FY2023 HP-CMV Grant Program

Multi-Sensor Fusion for Proactive Commercial Motor Vehicle Safety at Work Zone

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UNIVERSITY of NEBRASKA LINCOLN

University of Nebraska Lincoln (UNL), Lead

University of Alabama (UA), Tuscaloosa

MITRE

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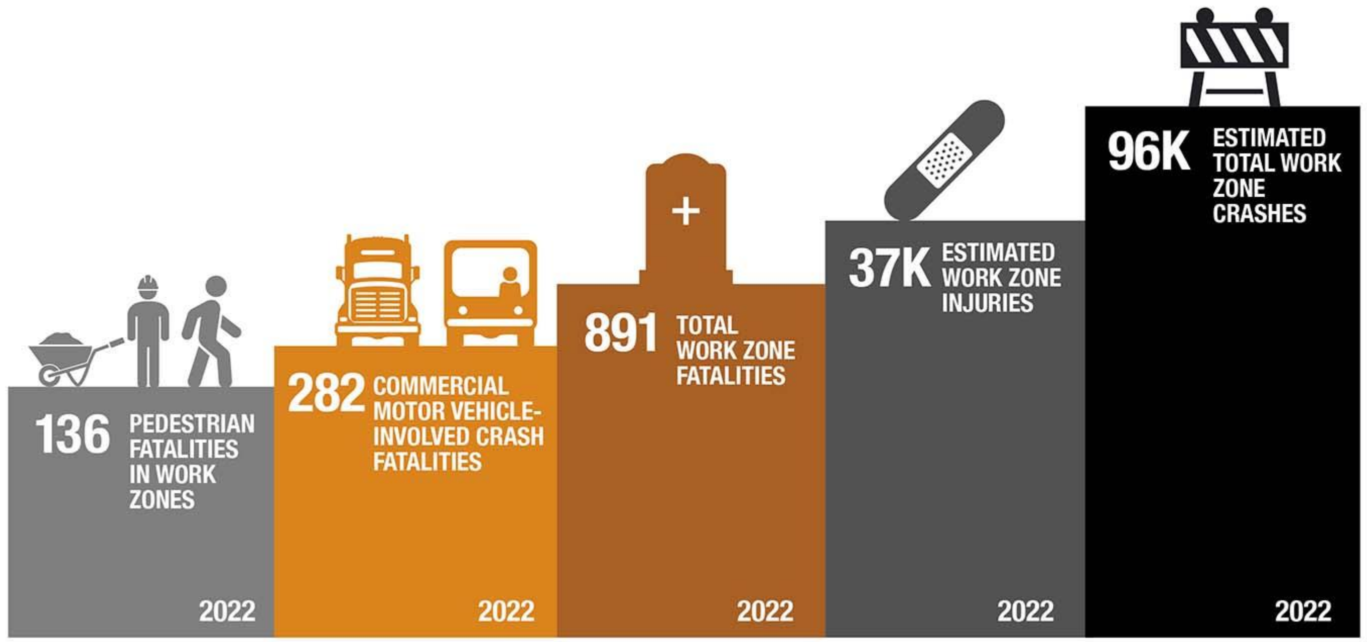
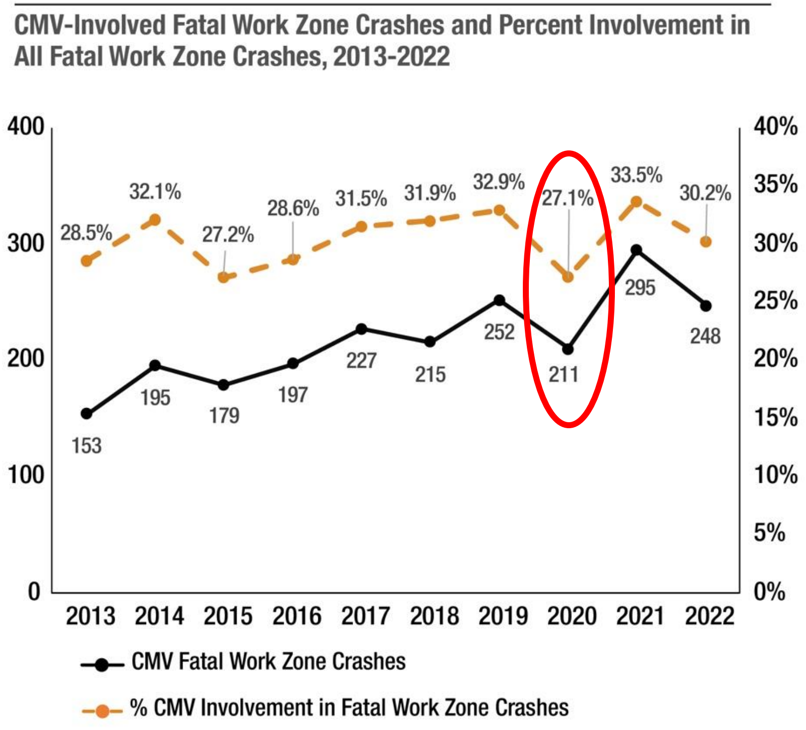
Work Zone Data – At a Glance



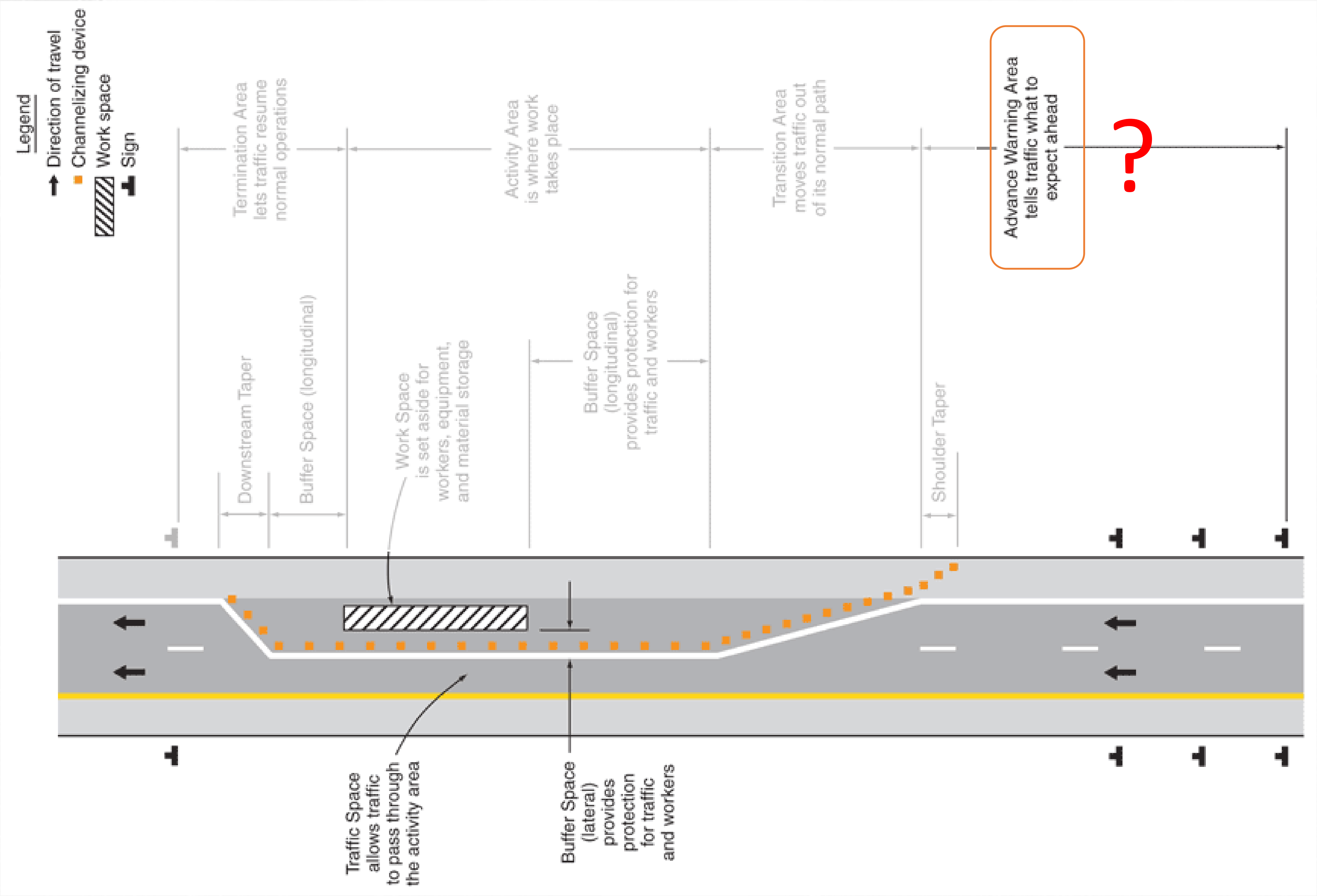


Proactive Safety at Work Zone Area

Reactive
(Real-time)

vs

Proactive
(Predictive)



Research Challenges

Challenges

- Unknown characteristics of approaching traffic stream
- Traditional non-proactive ITS work zone warning
- Absence of proactive safety countermeasures
- Limited public education of new system

Potential Solutions

- Multi sensor data fusion to detect driving behavior
- Distributed framework for predictive guidance
- Proactive safety considering holistic scenario
- Virtual collaborative environment: work zone education

Overarching Goals

Improve safety

- Make our transportation system safer for all people
- Advance a future without transportation-related serious injuries and fatalities

Transform work zone design

Modernize the transportation system to serve everyone today and in the decades to come

Project Objectives

Develop **a framework for the acquisition of enriched, high-quality data sets** of trucks' and non-trucks' movements in work zone areas

Develop a **digital twin of a work zone** for the assessment of potential collisions and suitable countermeasures

Provide **an educational and planning tool** for traffic engineers and contractors

Sub-Projects

Sub-Project 1: Real-Time, Distributed Multi-Sensor Data Fusion for Driving Behavior Estimation

Sub-Project 2: Proactive Work Zone Safety with Digital Twin Technology

Sub-Project 3: Development and Evaluation of a Co-Simulation Environment for the Predictive CMV Safety System

Sub-Project 4: Enhance Driver Awareness About Proactive Work Zone Safety Using Virtual Collaborative Training Environment

Sub-Project 1

Real-Time, Distributed Multi-Sensor Data Fusion for Driving Behavior Estimation

Lead Institutions

Co-lead Institutions

Project 1: Challenge and Solution

Existing Challenges

Unknown characteristics of approaching stream (aggressive/fatigued mix)

Solutions

Project 1 Multi sensor data fusion to detect driving behavior

Project 1: **Goal**

Develop and evaluate a distributed multi-sensor fusion (LiDAR, Radar, and Camera) framework for estimating driver behavior.

Project 1: Approach

Deep learning (DL) algorithms (e.g., recurrent neural networks, long-short term memory, gated recurrent units, temporal convolutional network, and transformer models)

Project 1: Approach – Sensor Fusion

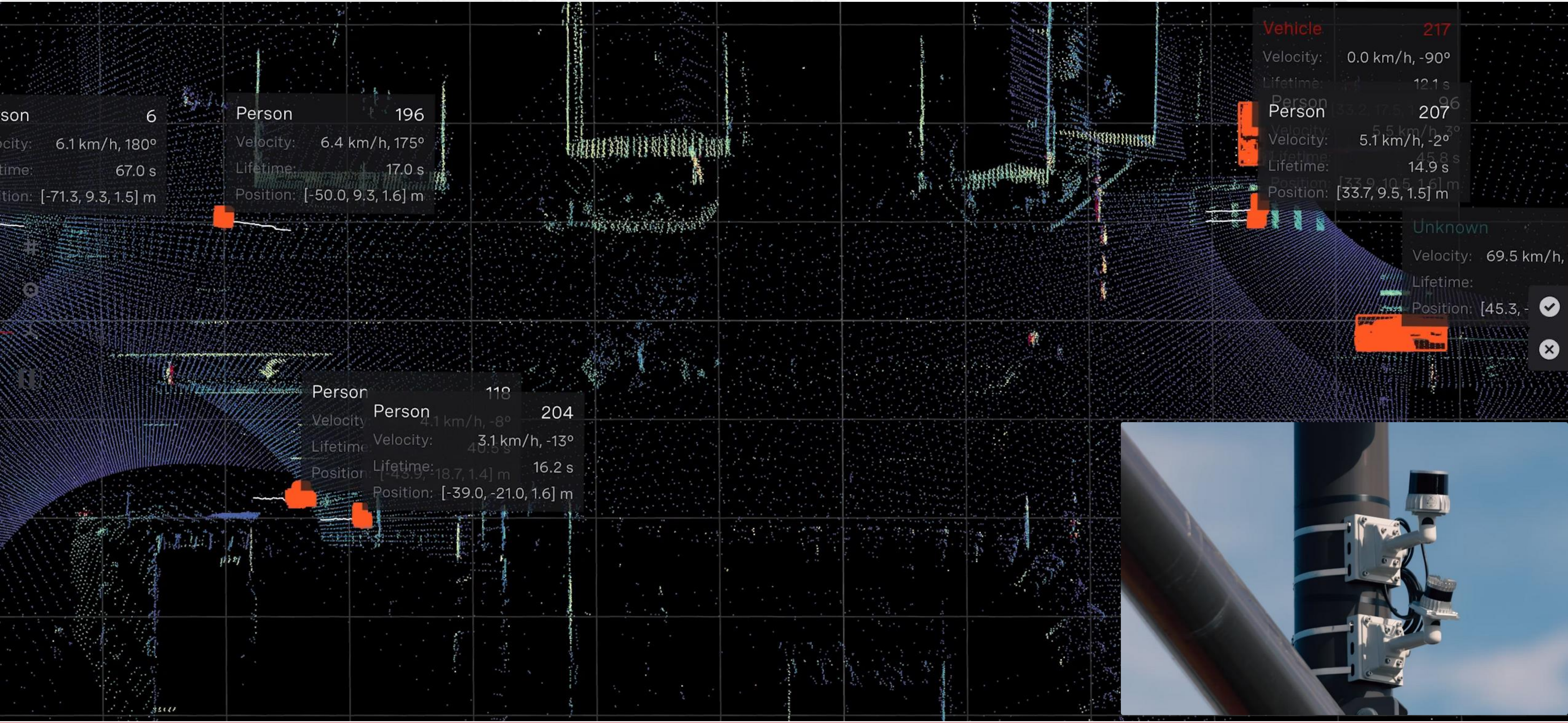
HD3D RADAR

- HD3D radar is accurate enough to sense a human heartbeat.
- Unlike traditional HD or UHD radar, this radar forms dense point clouds that can be used for count, classification, direction, speed, and occupancy detection.

HD VIDEO

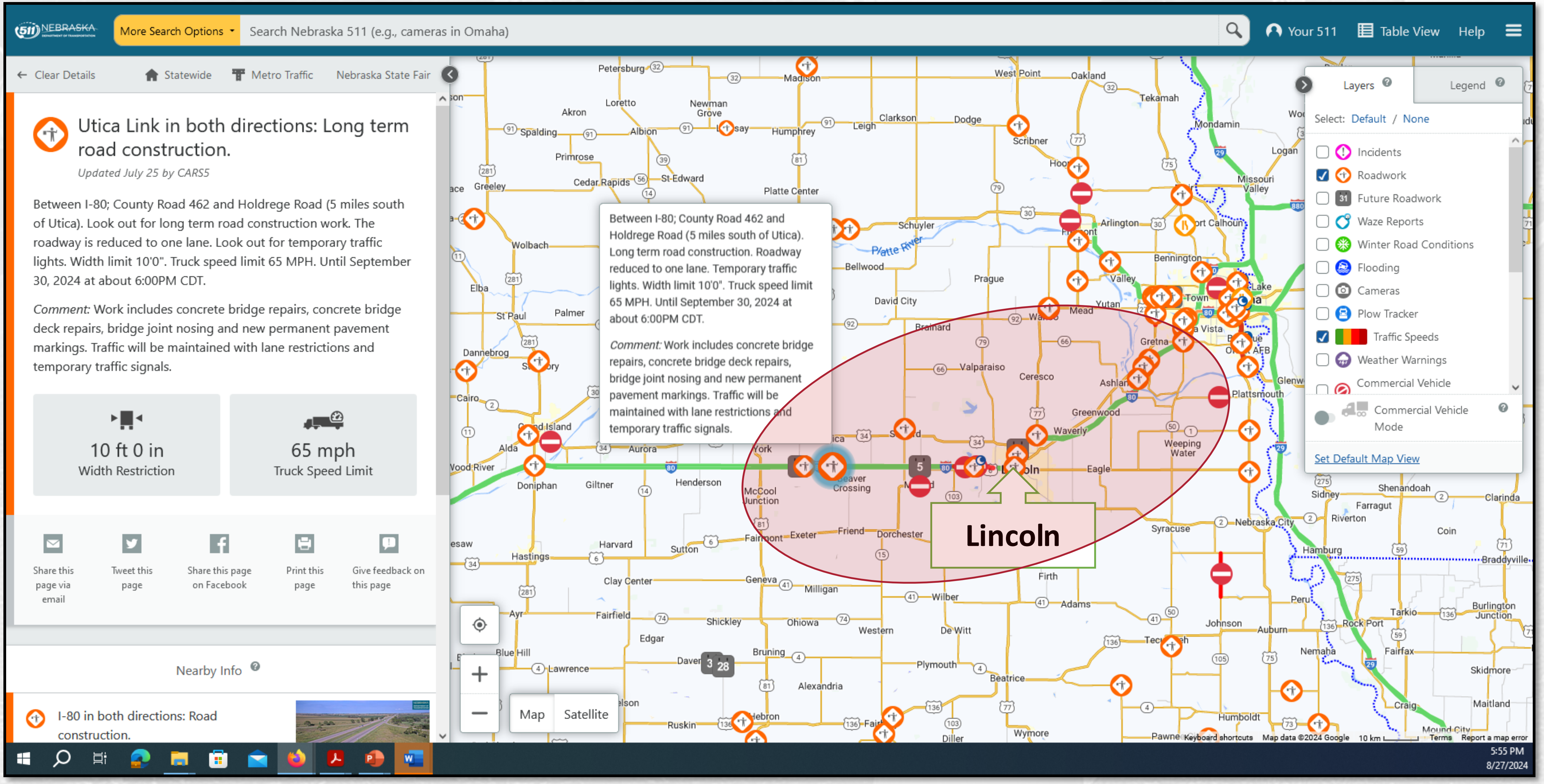
- AI-enabled HD Video provides unmatched classification capabilities.
- Video interference results are combined with the dense radar point clouds 20 times per second.

Project 1: Approach – Sensor Fusion



https://ouster.com/products/software/gemini

Project 1: **Real-world Data Collection Site**



Project 1: Lessons Learned

Enhanced reliability through redundant sensing

- Reduce likelihood of missed detections or false positives
- Necessary due to complex and dynamic work zone environment
- Improve detections in case of occlusions, varying lighting conditions weather-related challenges

Customization for effective sensor fusion

- No one-size-fits-all method for sensor fusion
- Needs to be tailored to the specific sensors available and the preferred system architecture

Real-time data processing

- Requires real-time data processing to provide timely warnings
- Could lead to missed opportunities for proactive safety warnings if there is a delays in data fusion
- Require significant computing resources for deep learning based object detection models

Project 1: Expected Outcomes

Validated Deep Learning-based driver behavior estimation model that outperforms current state-of-the-art model.

Sub-Project 2

Proactive Work Zone Safety with Digital Twin Technology

Lead Institutions

MITRE

Co-lead Institutions

UNIVERSITY of NEBRASKA LINCOLN

Project 2: Challenge and Solution

Existing Challenges

Traditional non-proactive ITS work zone warning

Solutions

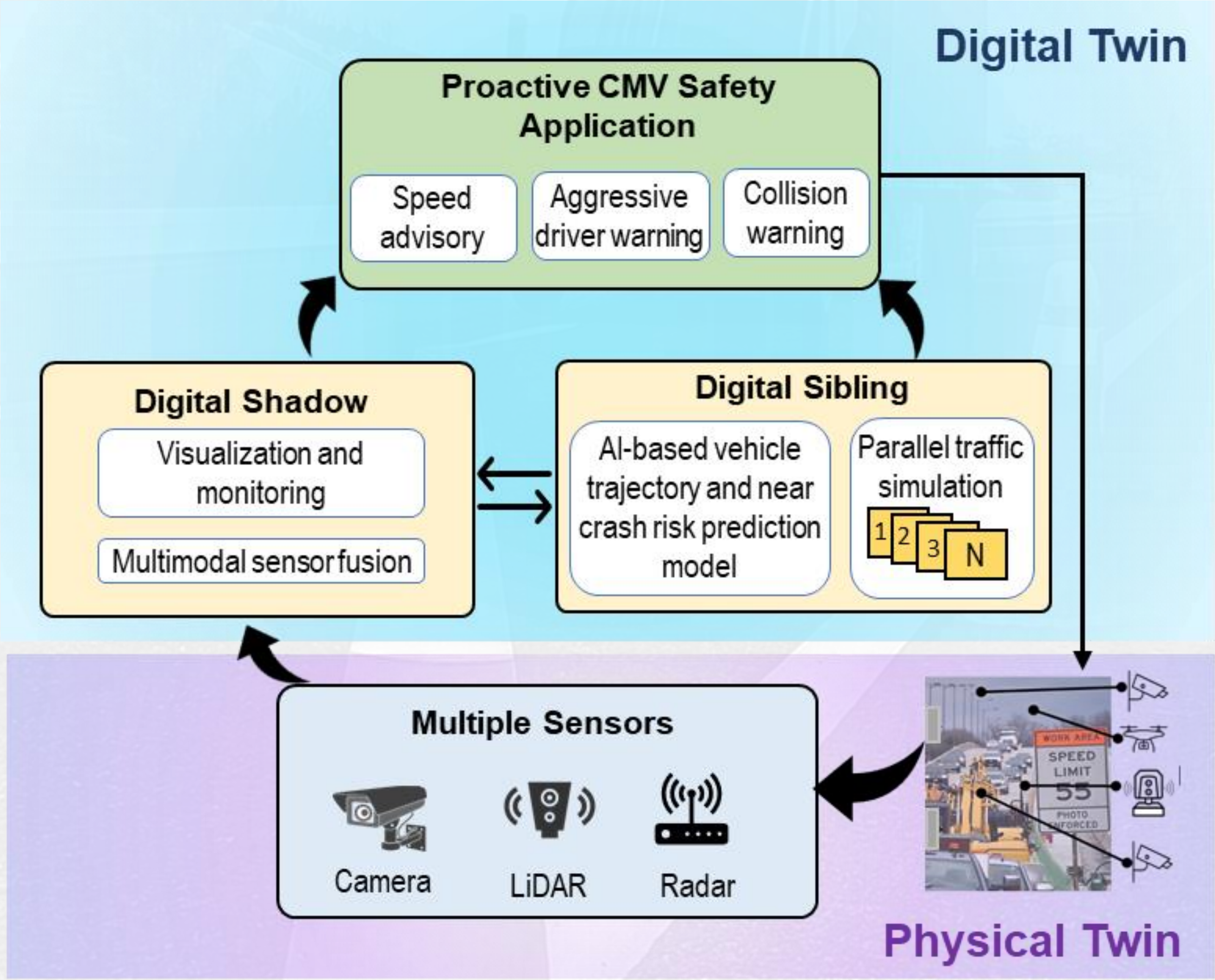
Project 2 Distributed framework for predictive guidance

Project 2: Goal

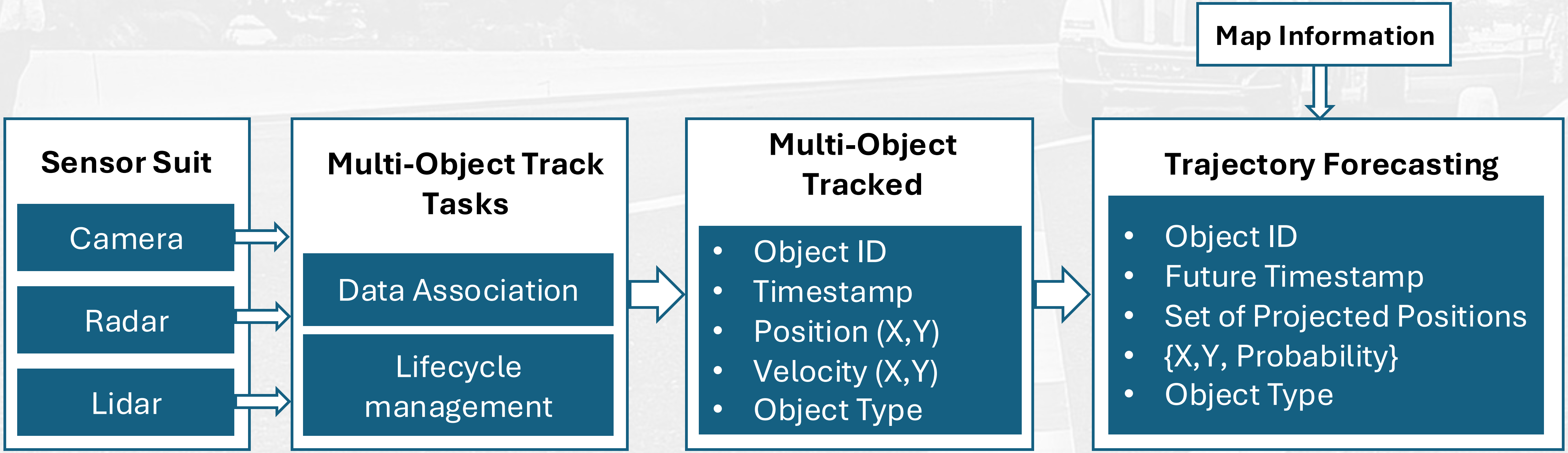
Develop a digital twin of a work zone area using the sensor data fusion framework and DL-based driver behavior estimation model from Project 1

Project 2: Approach

Parallel simulation strategy for simulating future safety-critical scenarios, and predictive analytics for vehicle trajectory and crash/near-crash risk forecasting using real-time traffic data from multiple sensors.



Project 2: **Approach**



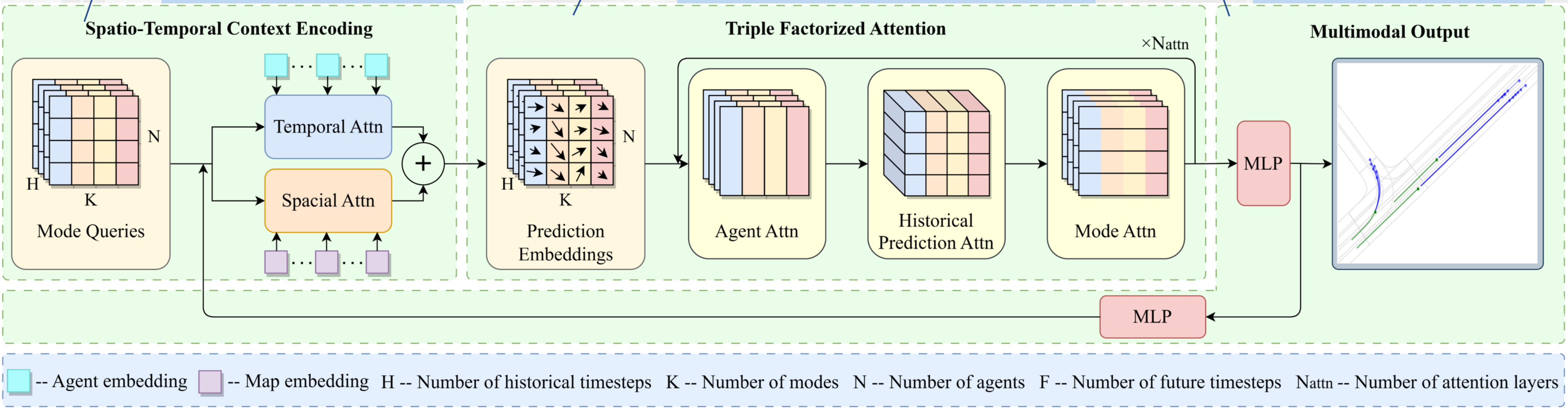
Project 2: **Approach**

Dynamic Trajectory Forecasting with Historical Prediction Attention

Aggregates information from map and vehicle trajectories to propose initial prediction for K possible modes

Refines the initially proposed prediction by modeling the interaction between all the vehicles on the road, past predictions, and the different modes

MLP decodes the prediction embeddings as usable future trajectories



Modes = Different possibilities of future trajectory

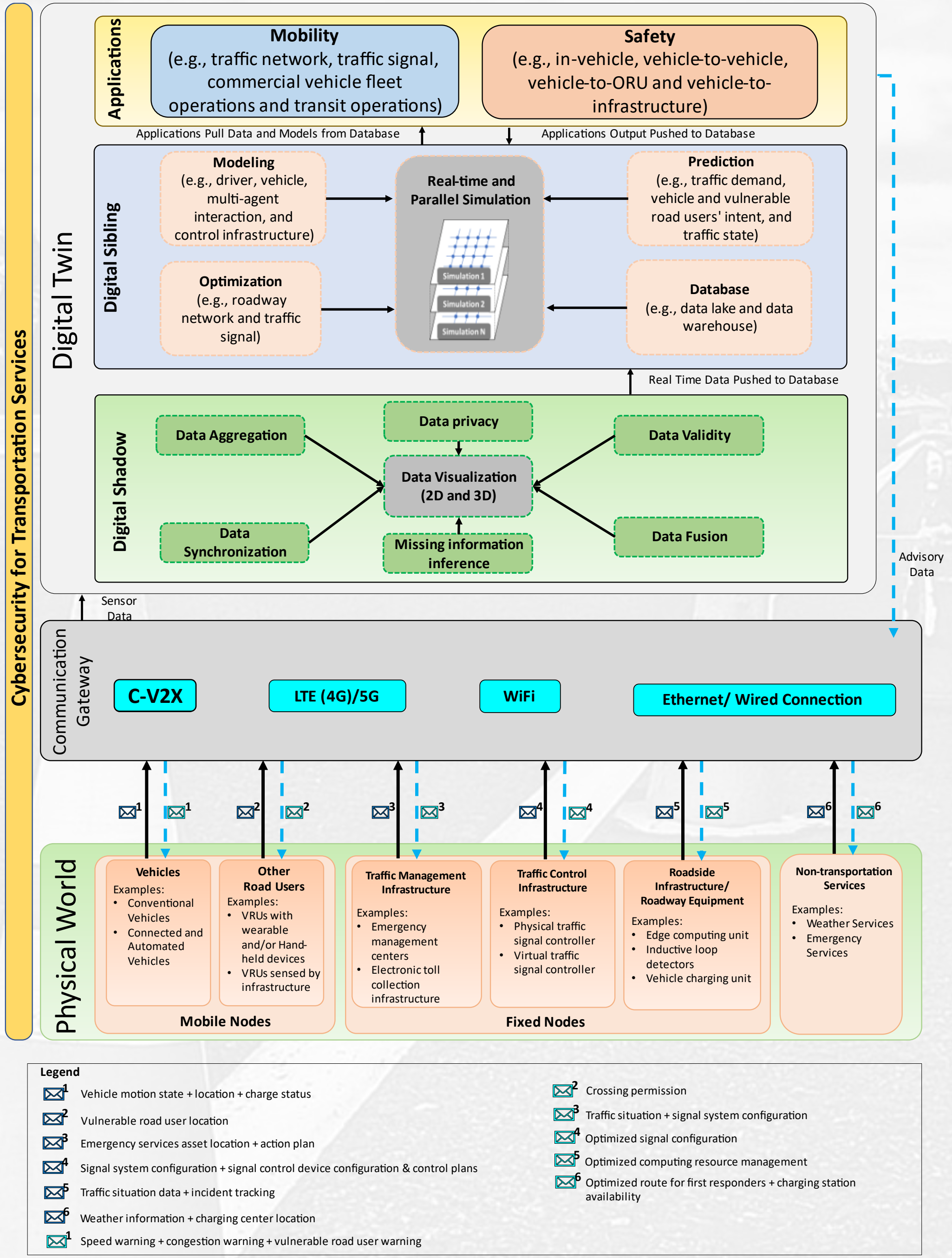
K Modes = 'K' number of different possible futures

https://openaccess.thecvf.com/content/CVPR2024/papers/Tang_HPNet_Dynamic_Trajectory_Forecasting_with_Historical_Prediction_Attention_CVPR_2024_paper.pdf

Project 3: **Lessons Learned**

- Digital sibling component can simulate interactions between vehicles and workers to identify potential conflicts and accident-prone zones

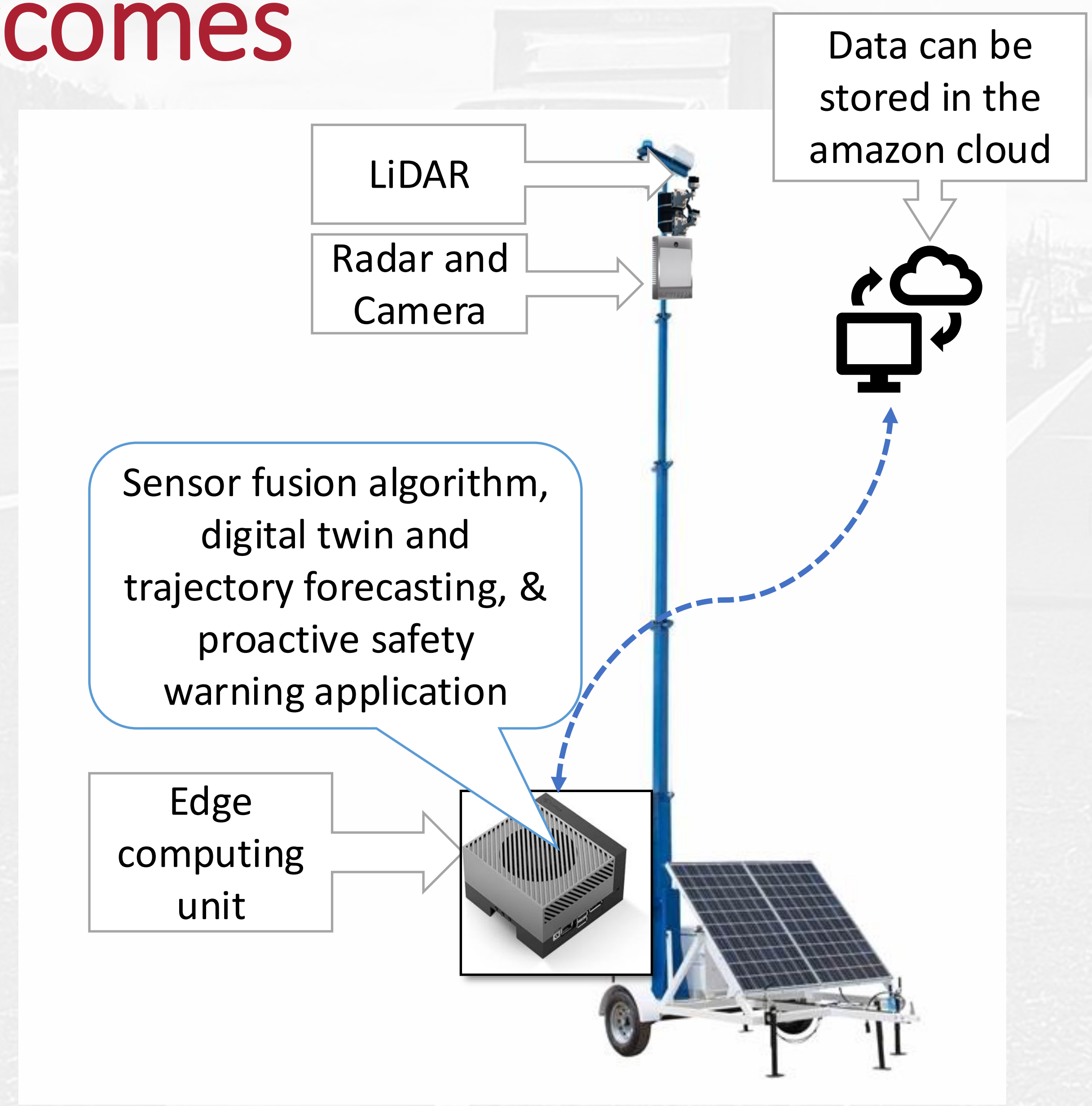
- This enables to proactively identify safety risks and suggest measures for correction



Published Article: M. S. Irfan, S. Dasgupta and M. Rahman, "**Toward Transportation Digital Twin Systems for Traffic Safety and Mobility: A Review**," in *IEEE Internet of Things Journal*, vol. 11, no. 14, pp. 24581-24603, 15 July15, 2024, doi: 10.1109/JIOT.2024.3395186.

Project 2: Expected Outcomes

A prototype of a work zone digital twin for proactive safety assessment.



Sub-Project 3

Development and Evaluation of a Co-Simulation Environment for the Predictive CMV Safety System

Lead Institutions

UNIVERSITY of NEBRASKA LINCOLN

MITRE

Co-lead Institutions

Project 3: Challenge and Solution

Existing Challenges

Absence of proactive safety countermeasures

Solutions

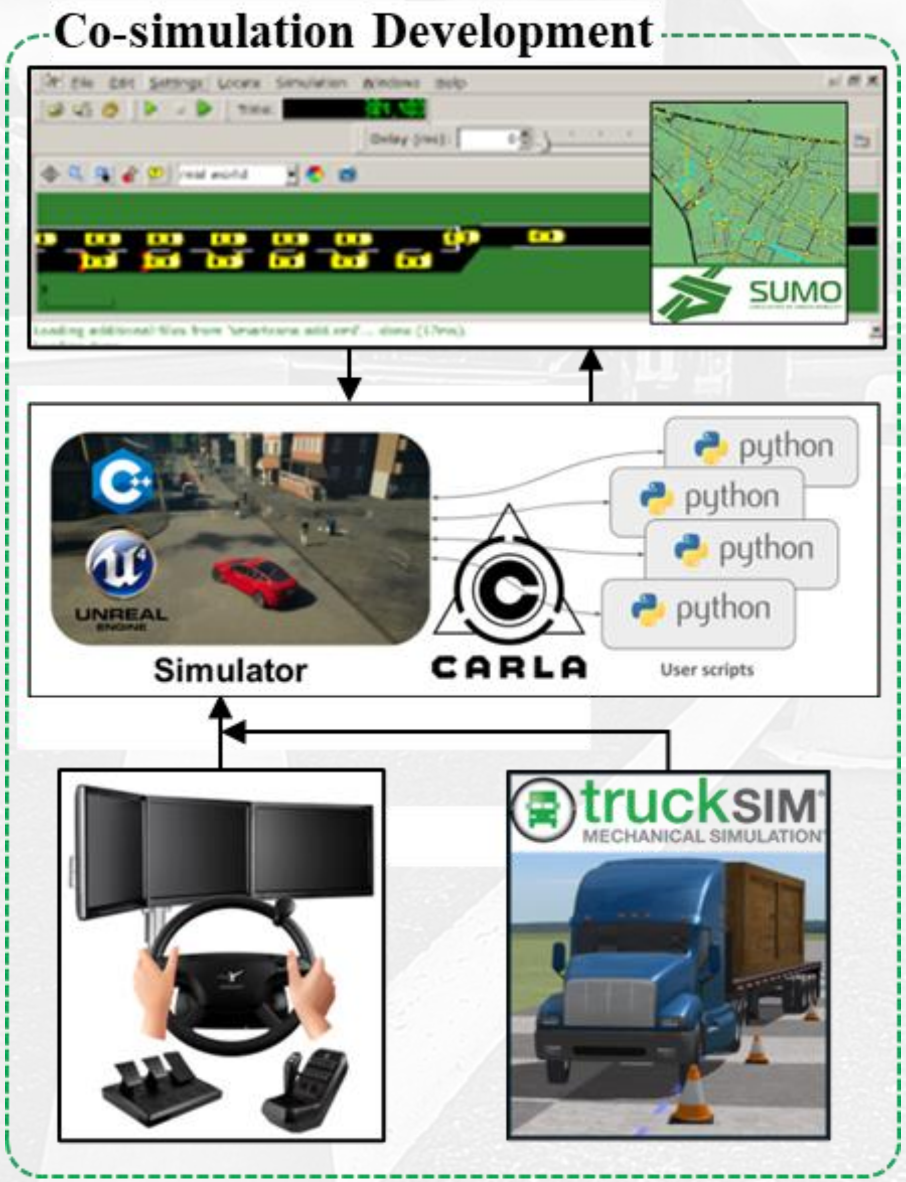
Project 3 Proactive safety considering holistic scenario

Project 3: **Goal**

Develop a co-simulation framework that integrates three well-known simulation platforms

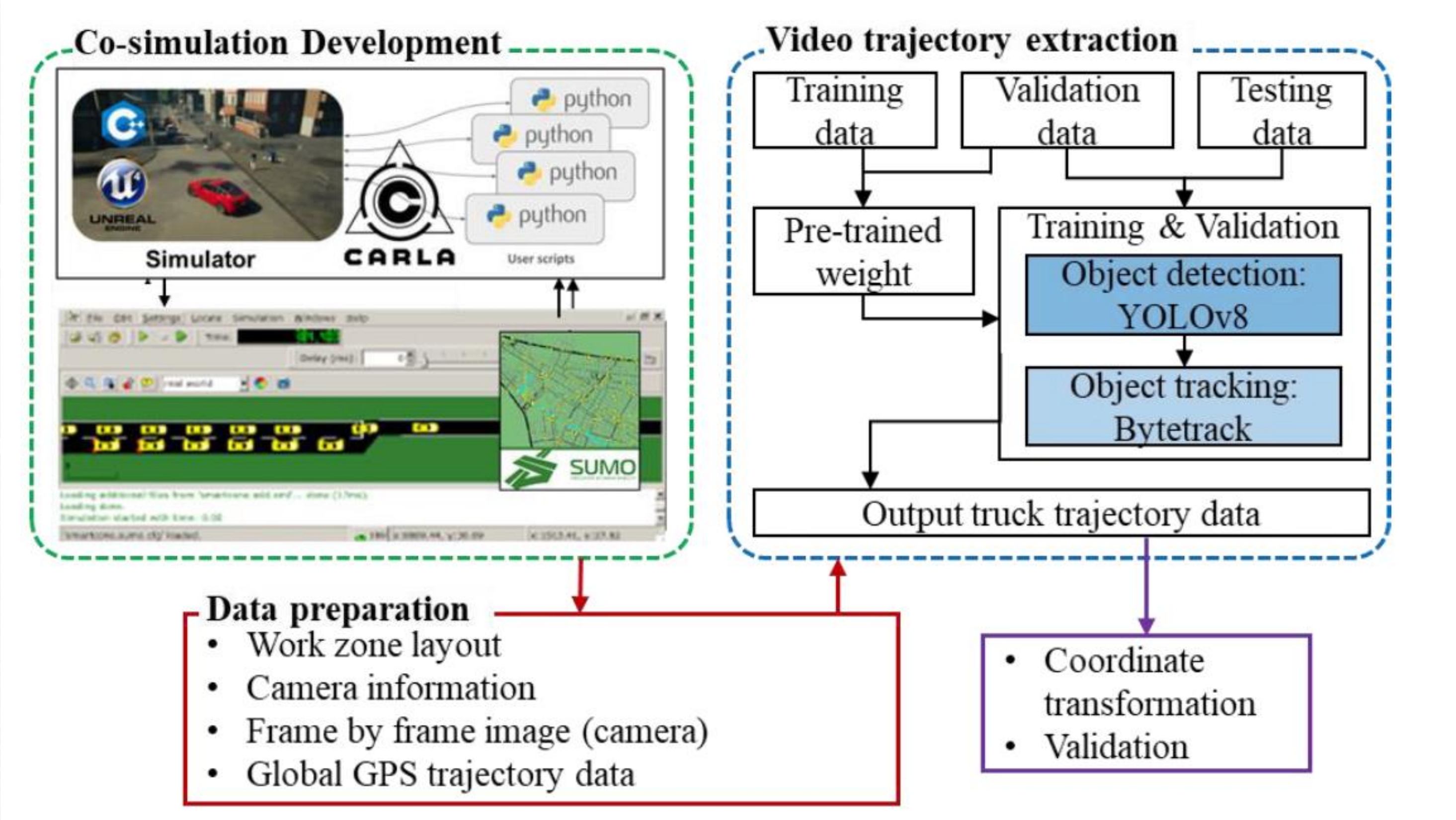
Project 3: Approach

Component-based software architectures and data exchange standards.



Project 3: Lessons Learned

Our analysis showed that on average, the detection confidence for cars and trucks is **90.7%** and **85.2%**, respectively, and the tracking deviation for cars and trucks is **0.880** and **1.578** meters, respectively.



Jiahe Cao, Li Zhao, Sakib Khan, Nathan Huynh, Qiang Liu, Mizanur Rahman, and Eren Erman Ozguven, "**Roadside Camera-based Detection and Tracking of Trucks in a Freeway Work Zone Area for Real-time Trajectory Generation**," 2025 TRB Annual Meeting, [Under Review].

Project 3: Expected Outcomes

Co-simulation environment will provide the missing piece to enable digital twin capabilities.

Sub-Project 4

Enhance Driver Awareness About Proactive Work Zone Safety Using Virtual Collaborative Training Environment

Lead Institutions

Co-lead Institutions

Project 4: Challenge and Solution

Existing Challenges

Limited public education of new system

Solutions

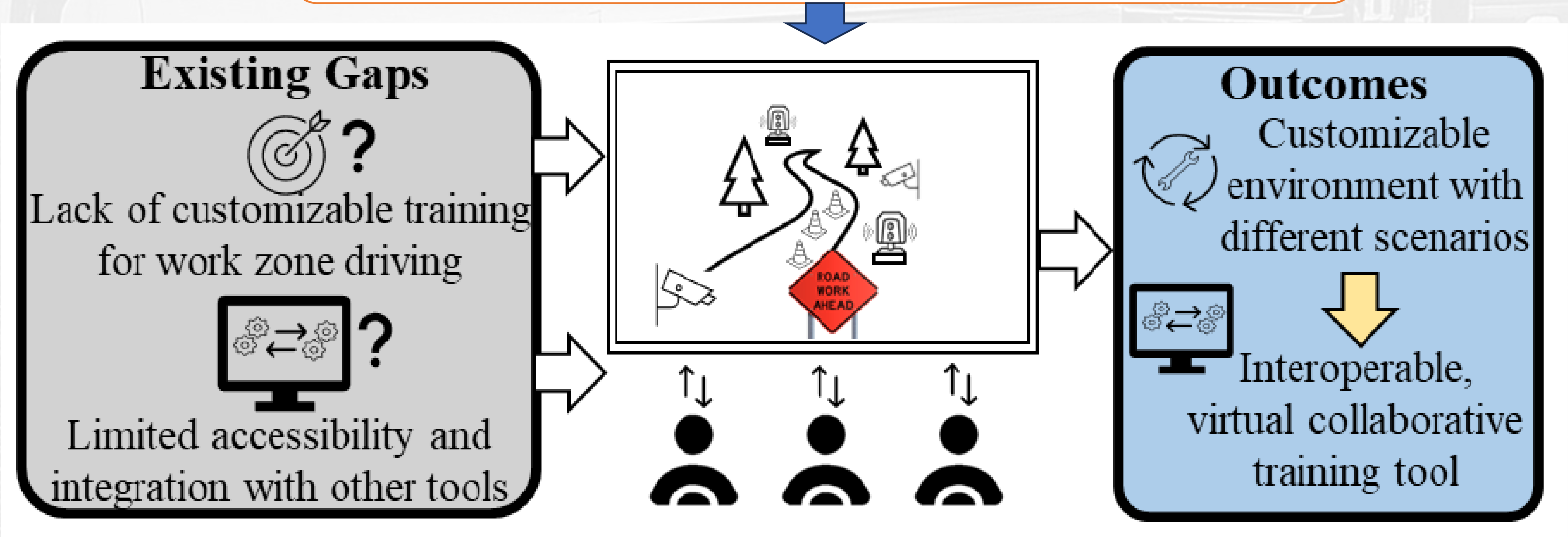
Project 4 Virtual collaborative environment: work zone education

Project 4: **Goal**

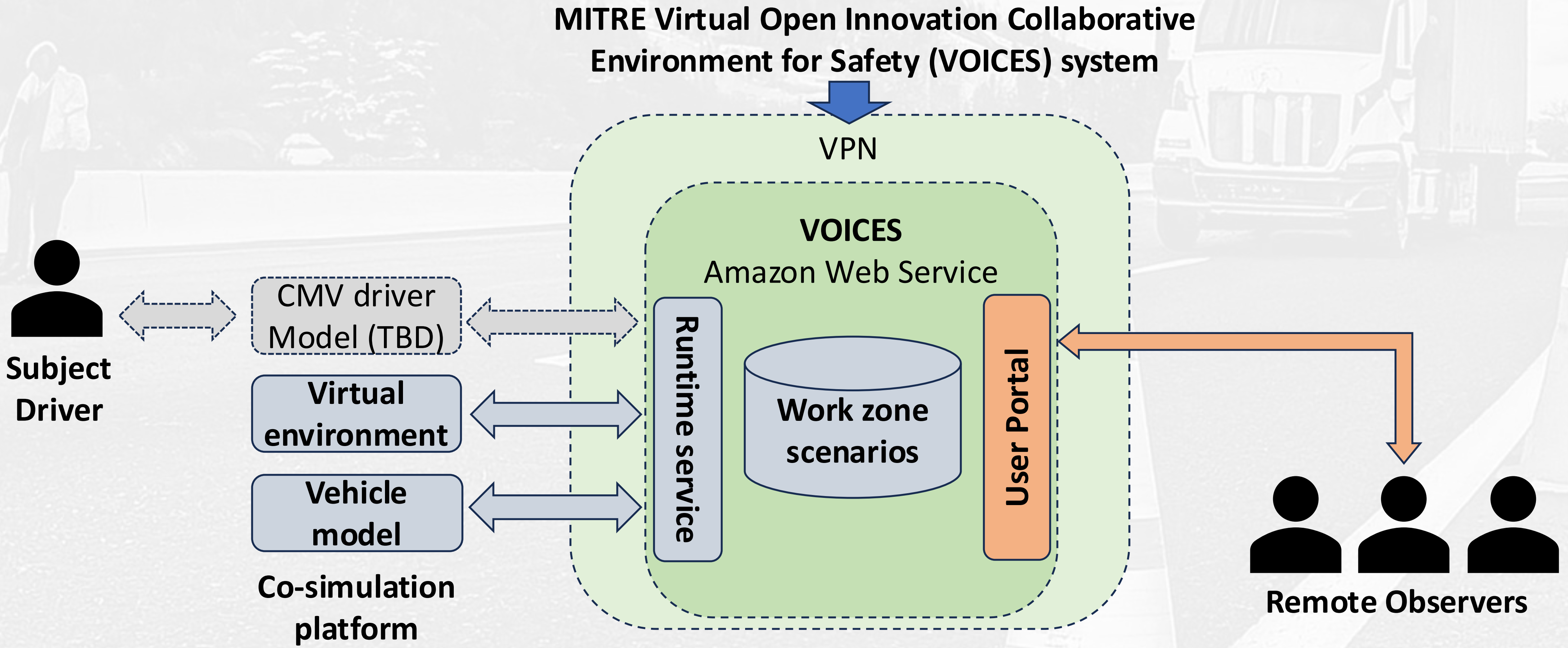
Create an interoperable, virtual collaborative education and training tool

Project 4: **Approach**

MITRE Virtual Open Innovation Collaborative Environment for Safety (VOICES) system



Project 4: Approach



Utilize the developed digital twin to provide an in-person, hands-on workshop for various stakeholders.

Project 4: Expected Outcomes

Improved awareness of work zone safety concerns and reduction in number of crashes at work zones.

Thank You!

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