

Development of Real-World-Emission Reduction Technologies (4th Report)

- A Study on Emissions Reduction through Driver Behavior Modification -

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Amid growing environmental awareness, a multi-pathway strategy toward carbon neutrality is being pursued, in which internal combustion engines continue to play an important role. As emission regulations become increasingly stringent, greater attention is being paid to emissions under real-world driving conditions. Because driver inputs in response to surrounding traffic can substantially affect exhaust emissions, the authors have developed real-world emission reduction technologies through an integrated approach involving the vehicle, driver, and traffic flow. This study proposes a personalized behavior-modification method and evaluates its effectiveness in reducing driver-induced emissions.

To evaluate behavior-modification interventions safely, a digital twin environment was developed. An approximately 18-km section of the Shin-Tomei Expressway, from Suruga-Bay Numazu Service Area to Shin-Fuji Interchange, was reproduced in Unreal Engine, while traffic-flow scenarios were generated using Vissim. Emissions were estimated from vehicle-state variables using a physics-based model. Because driver acceptance is critical, the system learned individual driving characteristics and personalized AI dialogue and interventions. An LSTM model used vehicle speed, accelerator-pedal position, headway distance, and related variables to predict emission-increasing accelerator inputs. These predictions triggered a generative AI agent to provide personalized voice prompts encouraging eco-driving. Ten participants in their 20s to 40s were evaluated under three conditions: Baseline, free driving at a target speed of 120 km/h; AI Dialogue, which incorporated each driver's interests and dialogue history; and AI Behavior Modification, which added interventions triggered by predicted emission deterioration. After approximately one hour of familiarization, the model was updated for each participant and the dialogue history was incorporated into the agent. The study was approved by Toyota Motor Corporation's research ethics committee.

The driver-specific models predicted accelerator inputs before the actual operation, enabling proactive prediction of emission deterioration. Accuracy tended to be higher for drivers who followed preceding vehicles and lower for those who frequently changed lanes to maintain their desired speed. Adding turn-signal information improved acceleration prediction during lane changes. Relative to Baseline, NOx emissions decreased by 7.5% under AI Dialogue and by 17.5% under AI Behavior Modification. A paired t-test showed a significant reduction for AI Behavior Modification ($p = 0.011$), whereas the reduction under AI Dialogue was not significant ($p = 0.100$) because of substantial inter-participant variability. The difference between the two AI conditions was also not significant ($p = 0.153$). Some drivers adopted smoother driving under AI Dialogue, whereas others made more abrupt inputs. In contrast, interventions delivered immediately before predicted accelerator inputs effectively suppressed emission-increasing acceleration.

Personalized interventions based on emission prediction suppressed abrupt accelerator inputs and significantly reduced NOx emissions, demonstrating the potential of driver-focused emission reduction technologies. However, acceptance of AI dialogue varied among drivers, and the effects may partly reflect the controlled driving-simulator environment. Moreover, this study demonstrated short-term behavioral change rather than sustained behavior modification. Future work will optimize interventions for individual drivers, integrate AI agents with HMI systems, and evaluate long-term effects across stages of behavior change.

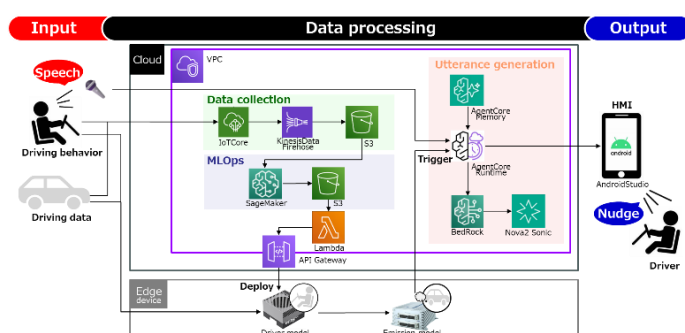


Fig.1 AI agent system architecture

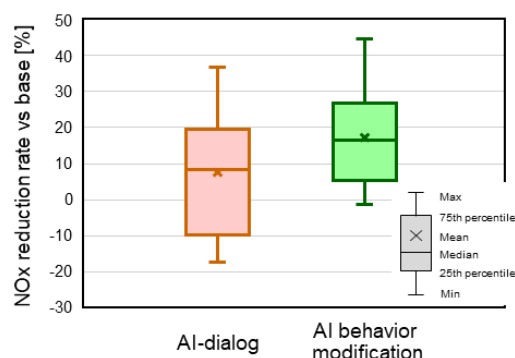


Fig.2 Effect of driver behavioral change on NOx emissions