period of reduced resources.

University of Utah has selected and initiated 8 research projects. Progress has been made on all of them. Several highlights are mentioned next. In a project on data-driven inspection planning for Utah culverts using federated learning (FL) (CTIPS-005), an assessment of FL's feasibility for culvert condition prediction with limited data and the performance of FL models compared with traditional centralized machine learning models have been completed and the benefits have been quantified for UDOT. In a project focused on artificial intelligence and mobile phone-based pavement marking condition assessment and litter identification (CTIPS-007), an algorithm has been developed for auto-identifying pavement marking issues and litter on roads have been completed. In a project about optimizing guardrail placements to enhance road safety and mitigate road departure crashes (CTIPS-008), roadside features have been

extracted from pathway images and the impacts of roadside features on road departure crashes have been analyzed. In CTIPS-010, a method suitable to monitor pavement retro-reflectivity using LiDAR data with traditional statistical analysis and machine learning has been developed. In CTPIS-035, field observations of actual implementation of epoxy injection in a Utah bridge have been completed and other tasks to investigate the distribution of epoxy injection in delaminated panels and the effectiveness of the epoxy injection repair method under realistic conditions are underway. In CTIPS-037 (automated low-cost track monitoring technologies for rail thermal buckling prevention), a data acquisition system for long-term local resonance measurement has been developed and the training of a machine learning predictive tool based on collected field data is underway.

At Utah State University, artificial intelligence is being utilized to assist in developing evacuation plans that can be adapted to changes in real time (CTIPS-030), cementitious materials are being investigated to assess the viability of thin overlays to extend bridge deck useful life (CTIPS-031), and computer vision methods are being investigated to provide a more accurate and comprehensive description of bridge condition than can be achieved using conventional inspection techniques (CTIPS-032). In CTIPS-003, Fort Lewis College aims to develop a cost-effective unmanned underwater drone and sensing system for swift bridge scour assessment. The team has selected ArduPilot, a widely used open-source autopilot software package for vehicle navigation. All necessary components have been acquired and will be assembled onto a boogie board, transforming it into a surface boat for testing the ArduPilot system.

In CTIPS-038, United Tribes Technical College is working with the North Dakota Department of Transportation to become third-party CDL testers. Additionally, UTTC is collaborating with Nueta, Hidatsa, Sahnish College in New Town to help address its bus driver shortage on the MHA Reservation and partnering with Bismarck State College to help its students obtain their School and Passenger Bus endorsement. The two institutions are discussing testing each other's students in the future.

In CTIPS-011 (Application of Multispectral Sensing for Detection of Corrosion in Steel Infrastructure) University of North Dakota is increasing capacity for autonomous noncontact corrosion detection. In CTIPS-012 (The Impact of Connected and Autonomous Vehicle Technologies on North Dakota's Highway Infrastructure), UND is advancing technical knowledge, proposed policies, and practices for adaptation of autonomous connected vehicles in North Dakota.

Although the timing of Year 3 funding is uncertain, proposal development and project selection are underway and will continue throughout the summer. Moreover, continued activities are planned for all currently active projects. For example, two full-time students will be hired in summer 2025 to contribute to CTIPS-003, with the goal of producing publications and open-source software for broader use. FLC will also organize a summer workshop in July 2025 for 32 local middle school students, teaching them how to build and integrate electronics into a boat.

In the upcoming period, more energy will be invested in technology transfer by publishing and presenting research findings. For example, the findings of CTIPS-013 (Pavement Management System for Wyoming County Roads) will be presented at the Wyoming Transportation and Safety Congress in Casper, Wyoming. In addition, these findings will be presented at the Annual Meeting of the Wyoming County Commissioner Association in Lander, Wyoming. At the conclusion of the study, the findings will be shared with the Wyoming Legislature to secure funding for county paved roads in the state. The internal compliance review started in this reporting period will continue and all new proposals will be screened for compliance before being selected.

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 DOT & Public Facilities, Juneau, AK, financial support
- Association of American Railroads, Pueblo, CO, financial support

- Bismarck State College, Bismarck, ND, collaborative research, personnel exchanges
- 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
- Denver Regional Council of Governments, Denver, CO, subject matter experts
- Department of Transportation and Infrastructure, Denver, CO, subject matter experts
- Durango Community Recreation Center, Durango, CO, facilities
- Gerber Construction, Lehi, UT, in-kind support
- North Dakota DOT, Bismarck, ND, subject matter experts
- North Dakota State University, Fargo, ND, facilities, subject matter experts, financial support
- Nueta, Hidatsa, Sahnish College, New Town, ND, subject matter experts, facilities
- Sika USA, Lyndhurst, NJ, in-kind support
- South Dakota DOT, Aberdeen, SD, in-kind support
- South Dakota State University, Brookings, SD, facilities, in-kind support
- Structural Technologies, Columbia, MD, in-kind support
- Truck Load Carrier Association, Alexandria, VA, in-kind support, financial support
- UDOT Maintenance & Facility Management Division, Salt Lake City, UT, subject matter experts, personnel exchanges
- United Tribes Technical College, Bismarck, ND, financial support, facilities
- University of Illinois Urbana-Champaign, Urbana, IL, collaborative research
- Utah Department of Transportation, Materials and Structures Division, Salt Lake City, UT, subject matter experts
- Utah Department of Transportation, Salt Lake City, UT, financial support, subject matter experts
- Utah Transit Authority, Salt Lake City, UT, in-kind support
- Wyoming Association of County Engineers and Road Supervisors, Cheyenne, WY, subject matter experts
- Wyoming Department of Transportation, Cheyenne, WY, financial support, 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 63 principal investigators, faculty, and administrators at eleven universities in Federal Region 8. In addition, we have been able to support, mentor, and develop research skills and knowledge in transportation for 57 students from the U.S. and countries around the world. These include 5 post-doctoral researchers, 26 doctoral students, 17 master's students, and 9 undergraduate students. The following additional collaborators outside of the CTIPS consortium are working with PIs on projects:

- University of Colorado Denver: Nick Ferenchak, University of New Mexico
- University of Denver: Pooja Belur, Doctoral Student, University of Southern California
- University of Utah: John Popovics, University of Illinois, Urbana-Champaign; Anish Poudel, MxV Rail; and Hal Johnson, Utah Transit Authority
- Utah State University: Jovan Tatar, University of Delaware

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

a. Publications can be found in Appendix D

During the period, CTIPS faculty and investigators published **18 peer-reviewed articles or papers** in scientific, technical, or professional journals. Since the beginning of this grant, CTIPS researchers have published 29 different peer-reviewed articles or papers.

b. Conference papers can be found in Appendix D

This reporting period we have published **10 conference papers** and 15 total papers since the grant began.

c. Presentations can be found in Appendix D

CTIPS researchers have presented at **20 different scientific, technical, or professional conferences** during this period. In total, 29 presentations have been made 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. Examples of other outputs include:

Colorado State University. (1) The PIs of CTIPS-020 (Field-Testing and Optimizing UAS Transportation Infrastructure Inspection Methods) are in the process of teaching *Engineering with Drones*, a 400-level class at CSU, with a total of 18 undergraduate students enrolled. Students will be included in some of the testing runs that PIs are performing on a deteriorated airport runway. (2) The PIs of CTIPS-022 (Using a Cosmic Ray Neutron Rover to Measure Unpaved Road Moisture for Improved Maintenance and Safety) have made progress toward planning a route that will be driven in the summer to collect rover data. Preliminarily field measurement locations that will be used to evaluate rover data have been determined. There has also been progress toward understanding how the rover has been used in other studies and how this information can be used or incorporated into this project. (3) The PIs of CTIPS-025 (Transforming Infrastructure Inspection by Integrating a UAS with a Continuum Robotic Arm and AI-enabled Multimodal Sensing for Comprehensive Damage Assessment) have filed a provisional patent that includes the tensegrity robotic arm as a key component.

Patent Title: Mobile Robots with Shape-Changing Tensegrity Structures
Inventors: Sydney Spiegel, Jianguo Zhao, Jiefeng Sun, Andrew Stefka, Joshua Christler
Patent Application Number: US20240351370A1

University of Utah. An algorithm has been tuned that is capable of auto-identifying faded road markings and litter. This is the first important step for counting, geolocating, and visualizing these identified issues. The algorithm will be shared with the Utah DOT in the final delivery of the project for further implementation. In addition, a new methodology has been developed for assessing roadside safety using computer vision, with FHWA ratings as the key predictor of rural road departure crashes and their severity. A manuscript detailing this methodology, "Assessing Roadside Safety with Computer Vision: FHWA Ratings as the Key Predictor of Rural Road Departure Crashes and Severity," has been submitted to a journal and is currently under review. In addition, a new mathematical model for placing guardrails to reduce the number of road departure crashes in the most effective way has been developed and a methodology to automate the processing of LiDAR data to produce estimates of retro-reflectivity of pavement markings was presented at the TRB annual meeting. By utilizing LiDAR and retro-reflectivity data, the approach automates the identification and evaluation of lane markings, reducing manual effort and increasing accuracy.

Fort Lewis College has developed hardware and software for an anti-collision system designed to prevent a surface boat from colliding with objects while mapping the water surface. An anti-collision system is essential for an autonomous vehicle during water surface mapping. While the vehicle's autonomous navigation system manages coordinates and locations, it cannot detect obstacles on the water. Integrating the vehicle with the anti-collision system enhances safety and ensures a thorough mapping process. In February 2025, the FLC team conducted a workshop in Nevada, teaching an eCYBERMISSION middle school team how to program and assemble the anti-collision system for a boat. The system's hardware and software designs will be made publicly accessible through GitHub and peer-reviewed articles.

United Tribes Technical College. In February 2025, UTTC conducted an eight-hour training session in collaboration with the North Dakota LTAP, providing essential education to state, county, and city agencies. The training, hosted at United Tribes, focused on key topics such as safety, general maintenance, and the basic operation of equipment commonly used in daily operations. Hands-on training that encouraged active participation and interaction among attendees was provided utilizing the equipment available on UTTC's campus. The session fostered valuable connections between UTTC's program and local agencies, strengthening partnerships that can lead to future training opportunities. The firsthand approach and direct engagement with agency personnel have contributed to enhanced workforce readiness, promoting safer and more effective equipment operation.

University of North Dakota. A VISSIM microsimulation model has been developed for the I-29 corridor between Grand Forks and Fargo, incorporating an adjusted car-following model to better replicate actual driver behavior in rural settings. Additionally, two research manuscripts are being prepared for submission to the TRB Annual Meeting.

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.

Colorado State University. The outcomes of projects underway at CSU will include: (1) improved understanding of transportation infrastructure conditions through advanced sensing and inspection methods; (2) enhanced awareness of the environmental and social impacts of transportation systems; and (3) greater understanding of how road conditions and maintenance practices affect public safety and infrastructure longevity. These outcomes are being realized through the implementation of innovative sensing technologies and the generation of real-world data for research and practice. The projects focused on UAV-based inspections, neutron rover sensing, and crowdsourced pavement monitoring are expanding practical knowledge and helping transportation professionals make better-informed decisions.

North Dakota State University. CTIPS-001 will raise awareness of autonomous aircraft cargo logistics, highlighting adoption prospects, deployment challenges, and implications for planning and policy development. Additionally, through targeted stakeholder outreach and presentations at key industry forums and conferences, the project will stimulate informed discussions among transportation planners, policymakers, and industry leaders. Anticipated outcomes of CTIPS-002 include a bottom-up crack propagation simulation combined with sensitivity analysis that provides valuable insights into how various parameters affect crack initiation and propagation in pavements for more accurate predictions of crack behavior under different traffic loading conditions. This will lead to more resilient and long-lasting pavement designs and preparation for two-layer pavement specimens with distributed fiber optic sensing (DFOS), allowing real-time monitoring of crack propagation. CTIPS-040 aims to develop, refine, and transfer knowledge about traffic safety planning and decision resources to rural and Tribal communities.

South Dakota State University's projects will result in: (1) improved manual bridge inspections (which are time consuming, error prone, and sometimes inconsistent) through applications of computer vision; (2) expedited damage identification and quantification using images of bridge elements; (3) computer-

vision software that automates measurements and reporting of defects for bridge decks; and (4) utilization of digital image correlation (DIC), along with the necessary hardware and software, to field test bridges using computer vision (including either a ground DIC and/or drone-DIC system).

University of Colorado Denver. The use of 311 complaint data in CTIPS-026 uncovers gaps in urban transportation asset maintenance and encourages more informed decision-making, while CTIPS-027 establishes a standardized approach that highlights critical corridors prone to severe crashes, helping cities identify common design flaws and foster conversations about safer infrastructure. At the same time, CTIPS-028 broadens knowledge of durable approaches to preserving existing transportation structures, illustrating how ultra-high performance concrete overlays can effectively extend the lifespan of bridge decks and ultimately promote more robust and resilient transportation networks.

University of Denver's work is contributing to a better understanding of workforce development needs and addressing the factors that affect driver shortages in the trucking industry.

University of Utah. The main outcome of CTIP-005 is demonstrating how cutting-edge machine learning techniques can revolutionize infrastructure management. The main outcome of CTIPS-008 is the development of a methodology for identifying optimal locations for deploying guardrails, leveraging both image data and statistical analysis. The expected outcome of CTIPS-010 is an automated decision support tool for transportation engineers, while the expected outcome of CTIPS-035 is improvement in repair methods for bridge decks constructed using partial-depth prestressed concrete panels and a cast-in-place concrete topping. The outcome of CTIPS-037 is an improved understanding of sensing and machine learning technologies, which can potentially manage thermal stress in continuous welded rails to prevent thermal buckling. The expected outcome of CTIPS-036 is an improved understanding of the behavior of highly modified asphalt mixtures, which will lead to development of new materials that could result in cost-effective road surfaces.

University of Wyoming. CTIPS-013 will improve understanding of transportation issues by providing data-driven insights into how road conditions and characteristics affect maintenance decisions. It will help local authorities develop a standardized approach to maintenance and rehabilitation planning, reducing reliance on subjective judgments. By integrating findings into academic courses, the research will also educate future professionals on effective transportation management.

The outcomes of **Utah State University's** projects include: (1) using AI to improve and update evacuation plans; (2) improving the durability and performance of bridge decks by using novel thin overlays; and (3) developing a new class of computer vision that improves bridge condition assessment, which will improve maintenance programs with more robust automation. These outcomes will be achieved through the collection of the current state of the art in these areas and advancing evacuation plans to adjust as needed using AI. Bridge durability will be enhanced by using better and novel materials in deck repair as well as improving inspection, leading to longer useful bridge life.

Fort Lewis College. By utilizing the system developed in CTIPS-003, engineers can better detect and assess structural vulnerabilities caused by water erosion. The project's findings and tools will be published on GitHub, making them freely accessible to civil engineers seeking to enhance the efficiency and effectiveness of scour monitoring techniques. Additionally, a summer workshop will be hosted to educate participants on transportation safety, bridge monitoring strategies, and infrastructure resilience.

United Tribes Technical College. CTIPS-038 addresses the critical need for more professionals in the trucking and school bus workforce, with the goal of unifying schools in both curriculum and teaching methods to ensure consistency and quality in training. A key objective is the fostering of communication among instructors. To facilitate this, all Tribal instructors who teach CDL programs will come together at the UTTC Tribal Leaders Summit in the fall, which will provide an opportunity to discuss each program's strengths and areas for improvement, ultimately leading to a more robust, education-focused program.

University of North Dakota. Technical knowledge about the reflectance properties of corroded steel is being generated in CTIPS-011, describing visual and spectral properties of corroded and non-corroded steel specimens. Several presentations and an under-review journal paper have been produced. CTIPS-012 identifies potential adverse and positive effects of CAVs on state surface transportation systems by synthesizing research and practical insights. The project highlights current advancements, technological implementations, and potential gaps requiring attention in the short and long term for adaptation of CAVs.

b. Passage of new policy, regulation, rulemaking, or legislation.

Colorado State University. Research at CSU will: (1) provide evidence to support future regulations that target the root causes of resuspension emissions; (2) encourage public-private partnerships toward the use of advanced materials in infrastructure; and (3) contribute to policy development related to the use of advanced robotic inspection technologies for bridge maintenance. The anticipated outcomes include initiation of collaborative structures such as task forces to guide material innovation in public infrastructure and the development of policy frameworks that recognize and support robotic inspection methods in transportation infrastructure.

North Dakota State University. Findings from advanced air freight mobility research (CTIPS-001) are expected to inform and assist stakeholders and policymakers, with preliminary results already disseminated to influential bodies like the North Dakota Aeronautics Commission and the Northern Plains UAS Test Site. These interactions will facilitate evidence-based discussions, potentially catalyzing new regulatory frameworks and funding initiatives specifically tailored for AAM. This collaborative approach could lead directly to targeted legislation and policy adjustments that provide clearer pathways and incentives for broader AAM adoption in logistics, emergency services, and rural connectivity.

University of Colorado Denver's CTIPS initiatives have the potential to shape future policies and regulations by supplying decision-makers with rigorous, data-based evidence of how specific infrastructure design or maintenance choices affect community safety and asset longevity. For example, applying a standardized approach to identifying high-injury corridors can spotlight persistent design problems linked to severe crashes. Likewise, research on the benefits of ultra-high performance concrete overlays in bridge maintenance can guide the creation of new technical guidelines, translating cutting-edge findings into policies that incentivize more durable transportation infrastructure.

University of Utah. CTIPS-035 will offer Utah DOT more information on the causes of delamination of partial depth precast concrete panels used in the construction of bridge decks and the method to repair such bridge decks, while CTIPS-036 is expected to result in a provisional specification to allow a new type of asphalt mixture to be used as road surface.

University of Wyoming. CTIPS-013 (A Pavement Management System for Wyoming County Roads) provides data-driven insights that can help policymakers create standardized guidelines for pavement maintenance and repairs. By demonstrating the benefits of a structured maintenance prioritization system, the research may influence regulations requiring counties to adopt consistent, evidence-based decision-making tools. Additionally, findings on financial requirements could support new policies aimed at securing funding and improving road conditions.

c. Increase in the body of knowledge.

Colorado State University. The projects at CSU will result in enhanced knowledge of how soil moisture levels affect the preservation and maintenance of gravel roads; identification of vehicle-specific characteristics that influence resuspension emissions; expanded understanding of conductive geopolymer concrete as an alternative construction material; and new insights into the use of UAS-based contact inspection methods and multimodal sensing for detecting structural degradation in transportation infrastructure.

North Dakota State University. CTIPS-001 substantially enriches the field's technical knowledge base regarding emerging cargo drone technologies and their potential to shift transport modes from surface vehicles to aerial solutions. It is anticipated that CTIPS-002 will provide practical guidance on how reflective cracks from existing concrete propagate into the asphalt overlay. Understanding these mechanisms is crucial for improving the durability and performance of asphalt-concrete composite pavements.

South Dakota State University. The projects at SDSU will increase the body of knowledge through a comprehensive inspection database (including RGB, thermal, and LiDAR scans) generated from various devices and the use of this new database to train AI models to find defects in bridge decks. Further outcomes may include a database that can be used by other researchers and a software tool, built on open-source computer vision libraries with a user interface, that will be publicly available.

University of Colorado Denver. The high-injury network study provides a standardized framework for identifying and understanding severe crash corridors across different urban settings, helping uncover common design and operational factors that persistently contribute to collisions. Moreover, CUD's research on ultra-high performance concrete overlays adds to existing knowledge by highlighting the complex interaction between new and existing concrete, supporting more durable bridge design. Similarly, work on a maintenance optimization system harnesses machine learning and operations research methods to predict bridge deterioration, refine long-term planning, and optimize resource allocation.

University of Denver's research will contribute to the understanding of the factors that influence 1) driver turnover, 2) job satisfaction, and 3) truck driver safety.

University of Utah. CTIPS-005 demonstrates that federated learning can overcome limitations of culvert inspection by enabling multiple DOTs to collaboratively train machine learning models without sharing raw data. CTIPS-007 will contribute new insights into how mobile phone-based data collection, combined with computer vision algorithms, can provide accurate, scalable, and cost-effective alternatives to traditional manual inspections and inspire further innovation in smart infrastructure management. CTIPS-008 will offer insights into methodologies for assessing roadside conditions and the optimal placement of guardrails. The development and validation of a tool to estimate retro-reflectivity of pavement markings using LiDAR (CTIPS-010) will clarify the relationships between field-measured retro-reflectivity of pavement markings and LiDAR datasets. Research on delamination of partial-depth panels in concrete bridge decks (CTIPS-035) will increase knowledge on repairing bridge decks constructed with partial depth precast concrete panels. CTIPS-037 will improve understanding of how sensing and machine learning technologies can help manage thermal stress in continuous welded rails and prevent rail thermal buckling. CTIPS-036 will improve understanding of the behavior of highly modified asphalt mixtures, leading to the development of cost-effective new materials.

University of Wyoming. CTIPS-016 will enhance the understanding of potential issues related to overtaking truck platoons on two-lane highways, as well as potential strategies to mitigate impacts on traffic safety and operations. Publications will include the results of simulation evaluations of a wider range of truck platooning-related highway safety and operational issues and potential variable regulatory strategies. CTIPS-033 will enhance transportation knowledge by advancing real-time intersection sight distance (ISD) measurement using vehicle-to-vehicle (V2V) communication, GPS, and deep learning. The research will refine ISD assessment methods, improve safety analysis, and provide insights into obstruction impacts through simulation.

Utah State University's projects will have the following outcomes pertaining to the increased body of knowledge in transportation: (1) the AI powered tool project will generate new knowledge regarding personal behavior during emergency evacuations; (2) the thin overlay project will generate hard experimental data to support the use of various bridge deck overlays in bridge maintenance applications;

and (3) the computer vision project will generate new methods for incorporating computer vision models along with visual inspection to enhance bridge maintenance practices.

Fort Lewis College. The published software and hardware technical files from CTIPS-003 will increase the body of knowledge on riverbed mapping vehicles.

United Tribes Technical College. CTIPS-038 will generate more qualified professionals in the trucking and school bus workforce and ensure consistency and quality in training by identifying best practices in curriculum and teaching methods.

University of North Dakota. In CTIPS-011, hidden properties of corrosion have been identified in a noncontact sensing manner, which can have far-reaching implications on how corrosion inspection, condition assessment, and preservation of transportation infrastructure can be augmented. CTIPS-012 provides new knowledge for adaptation of CAVs in response to autonomous driving needs in rural regions.

d. Improved processes, technologies, techniques and skills in addressing transportation issues.

Colorado State University's projects will have the following outcomes pertaining to the improved processes, technologies, techniques, and skills: (1) enhanced methods for monitoring unpaved road moisture using a cosmic ray neutron rover; (2) a potential alternative material for snow and ice management on roadways; (3) advancement of bridge inspection techniques through UAS-enabled, sensor-integrated technologies; and (4) improved student skills in ethical reasoning and critical thinking related to transportation decision-making. Further anticipated outcomes may include: (1) new gravel road maintenance protocols based on neutron sensing data; (2) more efficient winter maintenance practices through the adoption of snow-melting concrete; and (3) broader implementation of sensor-fusion-based UAS inspection technologies for structural health monitoring.

North Dakota State University. Advanced air mobility research from CTIPS-001 will enhance technical competencies in GIS, spatial analysis for mode optimization, data science, and machine learning techniques. Furthermore, by applying these advanced methods to real-world logistics challenges, the research will demonstrate the practical utility of these technologies in improving transportation planning, predicting infrastructure needs, and optimizing logistical routes. Continued research and outreach commitment to highly rural and persistently impoverished areas in CTIPS-040 will strengthen local decision processes to identify and address traffic safety priorities.

South Dakota State University. The computer vision-based inspection software tool, which is an anticipated outcome, will improve the routine bridge inspection process by automating data collection, defect quantification, and inspection reporting, saving time and reducing errors and inconsistencies. These outcomes are expected to improve the bridge load rating process by utilizing new technology, offering comparable accuracy at a lower cost and with reduced instrumentation effort.

University of Colorado Denver's projects are improving processes, technologies, techniques, and skills by introducing innovative frameworks and materials that address pressing transportation challenges. For instance, the standardized approach to analyzing high-injury networks refines data handling and GIS-based tools, helping transportation professionals more accurately identify collision hot spots and uncover design issues. At the same time, research on ultra-high performance concrete overlays advances practical knowledge about sustaining and upgrading bridge decks, giving engineers and practitioners new methods to extend the lifespan of transportation structures.

University of Denver. It is expected that the results of CTIPS-004 can be converted to a standard selection and screening tool for online use that can be readily deployed in the operational environment to determine characteristics of drivers who will likely enter the trucking industry and remain for many years. It is hoped the technology will lead to a reduction in turnover and an increase in driver retention.

University of Utah. Research from CTIPS-008 will refine methodologies for analyzing roadside conditions, evaluate the effectiveness of guardrail placements, and optimize safety measures using innovative computational approaches. The research stemming from CTIPS-010 will reduce reliance on specialized data collection by reusing existing LiDAR datasets already collected by DOTs, with the potential to reduce costs and streamline decision making The research emanating from CTIPS-035 will demonstrate the effectiveness of a repair method using epoxy injection for bridge decks constructed using partial depth precast concrete panels and allow practicing engineers to determine when such repair methods are appropriate. In CTIPS-037, a non-contact and low-cost sensing platform has been developed for rail thermal stress measurement in a non-destructive and non-disruptive manner while research from CTIPS-036 will show how a new type of asphalt mixture can be used in field applications.

University of Wyoming. The anticipated outcome of CTIPS-033 is the enhancement of intersection sight distance evaluation through advanced communication and real-time data processing, which will improve measurement accuracy, support better intersection design, and contribute to safer traffic operations.

Utah State University's projects are expected to have the following outcomes: (1) the AI project will help people navigate emergency situations to a safe outcome; (2) the thin overlay project will provide documented approaches to improve the current methods; and (3) the computer vision project will improve data analytics in bridge monitoring.

Fort Lewis College. Advancements in software and hardware will introduce innovative technical solutions for riverbed mapping projects, offering a new, cost-effective approach to monitoring bridge scour.

e. Enlargement of the pool of trained transportation professionals.

Colorado State University. The projects at CSU are having the following outcomes: (1) students are gaining practical training and licensure in drone operation and data collection through coursework linked to infrastructure inspection methods; (2) student learning in gravel road monitoring and maintenance is being supported through hands-on experience with specialized sensing technology; and (3) faculty and students are gaining greater awareness of transportation's environmental and societal impacts through multimedia educational materials.

North Dakota State University. In CTIPS-001, undergraduate and graduate students develop 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. CTIPS-002 is expected to provide valuable research opportunities for students, enhancing their skills in crack propagation simulations and sensor technology.

University of Colorado Denver's projects enlarge and enhance the pool of trained transportation professionals by involving students and researchers in highly practical data-driven work. By analyzing 311 complaint records, participants develop skills in big-data scoping and analysis, making them valuable to public and private organizations. They also gain firsthand experience with GIS, crash analysis, and standardized methodologies for identifying high-injury corridors, nurturing their ability to tackle complex road safety issues. Further opportunities in experimental design, physical testing, and data analysis for innovative bridge deck solutions enrich students' technical and problem-solving capabilities.

University of Denver's project will contribute to increasing the pool of 1) trained professionals, 2) truck drivers, and 3) transportation managers by informing them of whom to select as new hires.

University of Utah. The research from CTIPS-035 will allow engineers to understand and effectively address the issue of bridge deck repair. This will improve economic competitiveness and allow the bridge

decks to have longer life spans. The research from CTIPS-036 can be used to train engineers on how a new type of asphalt mixture can be used in field applications.

Fort Lewis College is providing undergraduate students interested in transportation safety with firsthand training in advanced technologies for monitoring bridge conditions. The published materials will serve as a valuable resource for transportation professionals, helping them identify more effective methods for evaluating bridge safety.

United Tribes Technical College. The integration of simulation-based training is expected to provide valuable insights into the effectiveness of advanced technology in driver education. The new simulator will allow UTTC to assess how virtual training environments improve driver preparedness, retention rates, and overall safety outcomes. Moving forward, this project may serve as a model for future studies on the role of simulation technology in vocational training.

f. Adoption of new technologies or practices.

Colorado State University. The projects at CSU are expected to have the following outcomes: (1) the creation of a new drone model and use of visual equipment to support transportation infrastructure inspection; (2) the demonstration of the feasibility of using crowdsourced data from rideshare vehicles for pavement condition monitoring; (3) the introduction of a cosmic ray neutron rover as a non-destructive and rapid method for measuring unpaved road moisture; and (4) the development of a continuum robotic arm integrated with a UAS for contact-based inspections in hard-to-reach infrastructure locations. These outcomes reflect direct project efforts to develop and test new methods and technologies aimed at improving how transportation systems are evaluated, maintained, and understood. Educational tools and new sensor-based inspection platforms are being designed and tested.

North Dakota State University. Advanced air freight mobility findings from CTIPS-001 will promote the adoption of electric vertical take-off and landing (eVTOL) aircraft as replacements for traditional helicopters, offering quieter, safer, and more efficient air mobility solutions for freight, passenger transport, and last-mile deliveries, especially in rural communities. Additionally, demonstrating successful real-world use cases in critical applications such as healthcare and same-day rural deliveries will validate the practicality and efficiency of eVTOL aircraft and related infrastructure and systems, thus encouraging broader industry acceptance, regulatory support, and accelerated commercial deployment of advanced air mobility solutions.

University of Colorado Denver's projects are fostering the adoption of new technologies, techniques, and practices through firsthand exploration of cutting-edge methods and tools. For instance, by developing and testing standardized high-injury network methodologies, researchers and students learn advanced data collection, modeling, and GIS skills, which can then be integrated into real-world road safety strategies. Meanwhile, the findings on ultra-high performance concrete overlays have the potential to refine DOT practice guidelines, encouraging wider use of more durable bridge upgrades. In parallel, CUD's research on maintenance optimization introduces advanced machine learning and optimization techniques, enabling transportation agencies to transition from reactive to predictive maintenance. Moreover, producing a prototype software tool for data-informed asset management paves the way for AI-driven approaches that can be adopted and scaled by state DOTs, ultimately setting new standards for infrastructure maintenance.

University of Utah. The research being conducted in CTIPS-005 has resulted in the adoption of federated learning as an innovative technology for infrastructure condition prediction, offering a privacy-preserving and data-efficient approach to transportation asset management. The research in CTIPS-007 has resulted in interest from UDOT in developing plans to adopt new technologies (AI algorithms) for automated pavement marking condition assessment and litter identification. The research from CTIPS-008 has demonstrated how computer vision, coupled with data science methods, can be used to assess roadside

safety effectively. The research from CTIPS-010 uses automation processes to ingest LiDAR datasets and produce estimates of retro-reflectivity of pavement markings using machine learning algorithms. In CTIPS-035. repair techniques are being proven for different bridge deck conditions, both experimentally and numerically, demonstrating the usefulness of the bridge deck repair method. The non-contact low-cost sensing system developed in CTIPS-037 is expected to assist in the inspection and evaluation of railway infrastructure.

University of Wyoming. CTIPS-033 will facilitate the adoption of advanced sensor integration, vehicle-to-vehicle communication, and deep learning techniques for real-time intersection sight distance measurement. These outcomes will improve data accuracy, streamline assessment processes, and enhance decision-making for transportation agencies.

Fort Lewis College. The primary objective of CTIPS-003 is the development of a new mobile monitoring system to enhance bridge safety, replacing traditional stationary monitors. This innovative technology has the potential to revolutionize scour assessment by enabling the evaluation of multiple bridges in a short time while significantly reducing material and labor costs.

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's projects are expected to have the following impacts: (1) enhanced efficiency and timeliness in transportation infrastructure inspection; (2) improved pavement condition monitoring through crowdsourced data; (3) increased effectiveness of gravel road maintenance through real-time moisture monitoring; (4) reduced roadway air contaminants through a better understanding of resuspension emissions; (5) improved durability and sustainability of concrete infrastructure; and (5) earlier detection of bridge damage through advanced inspection technologies.

North Dakota State University. The propensity to shift certain cargo flows away from surface transportation modes through advanced air freight mobility (CTIPS-001) can help reduce congestion, emissions, and loads on roads and railways, increasing their longevity and reducing maintenance costs. By developing more accurate simulations and experimental validations of bottom-up crack propagation in pavement structures, CTIPS-002 will enable timely and effective pavement maintenance. Early detection of cracks and a better understanding of their propagation will allow for preventive repairs.

South Dakota State University's projects will result in: (1) substantial reductions of time and cost in bridge deck inspection; (2) automation in bridge inspection data processing and reporting; (3) reductions of bridge field testing time, effort, and cost by eliminating conventional sensors and data acquisition systems; and (4) more realistic and reliable load ratings.

University of Colorado Denver's projects are enhancing transportation effectiveness by using 311 complaint data to uncover underreported maintenance issues, applying standardized methods to pinpoint high-injury corridors, exploring ultra-high-performance overlays to extend bridge life, and refining predictive maintenance models that reduce disruptions and optimize resources. These efforts are expected to yield cost-effective infrastructure upgrades, improved road safety, and more durable transportation networks.

University of Denver's research will improve understanding of the factors affecting driver retention and the project will increase 1) driver satisfaction, 2) longevity, 3) safety, and 4) workforce efficiency.

University of Utah. The federated learning approach in CTIPS-005 could lead to widespread adoption of AI-driven predictive maintenance strategies, which would improve transportation system reliability and

promote data-driven decision-making. A seismic inversion technique developed in CTIPS-009 can accurately detect small-scale subsurface anomalies to enable implementation of corrective measures, helping prevent significant damage and mitigate the risk of catastrophic roadway failure. The approach implemented in CTIPS-010 has demonstrated the potential to obtain reliable retro-reflectivity assessments to comply with new FHWA regulations. The repair methods from CTIPS-035 will improve the state of bridge decks with delamination issues and reduce life-cycle costs by avoiding complete replacement.

University of Wyoming. CTIPS-013 will provide decision makers in Wyoming with the dollar figures needed to fund paved county roads. These roads are currently underfunded and need significant state investments. CTIPS-033 will facilitate the development of a device to enhance intersection safety.

Utah State University. Projects at USU will lead to quick and efficient evacuation of people in emergency situations, saving lives and property; and by preserving bridge decks, they will extend the lives of bridges, thereby saving money and minimizing traffic delays.

Fort Lewis College. Current stationary scour monitoring systems are expensive and challenging to maintain. By introducing a mobile and autonomous mapping and evaluation system, FLC aims to transform scour monitoring methods, offering civil engineers a more cost-effective alternative.

United Tribes Technical College. The initiative to bring Tribal CDL instructors together at the UTTC Tribal Leaders Summit is expected to foster knowledge sharing, enhance instructional techniques, and create a more cohesive training network. This, in turn, will improve workforce readiness and address critical shortages in the trucking and school bus industries.

University of North Dakota. Both projects provide new insights into technology-driven transportation systems, enhancing the overall effectiveness of transportation. UND's projects offer fresh perspectives in autonomy, and the results can be used to allow authorities to make roads and bridges safer.

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's projects are expected to have the following impacts: (1) development of guidance for UAS-based infrastructure inspections to inform industry standards; (2) promotion of crowdsourced pavement monitoring tools to state agencies such as the Colorado Department of Transportation (CDOT); (3) introduction of a new moisture estimation technique using a cosmic ray neutron rover for unpaved road maintenance; (4) advancement of a policy outline to guide regulatory strategies for resuspension emissions based on vehicle characteristics; and (5) preparation for the adoption of new materials practices involving conductive geopolymers and recycled byproducts.

North Dakota State University. The AAM publications released this reporting period from CTIPS-001 will enhance awareness of the research and its objectives. Once validated, the technology developed in CTIPS-002 will provide a reliable, real-time method for detecting cracks, offering a superior alternative to traditional inspection methods. The data-driven and strategic approach to community safe travel being developed in CTIPS-040 will enhance traffic safety decisions in highly rural impoverished communities.

South Dakota State University. The use of LiDAR-sensors in smartphones and RGB-thermal sensors in drones will allow transportation agencies to collect information quickly and safely using cutting-edge technologies. The use of state-of-the-art AI models to detect defects in point cloud, RGB, and thermal maps of bridge decks will partially automate bridge asset management. The use of cutting-edge and open-source computer vision technologies to allow non-contact measurements of bridge displacements without the need for conventional sensors will improve bridge engineering. Moreover, substantial reductions in the cost and effort of bridge field testing can be realized through the implementation of these research findings.

University of Colorado Denver. During this period, CTIPS projects have helped spur new practices by demonstrating how 311 data can guide more effective maintenance priorities, offering a standardized framework for pinpointing high-injury networks, and showing how ultra-high performance concrete overlays might shape updated guidelines. Further, these projects have laid the groundwork for commercializing predictive analytics and optimization tools that shift agencies toward proactive maintenance approaches, setting new standards for data-driven infrastructure management.

University of Denver's research results will likely lead to an improvement in recruitment and selection processes and in technology, which is one of the top five major concerns of the trucking industry.

University of Utah. In CTIPS-005, researchers introduced a new data-sharing paradigm in infrastructure management that allows transportation agencies to collaborate on predictive modeling without sharing raw inspection data, particularly for predicting and pinpointing culverts in poor condition. In CTIPS-009, a more efficient and accurate method for detecting subsurface anomalies in transportation infrastructure has been introduced. This approach has the potential to reduce data acquisition costs and improve the resolution of seismic imaging in complex geological settings. CTIPS-007 has set the stage for adopting innovative practices in roadway management by laying a strong foundation for future integration of AI into transportation workflows, with the potential for transforming transportation agency practices with reduced routine workload burdens. Guidelines are being developed in CTIPS-010 to reduce the contracting needs and reliance on field data collection using specialized equipment by leveraging existing LiDAR datasets that the state already owns.

Utah State University. USU's projects will provide useful tools for companies and government agencies to improve their practices. Moreover, the results may lead to the adoption of novel materials that could be utilized on bridges and online databases used by industry practitioners, thus streamlining inspections.

Fort Lewis College. The system developed in CTIPS-003 will offer civil engineers an alternative method for efficiently monitoring bridge piers. Once completed, it has the potential to be adopted by civil engineering contractors for rapid and effective pier and scour assessments, thus enhancing bridge safety.

United Tribes Technical College. By analyzing training outcomes and workforce placement data, UTTC anticipates contributing to research on the effectiveness of standardized CDL training, the impact of online learning in technical skill development, and strategies for addressing workforce shortages in the trucking industry. Additionally, potential integration of new training technologies—such as simulation-based learning—may provide opportunities for further study and innovation in transportation education.

University of North Dakota. The knowledge gained from CTIPS-011 is expected to help government and industry develop real-time detection of corrosion. The advanced simulation practices, particularly microsimulation modeling, from CTIPS-012 may be adopted by transportation agencies, which could enhance decision-making for CAV deployment and infrastructure planning.

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

Colorado State University. The projects at CSU will: (1) improve understanding of how to compare and optimize drone-based inspection methods for transportation infrastructure; (2) enhance knowledge of how specific vehicle types influence resuspension emissions; (3) introduce new methods for estimating road moisture by separating it from landscape moisture using remote sensing data; (4) produce insights into the use of crowdsourced rideshare vehicle data and machine learning for pavement condition monitoring; and (5) contribute to the development of sustainable construction materials through the study of fly ash and graphene nanoplatelet-enhanced geopolymer concrete.

North Dakota State University. Surveys of literature and industry in CTIPS-001 will be used to quantify the performance and capacities of drones, architecture types, and applications. Publications will demonstrate the positive benefits of moving cargo to electrified aircraft as well as the potential downsides

and how those could be mitigated. The technology transformation for advanced crack propagation simulations and the integration of sensor technology in CTIPS-002 are likely to influence future practices in government and industry and improve pavement monitoring and maintenance.

South Dakota State University's projects will have the following impacts: (1) the RGB, thermal, and LiDAR scan database developed in the previous period has been used to train AI models for defect detection; (2) the trained AI models have been integrated into a software platform with a user-friendly interface; (3) the first draft of the software has undergone testing using the database developed in the previous term; (4) the software will be built on open-source Python libraries and will be publicly available.

University of Colorado Denver's projects have helped improve transportation research by introducing novel applications of 311 data for maintenance needs, offering a standardized framework to identify high-injury roads, and delving into multi-material interactions that deepen understanding of concrete overlay mechanics. In addition, integrating machine learning and optimization for bridge management represents a pioneering step in data-driven asset management, setting the stage for more advanced methodologies in infrastructure research.

University of Denver. The outcomes of DU's projects will clarify understanding of the relative importance of factors affecting retention in the trucking industry. It is known that driver pay is important, but the question of how important and what other factors contribute is less understood.

University of Utah. Trade-offs between data privacy, model accuracy, and computational efficiency have been quantified, providing a scientific basis for selecting the most suitable AI models for asset management and new methods for roadway condition assessment. Advanced understandings of how mobile-based data collection and computer vision can be applied to transportation infrastructure monitoring have resulted from the research. Moreover, it has been demonstrated that reliable estimates of retroreflectivity can be obtained from LiDAR datasets to develop classification methodologies leading to maintenance decisions.

University of Wyoming. CTIPS-033 will contribute to engineering knowledge by introducing a novel approach to measuring intersection sight distance in real-world conditions. The findings will provide valuable insights into the role of obstructions, vehicle positioning, and environmental factors in sight distance availability. CTIPS-034 will support decision making for preventive maintenance.

Utah State University's projects will provide new knowledge about human behavior in emergencies and how formulations of non-proprietary engineered cementitious composite overlay materials can be used in transportation and other applications. The outcomes will significantly advance knowledge of how drone imagery can be leveraged to extract beyond simple object detection and semantic segmentation applications, mimicking how bridge inspectors assess bridge conditions.

Fort Lewis College. Software and hardware have been developed for a boat anti-collision system. Through this process, relationships between the boat's speed and the effective range of the ultrasonic anti-collision sensor have been analyzed, providing guidelines for future research and development.

United Tribes Technical College. By collecting data on trainee performance before and after simulator use, UTTC will contribute to research on the best practices for CDL instruction, particularly for school bus endorsements. As more individuals complete training and enter the workforce, further insights will be gained on how standardized, technology-enhanced training impacts transportation workforce shortages. Moving forward, the effort may serve as a model for future studies on the role of simulation technology in vocational training, potentially influencing broader advancements in education.

University of North Dakota. The methods developed in CTIPS-011 to measure corrosion by analyzing the diffuse reflectance properties of structural steel surfaces and the new noncontact tools will help monitor steel corrosion. The findings will enhance future research on corrosion characteristics and enable

detection of steel corrosion before it becomes visible using diffuse spectroscopy. The outcomes of CTIPS-012 are expected to influence state-level regulatory and planning practices by providing foundational data about the impacts of CAVs on traffic flow and capacity.

d. What is the impact on transportation workforce development?

Colorado State University's projects will have the following impacts: (1) hands-on research and technical training opportunities for undergraduate and graduate students in transportation and related disciplines; and (2) new course content and interactive educational materials aimed at preparing students for careers in transportation. Graduate and undergraduate students have participated in a variety of research activities across projects, including programming robotic systems, conducting fieldwork with advanced sensing equipment, and analyzing transportation data. These experiences are equipping students with practical skills and exposure to emerging technologies in infrastructure inspection and engineering.

North Dakota State University. In CTIPS-001, undergraduate and graduate students develop Python scripting and literature review skills to create machine learning models that can identify and rank societal benefits from freight innovation and cost-effectiveness. CTIPS-002 is expected to provide student research, enhancing student skills in crack propagation simulation and sensor technology.

South Dakota State University. Several Ph.D. students benefited from the experimental and analytical activities in the projects and have been encouraged to work as bridge engineers or software developers.

University of Colorado Denver's CTIPS projects strengthen workforce development by training graduate students in advanced data analysis, GIS, and predictive modeling; preparing them for roles in both government and private industry; creating hands-on learning opportunities; and introduce emerging technologies like AI-driven asset management, ensuring that a new generation of transportation professionals will be better equipped to address evolving infrastructure challenges.

University of Denver's CTIPS projects will continue to develop a more effective workforce in terms of researchers working in the industry, managers leading the industry, and drivers operating equipment.

University of Utah. Graduate students are gaining hands-on experience in advanced machine learning techniques and their application in transportation asset management. The findings of CTIPS-009 are being incorporated into a graduate course: Signal Processing and Inverse Problems. By integrating the methodologies and results from this research into the course materials, the project provides students with the latest tools and techniques used in the field, thus bridging the gap between research and practice.

University of Wyoming. All UW project findings will be integrated into transportation-related classes. As an example, CTIPS-013 (A Pavement Management System for Wyoming County Roads) will be part of the materials for the UW pavement management class for graduate students.

Projects at **Utah State University** will impact transportation workforce development by giving experiences to students working on the actual projects. These students will graduate and enter the workforce with specialized knowledge and experience garnered through their graduate studies. Several undergraduate students also work on each project.

Fort Lewis College. Two undergraduate students were hired for the CTIPS project and the FLC team mentored a middle school group in Nevada for the eCYBERMISSION design competition.

United Tribes Technical College. A key component of UTTC's effort will be the integration of a new driving simulator, which allows trainees to practice real-world scenarios in a controlled environment. This technology enhances training by providing hands-on experience without the constraints of vehicle availability.

University of North Dakota. The findings of CTIPS-011 are being leveraged to engage high school and undergraduate students in learning about diffuse spectroscopy for detecting steel corrosion. The principal

investigator (PI) has introduced a course, "Application of AI in Civil Engineering (CE 590)," incorporating the project's dataset and model to inspire student research. This initiative aims to develop a skilled workforce familiar with diffuse spectroscopy, a noncontact technology for assessing infrastructure conditions. CTIPS-012 is expected to positively affect the transportation workforce by providing current and future professionals with specialized knowledge in connected and autonomous vehicle (CAV) technologies. It will also enhance engineering curricula by developing course materials on traffic simulation and CAV applications. This educational effort will prepare the workforce to manage and adapt to technological advancements, ensuring a smooth transition to a more automated transportation system.

6. CHANGES/PROBLEMS:

a. Changes in approach and reasons for change.
The UV-visible spectroscopy initially planned for use in CTIPS-024 was not performing well and the results were inconsistent and unsatisfactory. Hence, the PIs decided to exclude UV-visible spectroscopy, streamlining the process while still ensuring accuracy.

b. Actual or anticipated problems or delays and actions or plans to resolve them.

- CTIPS-036 has been delayed pending contract negotiations with construction companies.
- Dr. Mostafa Tazarv, who served as the former PI of the two SDSU projects, has left SDSU. Beginning in January, Dr. Kwanghee Won, the project's co-PI, assumed the PI role at SDSU.
- Activities in CTIPS-019 Developing Course Modules on Social Equity for Transportation Courses in Engineering and Construction have been suspended pending a compliance review
- CTIPS-039 Creating Multimedia Resources for Engineering Curriculum on Environmental and Social Impacts and Sustainability Aspects of Transportation Projects is currently under review for revision and redirection of focus.

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.