EXPLORATORY ADVANCED RESEARCH

DIGITAL TWIN-ENABLED EXTENDED ACTIVE SAFETY ANALYSIS FOR MIXED TRAFFIC

April 2024

FACT SHEET

Traffic safety is a primary focus for policymakers and transportation researchers. The Federal Highway Administration (FHWA) has promoted various projects and initiatives to achieve its goal of zero traffic fatalities, including the National Roadway Safety Strategy.[1] This comprehensive plan embraces the Safe System Approach, which includes five elements that need to be addressed to achieve zero traffic deaths: safe road users, safe vehicles, safe speeds, safe roads, and post-crash care.[2]

In line with this overarching goal, FHWA's Exploratory Advanced Research (EAR) Program is sponsoring researchers at Texas A&M Transportation Institute who are developing a novel framework for traffic safety analysis. The 3-yr study, called Digital Twin-Enabled Extended Active Safety Analysis for Mixed Traffic, seeks to build a predictive, extended active safety approach for mixed traffic of human-driven vehicles (HDVs) and connected and automated vehicles (CAVs) through a digital twin technique.

Background

Traffic safety analysis has increasingly relied on an active model based on surrogate safety measures (SSM). This framework uses data points like traffic conflicts, near misses, or other observable behaviors that indicate potential safety risks to assess safety without having to rely solely on actual crash data. Since the late 1970s, research has helped develop SSM-based safety analysis and increased its adoption in simulations.[3] But its use in mixed-traffic scenarios has been limited.

Current active safety analysis is also limited in its practice. The framework can only be applied in certain simulated scenarios (e.g., one-dimensional vehicular motion and two-dimensional vehicular motion); it depends on over-simplified vehicle dynamics; and it assumes a relatively ambient (i.e., normal) traffic pattern.[4] These shortcomings limit the use of SSM-based safety analysis for rural highways, which are critical crash-risk sites. Also, control and driving behaviors are not reflected in traditional SSM.

Digital twin technology creates a virtual replica of a physical object, system, or process, helping researchers understand real-world performance.

The research team at Texas A&M Transportation Institute is planning to build on this framework to create an extended active safety analysis model through advanced digital twin technology and artificial intelligence (AI). Digital twin technology creates a virtual replica of a physical object, system, or process, helping researchers understand real-world performance. The team will use this technique to capture the three-dimensional road geometries and corresponding impact on vehicle dynamics, addressing the shortcomings of SSM. AI will also be applied to develop a predictive component to the extended safety analysis model. Figure 1 shows how the components of a digital twin active safety system relate to each other.

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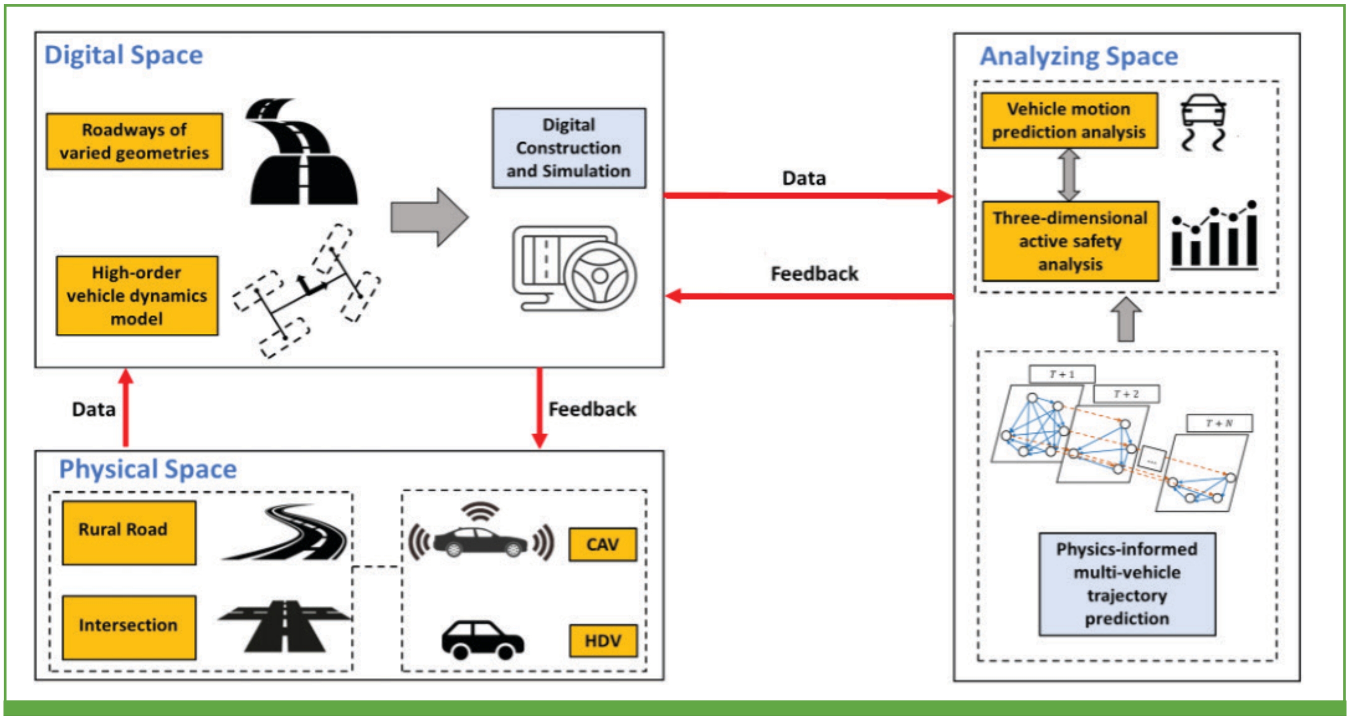

Figure 1. Digital twin active safety system.

FACT SHEET

STUDY OVERVIEW

This study is broken down into five main tasks, as shown in figure 2.

Task 1: Transportation Environment Digitalization and Data Collection

For this part of the study, the researchers will use portable sensors, CAVs, and drones to collect static data (i.e., data that are stored and rarely changed) on road geometries (e.g., curvatures, superelevation, gradient) and ambient road environments (e.g., traffic control devices, obstacles). The researchers will also collect dynamic data (i.e., data that are regularly updated) on the high-resolution vehicular trajectory under different traffic environments.

The collected static and dynamic data will then be integrated to create a digitalized replica of transportation systems. The data acquired from multiple sensors will be fused using a diffusion neural network, which helps understand and predict patterns in data that occur over time.

Task 2: Three-Dimensional Active Safety Analysis

In this task, the team will use the digital twin transportation system developed in task 1 to develop a framework for modeling vehicle movement in a three-dimensional space that includes road curvatures, gradient, and superelevation. A curvilinear coordinate system (i.e., a framework to specify positions in a space where the coordinate lines follow curves) will be used to represent vehicular movement along a road surface on a rural highway. The team will evaluate vehicular motion under different road conditions, investigating multiple vehicle dynamics models (i.e., the mathematical representation of a vehicle's movement and behavior), and calibrate them to construct a model for computing-enhanced active safety analysis and SSM design.

FACT SHEET

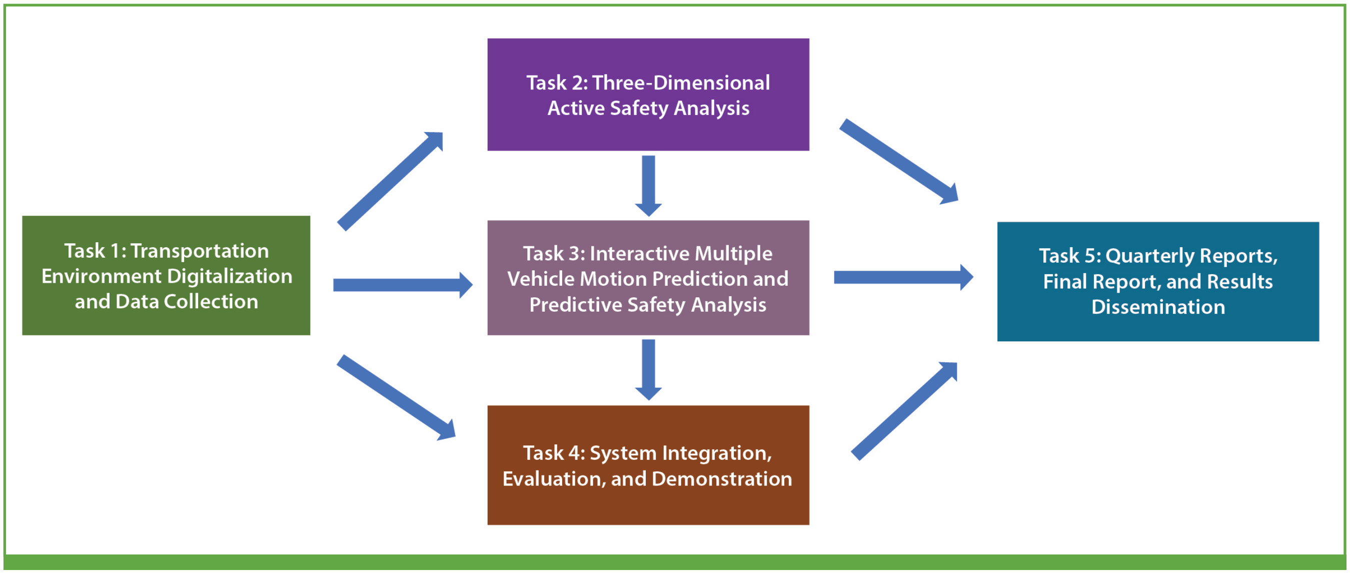

Figure 2. Task descriptions and organization.

Task 3: Interactive Multiple Vehicle Motion Prediction and Predictive Safety Analysis

For this task, the researchers plan to develop algorithms that supplement their extended active safety analysis with predictive capability. This work includes developing algorithms that can predict vehicular motions (such as lane changing, merging, and diverging) and vehicle trajectory in realtime. Through cross-comparisons analyzing various factors and environments, researchers will be able to predict which conditions would be the most adversarial to vehicle safety.

Task 4: System Integration, Evaluation, and Demonstration

In this task, the team will evaluate its model through simulations and field tests. Containing three interrelated components: physical space, digital space, and analysis space, the simulation system will draw on the digital transportation system developed in task 1 and the vehicular dynamics model developed in task 2 to construct a digital space that reproduces an accurate physical space. A feedback loop through conducted simulations will help modify and improve the system's precision. The simulations will involve a wide variety of real-world scenarios, roadway types (such as rural roads and urban intersections), traffic conditions, and vehicle behavior to ensure a rigorous evaluation of their predictive extended safety analysis system. Once the system is validated by the simulations, the researchers will conduct extensive field testing in a controlled environment and in certain open, mixed-traffic environments on a rural highway and at an urban intersection.

Task 5: Quarterly Reports, Final Report, and Results Dissemination

The team plans to provide a quarterly progress report throughout the study. To disseminate its results, the team will create a final report, a project website, academic conference papers, and journal articles.

FACT SHEET

REFERENCES

[1]FHWA. 2023. "About Safety" (web page). https://highways.dot.gov/safety/about-safety, last accessed January 12, 2023.

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[4]Song, Y., M. V. Chitturi, and D. A. Noyce. 2022. "Intersection Two-Vehicle Crash Scenario Specification for Automated Vehicle Safety Evaluation Using Sequence Analysis and Bayesian Networks." *Accident Analysis & Prevention* 176, no. 4: 106814.

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For more information about this EAR Program project, please contact Mohamadreza Banihashemi (202-493-3334 or mohamad.banihash@dot.gov), transportation specialist in the FHWA Office of Safety and Operations Research and Development.

To learn more about the EAR Program, visit https://highways.dot.gov/research/exploratory-advanced-research.

What Is the EAR Program?

The EAR Program supports longer term, higher risk research with the potential for transformative improvements to the U.S. transportation system. The EAR Program seeks to leverage promising expertise and advances in science and engineering to create breakthrough solutions to highway transportation issues.

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