Improving Merging Efficiency for Highway-Ramp Multi-modal and Mixed Traffic

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Project Objective

The project objective is two-fold:

- To develop a multi-human-in-the-loop (MHuiL) co-simulation platform that can empower the analysis, modeling, and validation of multiple human drivers' behaviors and their interactions.
- To evaluate the effectiveness of a proposed connected vehicle-based speed guidance system that enables cooperative ramp merging of truck-involved traffic.

Problem Statement

Ramp merging has garnered considerable attention, primarily due to the safety and mobility challenges arising from the disorderly nature of traffic, characterized by factors like lane changes and speed variations. The advent of connected and automated vehicle (CAV) technology presents unprecedented opportunities to tackle this problem. However, a notable limitation in existing CAV-based cooperative ramp merging systems is their assumptions that: 1) all vehicles are light-duty CAVs; and 2) all vehicles are CAVs, so they can perfectly adhere to the reference speed. These assumptions are far from being realistic in a multi-modal (including both light-duty vehicles and heavy-duty trucks) and mixed (connectivity and automation level[1]) traffic environment, diminishing the practicality and adaptability of such systems.

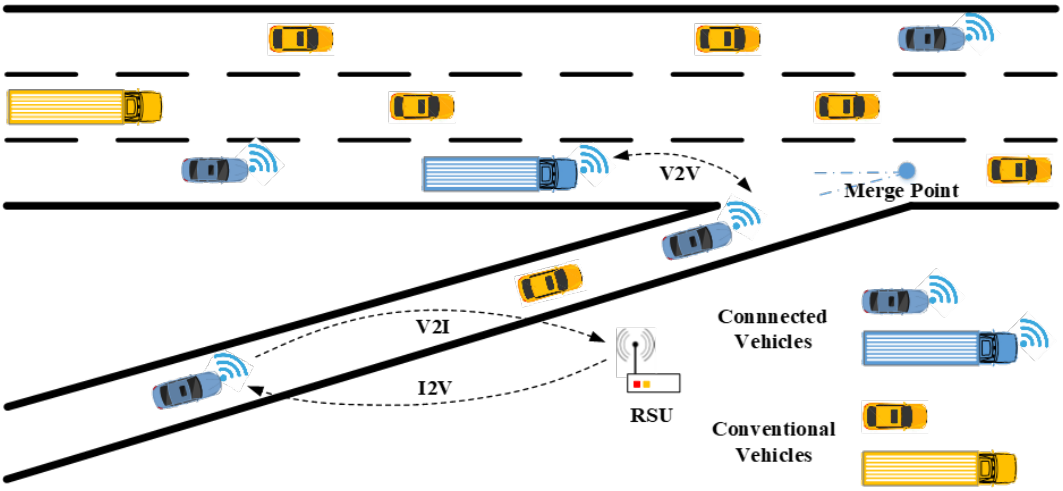

Figure 1. Connectivity-based cooperative ramp merging system.

Research Methodology

The project team has created a connectivity-based decentralized cooperative ramp merging system (see Figure 1) that can accommodate various vehicle types (i.e., cars and trucks), and cater to mixed traffic

[1] SAE International. "Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles", SAE J3016, April 2021

conditions (involving connected vehicles and non-connected vehicles). Furthermore, the project team has developed a multi-human-in-the-loop (MHuiL) co-simulation platform. This platform seamlessly integrates one traffic simulator with two game engine-based driving simulators, allowing the project team to observe and analyze driving behaviors and interactions from two human drivers. This new platform enhances the ability to model and validate the interactions between drivers within an immersive simulation setting. Volunteers participated simulation experiments by operating a passenger car driving simulator and a truck driving simulator. The experimental scenarios encompass both on-ramp and mainline driving situations. During the experiments, drivers went through different scenarios, i.e., with and without the provision of speed guidance through the cooperative ramp merging system.

Results

The case study experiments revealed that the MHuiL simulation platform can serve as a valuable tool for the analysis, modeling, and simulation of driving behaviors and interactions. The experimental findings suggest that the suggested cooperative ramp merging system is effective in enhancing both traffic safety and driving smoothness. When utilizing the system, the median minimum time headway for the yielding passenger car on the mainline experiences a notable 57% increase. Additionally, there is a 17% reduction in speed variations for these yielding vehicles, and a corresponding 19% decrease in speed variation for the merging truck from the on-ramp. These results underscore the potential of the proposed application to significantly enhance the safety and efficiency of ramp merging for heavy-duty trucks, particularly in scenarios where on-ramps feature relatively short merging lanes.

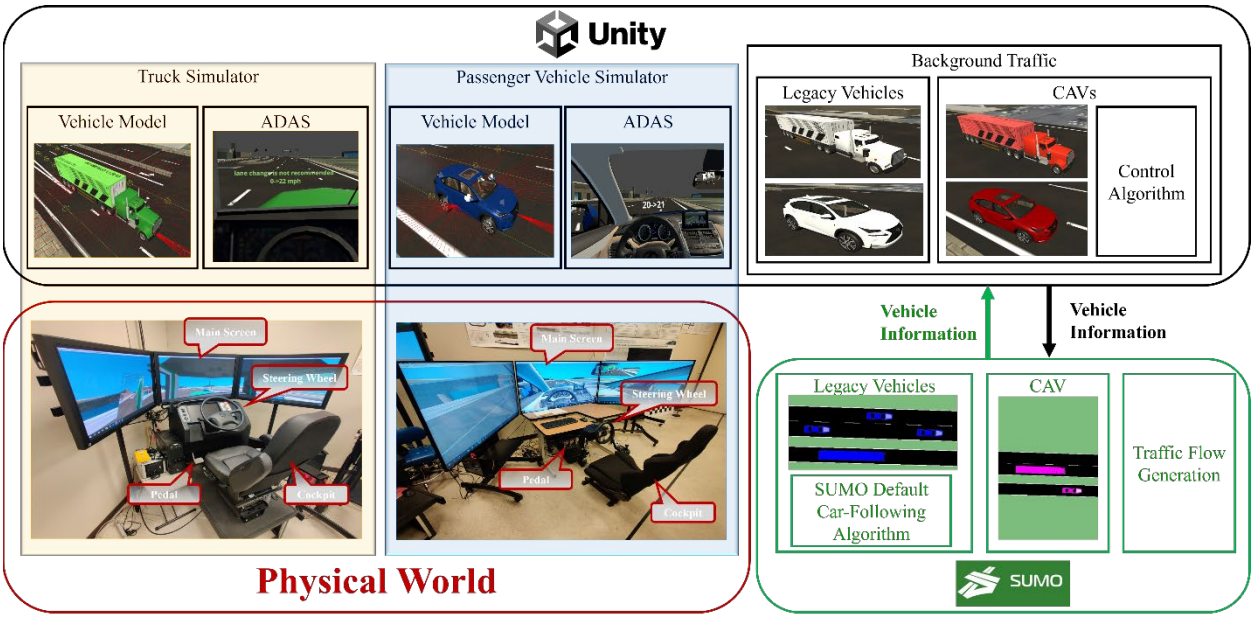

Figure 2. Architecture of the multi-human-in-the-loop (MHuiL) co-simulation platform.