

High-Accuracy Prediction of Modal Emissions Using a Data-Driven Model

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KEY WORDS: Heat engine, Post treatment system, Numerical calculation, Data-Driven approach [A1]

Increasingly stringent emission regulations have increased the demand for accurate emission prediction during the early stages of vehicle development. Conventional neural-network-based models require vehicle test data for each target specification, limiting their applicability to new vehicle development where such data are unavailable. To address this challenge, a data-driven modal emission prediction framework was developed by combining steady-state emission maps with neural-network-based transient correction.

The proposed framework consists of engine-out (Raw EM) and three-way catalyst (TWC) conversion models constructed using engine bench and vehicle test data. Steady-state emission maps represent specification-dependent characteristics for each engine and TWC specification, while a multilayer perceptron (MLP) learns transient deviations between measured emissions and steady-state map predictions. Figure 1 illustrates the overall architecture of the proposed framework. Unlike conventional data-driven approaches, specification-dependent characteristics are represented by steady-state emission maps, while transient emission behavior is learned independently by the neural network. By separating specification representation from transient behavior correction, the framework can reflect hardware differences while utilizing a common transient correction model trained using multiple vehicle configurations.

A key feature of the proposed approach is its applicability to vehicle specifications that are not included in the training dataset. This capability makes the framework particularly suitable for early-stage vehicle development, where specification studies must be conducted before vehicle measurement data become available. Validation was performed using multiple engine and TWC specifications, including naturally aspirated, turbocharged, hybrid, and non-hybrid vehicles. Validation results demonstrated that the proposed framework improved prediction accuracy for both raw emission and TWC conversion models across multiple engine and catalyst specifications. For the raw emission model, the average cumulative prediction error was reduced from 38% to 14%, satisfying the internal development criterion for all validation cases. These results demonstrate that the proposed framework achieves robust prediction accuracy across a wide range of hardware configurations.

Furthermore, the developed framework was integrated into a vehicle simulation environment and applied to emission variability assessment for a new vehicle program. Figure 2 presents an example of the evaluation result. The analysis demonstrated that emission variability and specification sensitivity can be quantitatively assessed before prototype vehicle availability, enabling early validation of vehicle specifications and emission performance.

These results demonstrate that the proposed framework provides a practical solution for front-loading emission development. By combining specification-dependent emission maps with generalized transient correction, the framework enables accurate modal emission prediction for vehicle specifications beyond those represented in the training data. The proposed approach supports quantitative assessment of emission performance and robustness during the concept and design phases of new vehicle development, thereby contributing to more efficient model-based development. Future work will focus on extending the framework to alternative fuels and a wider range of driving conditions.

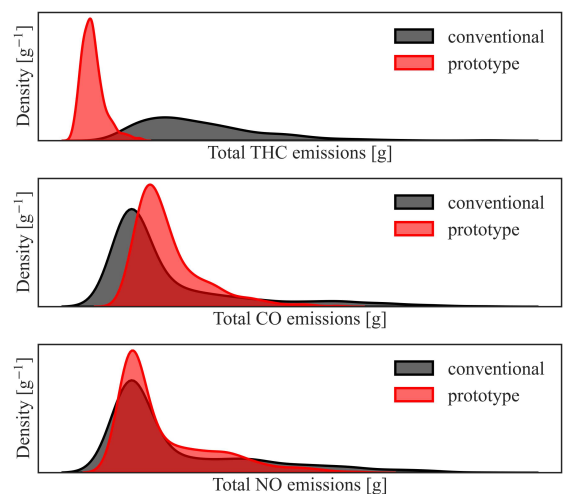


Fig. 2 Kernel density distributions of total emissions obtained under varying model parameters.

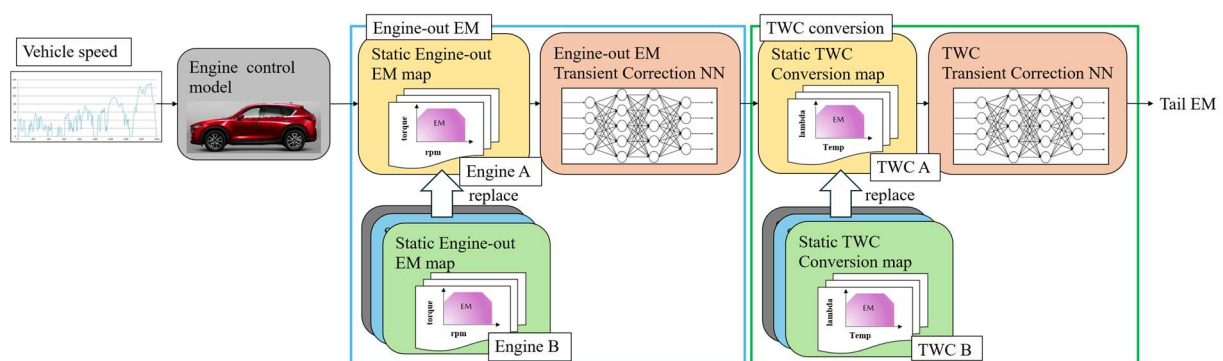


Fig. 1 Overview of the proposed modal emission prediction framework.