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A review of vehicle fuel consumption models to evaluate eco-driving and eco-routing

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ABSTRACT

Fuel consumption models have been widely used to predict fuel consumption and evaluate new vehicle technologies. However, due to the uncertainty and high nonlinearity of fuel systems, it is difficult to develop an accurate fuel consumption model for real-time calculations. Additionally, whether the developed fuel consumption models are suitable for eco-routing and eco-driving systems is unknown. To address these issues, a systematic review of fuel consumption models and the factors that influence fuel economy is presented. First, the primary factors that affect fuel economy, including travel-related, weather-related, vehicle-related, roadway-related, traffic-related, and driver-related factors, are discussed. Then, state-of-the-art fuel consumption models developed after 2000 are summarized and classified into three broad types based on transparency, i.e., white-box, grey-box and black-box models. Consequently, the limitations and potential possibilities of fuel consumption modelling are highlighted in this review.

1. Introduction

The automobile industry is currently experiencing pressures due to the oil shortage crisis and environmental protection requirements (Salvi and Subramanian, 2015). A considerable amount of fuel is consumed by cars each year, resulting in a large amount of exhaust emissions. In 2011, approximately 59% of oil was used for transportation (World Oil Outlook, 2014), which resulted in approximately 22% of anthropogenic carbon dioxide emissions (IEA, 2013). Therefore, automobile manufacturers are currently under pressure to provide more environmentally friendly and fuel-efficient vehicles to consumers.

There are various ways to improve vehicle fuel economy, including new engine technologies, new vehicle technologies, new energy as well as new planning and control technologies, as indicated in Fig. 1. However, new engine and vehicle technologies have limited effects on lowering fuel consumption; advanced engine and vehicle technologies have potential efficiency improvements of 4–10% and 2–8%, respectively (U.S. Environmental Protection Agency, 2015a). Furthermore, although new advanced energy vehicles represent the future development trend of automobiles, more challenges in terms of battery mileage, battery lifetime and battery charging time should be overcome (U.S. Environmental Protection Agency, 2015b). Another available method for improving fuel economy is eco-driving and eco-routing. Several studies have indicated that eco-driving can improve fuel economy by 15–25% (CIECA, 2007; Hellström et al., 2009; Kamal et al., 2011; Cheng et al.,

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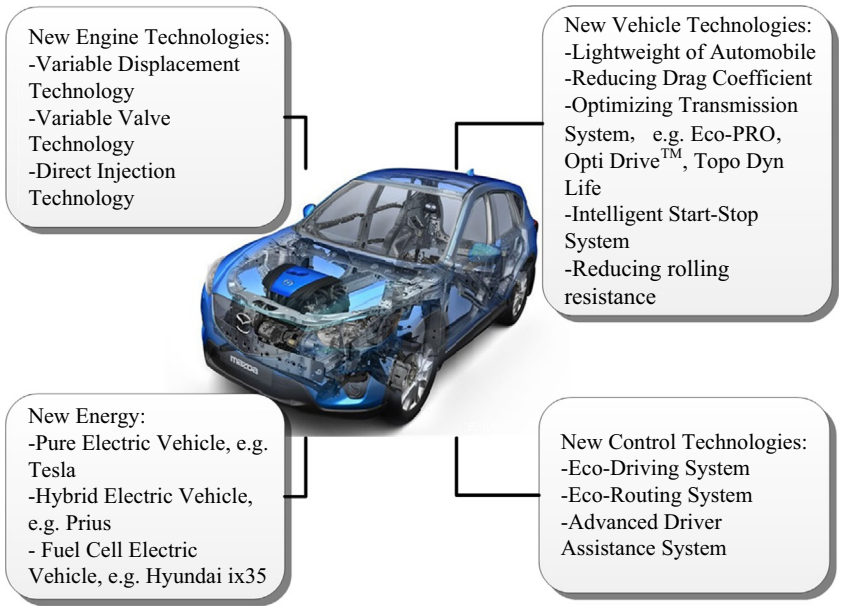

Fig. 1. New technologies for improving vehicle fuel economy.

2013; Casavola et al., 2010; Kundu et al., 2013; Ben Dhaou, 2011), and approximately 12–33% of fuel can be saved through eco-routing (Ben Dhaou, 2011; Navteq Green Streets, 2009). Therefore, eco-driving and eco-routing are effective ways to improve fuel economy in both the short-term and long-term.

To evaluate eco-driving and eco-routing algorithms, an appropriate fuel consumption model that can predict instantaneous fuel consumption second by second is needed. To identify the fuel consumption models that are best suited for eco-driving and eco-routing, a review of state-of-the-art fuel consumption models is necessary. Faris et al. performed a comprehensive review of state-of-the-art fuel consumption and emission models, such as the VT-Micro model (Ahn et al., 2002), power-based fuel consumption model (Post et al., 1984), and POLY model (Teng et al., 2002), and classified these models into five broad categories: (1) modelling based on the scale of the input variables, (2) modelling based on a formulation approach, (3) modelling based on the type of explanatory variables, (4) modelling based on state variable values and (5) modelling based on the number of dimensions (Faris et al., 2011). However, the authors only discussed the application of these models in evaluating the regional impacts of transportation projects. Whether these models are suitable for evaluating emerging eco-driving and eco-routing systems was not mentioned. Additionally, there are various factors that can influence fuel consumption, and few scholars have reviewed these factors thoroughly and systematically. Therefore, to help develop better fuel consumption models and find the fuel consumption models that are best suited for eco-driving and eco-routing systems, this paper discusses the main factors affecting fuel consumption and reviews classical fuel consumption models from the perspective of transparency. The paper classifies factors affecting fuel consumption into six broad categories, divides fuel consumption models into white-box, black-box and grey-box models, and addresses the following three problems:

(1) The main factors affecting of fuel consumption, including travel-related, weather-related, vehicle-related, roadway-related, traffic-related and driver-related factors, are systematically analyzed and quantified, providing a systematic reference and direction for the development of future fuel consumption models.
(2) The existing fuel consumption models are divided into white-box, black-box and grey-box models from the perspective of transparency. These three types of models are then compared in terms of advantages, disadvantages, accuracy, model structure and characteristics. This analysis will help engineers and researchers choose appropriate types of models and modelling methods while developing new fuel consumption models.
(3) The models best suited for eco-driving and eco-routing systems are selected by comparing the model accuracy and structure of white-box, black-box and grey-box models. The limitations and potentials of fuel consumption modelling are highlighted by comparing the fuel consumption models based on their modelling methods and transparency. This analysis lays a good foundation for fuel consumption modelling and application.

This report is organized as follows: The primary factors that affect the fuel consumption are discussed in Section 2. Section 3 elucidates the classification method, dividing the models into three categories and presents the main models of each category. The different model categories are compared in terms of advantages, disadvantages, accuracy and model structure in Section 4. Conclusions and ideas for future studies are presented in Section 5.