MIDWEST TRANSPORTATION CENTER MTC

Estimating Energy Efficiency of Connected and Autonomous Vehicles in a Mixed Fleet

tech transfer summary

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RESEARCH PROJECT TITLE

Estimating Energy Efficiency of Connected and Autonomous Vehicles in a Mixed Fleet

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The Midwest Transportation Center (MTC) is a regional University Transportation Center (UTC). Iowa State University, through its Institute for Transportation (InTrans), is the MTC lead institution.

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Two adaptive cruise control models for connected and autonomous vehicles (CAVs)—one for gasoline and one for electric vehicles—were developed to investigate the fuel efficiency of CAVs in a mixed traffic stream.

Objective

The objective of this project was to evaluate two rule-based energy efficient adaptive cruise control (ACC) models in a traffic stream with both connected and autonomous vehicles (CAVs) and human-driven vehicles to investigate the fuel efficiency of CAVs in a mixed fleet.

Problem Statement

While other ACC strategies exist, they have been formulated as an optimization problem rather than a rule-based model that has low computational demand, natural adaptability to online applications, and reliability. In addition, most models have not taken into account that CAV and human-driven vehicles will likely share the road network in the near future and CAVs will be implemented gradually over time.

Project Description

The researchers evaluated the ecological smart driver model (Eco-SDM) for gasoline CAVs and the energy-efficient electric driving model (E3DM) for electric CAVs using energy consumption models developed and calibrated based on on-road vehicle fuel economy data.

The Eco-SDM considered the location of a CAV relative to other CAVs and to manually driven vehicles, and adjusted the desired spacing between the following and leading vehicle to provide smooth deceleration and acceleration. TThe VT-Micro model is calibrated based on road vehicle operational data and used to investigate the Eco-SDM's impact on fuel consumption.

Likewise, the E3DM considered the location of an electric-CAV (e-CAV) relative to other e-CAVs and human-driven vehicles. It also maintained high efficiency of regenerative braking and provided smooth deceleration and acceleration by adjusting the spacing between the leading and following vehicles.

For battery electric vehicles (BEVs), the research team also proposed a power-based energy consumption model to estimate on-road energy consumption and used that model to investigate E3DM's impact on energy consumption of both individual vehicles and the entire fleet.

Key Findings

The results showed that the Eco-SDM and E3DM outperform the intelligent design model (IDM-ACC) and the Nissan-ACC model in terms of energy consumption. For Eco-SDM-based CAVs, the fuel saving benefit was greatest when a CAV was at the front of a platoon. For E3DM-based e-CAVs, higher market penetration of e-CAVs may not result in higher energy efficiency of the entire fleet.

Considering mixed traffic streams with BEVs and gasoline vehicles, the energy consumption of the entire fleet decreases when the market penetration of BEVs (containing both e-CAVs and manual BEVs) increases. A higher ratio of e-CAVs to manual BEVs (m-BEVs) results in higher energy efficiency.

Other key findings regarding the energy efficiency of gasoline CAVs in a mixed fleet were as follows:

- By simulating single-lane vehicle dynamics in a platoon with different percentages of CAVs, the results show that CAVs are generally more fuel efficient than the manually driven vehicles.
- The Eco-SDM outperforms IDM-ACC and Nissan-ACC in terms of fuel efficiency and travel time.
- Higher market penetration of CAVs results in better fuel efficiency of the fleet. When the market penetration of the Eco-SDM-equipped CAVs exceeds 30%, the marginal improvement of fuel efficiency decreases.
- One Eco-SDM CAV may result in up to 2% reduction in total fuel consumption if placed at the front of the platoon.

Other key findings about the energy efficiency of e-CAVs in a mixed fleet were as follows:

- By simulating single-lane vehicle dynamics in a platoon with different percentages of e-CAVs, the results show that e-CAVs equipped with the E3DM and Nissan-ACC consume less energy than human-driven vehicles.
- The E3DM outperforms IDM-ACC, CACC, and Nissan-ACC in terms of energy efficiency.
- Higher market penetration of e-CAVs may not result in better energy efficiency of the entire fleet. With the E3DM, the highest energy efficiency is achieved when the market penetration of e-CAVs is 20%. This is because more e-CAVs in the traffic stream results in faster string stabilization and decreases the regenerative energy.
- Considering mixed traffic streams with BEVs (e-CAVs and m-BEVs) and internal combustion engine vehicles (m-ICEVs), the marginal improvement in energy efficiency decreases when the market penetration of BEVs, including e-CAVs and m-BEVs, exceeds 20%.
- The larger the market penetration ratio of e-CAVs to m-BEVs is, the faster the marginal improvement in energy efficiency reaches the turning point.

Implementation Readiness and Benefits

The two newly developed rule-based ACC models—the Eco-SDM for gasoline CAVS and the E3DM for electric CAVs—outperform previous models in terms of energy consumption that shows potential benefits in a mixed traffic stream.

Recommendations for Future Research

The models ignored lane-changing behavior, and future research should design an energy-efficient strategy for lane-changing, which should be implemented in tandem with the Eco-SDM and E3DM to simulate real-world driving behavior.

Further, the simulation was not able to represent different traffic congestion levels because the lead vehicle in each platoon was assumed to follow the Urban Dynamometer Driving Schedule (UDDS). Future research should simulate different traffic states to investigate the impact of the two models, Eco-SDM and E3DM, under different congestion levels.

Finally, the models ignored potential communication delays and sensor failures in the CAVs. Future research should investigate the impact of these factors on the performance of CAVs.