Edge-Based Work Zone Monitoring for Safe and Intelligent Rural Infrastructure Preservation

CTIPS-075 – UTC Project Information

Recipient/Grant Number:	North Dakota State University, University of Wyoming Grant No. 69A3552348308
Center Name:	Center for Transformative Infrastructure Preservation and Sustainability
Research Priority:	Preserving the Existing Transportation System
Principal Investigator(s):	Yu "Fred" Song, Ph.D. Chengyi "Charlie" Zhang, Ph.D., P.E.
Project Partners:	USDOT, Office of the Assistant Secretary for Research and Technology – $100,534 University of Wyoming – $109,293
Total Project Cost:	$209,827
Project Start and End Date:	8/28/2026 to 11/30/2029

Project Description

Rural highway work zones present elevated safety risks due to high-speed traffic, limited visibility, and dynamic construction activity, posing dangers to drivers and workers while also threatening the long-term integrity of infrastructure projects. To address these challenges, this project develops a simulation-based framework to design and evaluate a mesh sensor network capable of real-time incident detection and alerting. The proposed system integrates low-cost sensors with edge computing and self-organizing LoRaWAN (Long Range radio-carried Wide Area Network) communication to detect vehicle intrusions, equipment-lane conflicts, and worker proximity violations. Simulations will combine microscopic traffic modeling (SUMO), construction activity simulation (ROS/Gazebo), and wireless network emulation (NS-3) to enable synchronized, multi-domain testing. The system's detection performance, message latency, localization accuracy, and communication reliability will be assessed across varied work zone scenarios and sensor configurations. Comparative evaluation against fixed-point detection, manual reporting, and cloud-based mesh networks will quantify the benefits of edge processing and network resilience. Outputs include detection benchmarks, design guidelines, and synthetic datasets of safety-critical interactions. This research advances USDOT strategic goals by improving rural safety, enabling intelligent infrastructure transformation, and preserving critical transportation assets through early detection of hazards that could disrupt construction schedules or damage facilities. The simulation framework and findings will be shared with state DOTs to support future deployment of proactive, intelligent monitoring systems.

USDOT Priorities

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Outputs

The research team will actively engage the transportation community to share methodologies, tools, and findings from this simulation-based study on rural work zone safety monitoring. Transportation practitioners, state DOT officials, and academic researchers are the primary audiences. Dissemination will occur through project webpages, webinars, conference presentations, peer-reviewed publications, and direct communication with stakeholders. The team will also host workshops and demonstrations to gather feedback on sensor network design, interaction modeling, and simulation tools. Given WYDOT's strong interest in rural highway safety, ITS, and intelligent infrastructure preservation, WYDOT personnel will be invited to review interim findings and explore opportunities for future pilot projects. Their input will help shape refinements to simulation parameters and identify field deployment needs. The virtual sensor network architecture, interaction detection framework, and scenario evaluation tools developed in this project are designed for scalability. They can be adapted into decision-support tools for planning and designing safer, more responsive work zones. The research team will work with WYDOT and interested DOTs to transition key components (e.g., sensor units, small-scale network) into practice-ready prototypes for testing and future deployments.

Outcomes/Impacts

This project will result in a validated simulation framework for evaluating mesh sensor networks in rural highway work zones. By integrating models of traffic flow, construction activity, and wireless communication, the framework will enable realistic, scenario-based testing of detection strategies under varying conditions. It will serve as a flexible research tool that can be adapted for future studies on intelligent work zone safety and infrastructure monitoring.

A key outcome will be a set of design guidelines and performance benchmarks for sensor network configurations, including metrics such as detection accuracy, communication reliability, message latency, and deployment cost-effectiveness. These results will inform practical decision-making by transportation agencies, offering insights into how sensor placement, network density, and edge computing capabilities affect incident detection and response performance.

In addition, the project will generate a curated collection of simulated scenarios, agent behavior models, and synthetic sensor datasets capturing critical work zone safety events such as vehicle intrusions, equipment-lane conflicts, and worker proximity violations. These resources will be valuable to researchers and practitioners seeking to evaluate safety countermeasures or develop virtual training and testing environments.

Finally, we will summarize the project in a comprehensive technical report, with details including the simulation methodology, system architecture, evaluation results, and actionable design recommendations. Findings will also be disseminated through peer-reviewed publications and conference presentations, to broaden the impact of our research on data-driven, intelligent monitoring solutions for rural highway safety. The outcomes will support WYDOT and other state DOTs in advancing smart work zone planning, incident mitigation strategies, and infrastructure resilience.

Final Report

Upon completion, the final report link will be added to the project page on the CTIPS website.