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Original Research Paper

Estimating impacts of emission specific characteristics on vehicle operation for quantifying air pollutant emissions and energy use

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HIGHLIGHTS

- Model predicts the fraction of time vehicles spend in various operating conditions.
- The output can be used to estimate air pollutant emissions and energy use.
- Authors combine micro-simulation for vehicle operations with structural equations.
- Geometric design elements have the largest influence on link speed.
- Most impact on vehicle operation, speed limit, then facility type and driving style, have been found.

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ABSTRACT

This paper proposes and illustrates a methodology to predict the fraction of time motor vehicles spend in different operating conditions from readily observable variables called emission specific characteristics (ESC). ESC describe salient characteristics of vehicles, roadway geometry, the roadside environment, traffic, and driving style (aggressive, normal, and calm). The information generated by our methodology can then be entered in vehicular emission models that rely on vehicle specific power, i.e., comprehensive modal emissions model (CMEM), international vehicle emissions (IVE), or motor vehicle emission simulator (MOVES) to compute energy consumption and vehicular emissions for various air pollutants. After generating second-by-second vehicle trajectories from a calibrated micro-simulation model, the authors estimated structural equation models to examine the influence of link ESC on vehicle operation. Authors' results show that 67% of the link speed variance is explained by ESC. Overall, the roadway geometry exerts a greater influence on link speed than traffic characteristics, the roadside environment, and driving style. Moreover, the speed limit has the strongest influence on vehicle operation, followed by

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facility type and driving style. Better understanding the impact on vehicle operation of ESC could help metropolitan planning organizations (MPOs) and regional transportation authorities predict vehicle operations and reduce the environmental footprint of motor vehicles.

1. Introduction

Spurred by increasing concerns about global warming, the state of California committed in 2006 to reducing its greenhouse gas (GHG) emissions to 1990 levels by 2020. To help achieve this ambitious goal, SB 375 (Sustainable Communities and Climate Protection Act of 2008, passed in 2008) attempts to reduce passenger vehicles GHG emissions by incorporating regional land use and housing strategies into regional transportation plans (RTPs). To better measure the effectiveness of emission reduction measures, guidelines for preparing RTPs require improving transportation models, including methods for travel forecasting, traffic analysis, and emissions modeling.

Improving estimates of vehicular emissions and fuel use over conventional models requires a better understanding of vehicle operation (i.e., driving patterns). It is well known that vehicle operation changes significantly with traffic conditions, yet these are ignored by current emission inventory models. More generally, vehicle operation is influenced by a variety of factors, which we call emission specific characteristics (ESC). Apart from engine and vehicle characteristics, they include geometric design elements, traffic characteristics, the roadside environment, weather conditions, and driving style. The potential impact of ESC is not negligible. For example, recent research suggests that eco-driving (the adoption by drivers of fuel economy-maximizing behavior) alone could reduce fuel consumption and emissions by 5%–40% (Alam and McNabola, 2014).

The relationship between vehicle operation and emission specific characteristics (Fig. 1, dotted boxes show the points not used in this study) has attracted interest from researchers for some time but investigations have so far focused on subsets of ESC variables. Kent et al. (1978) considered average speed, the root mean square

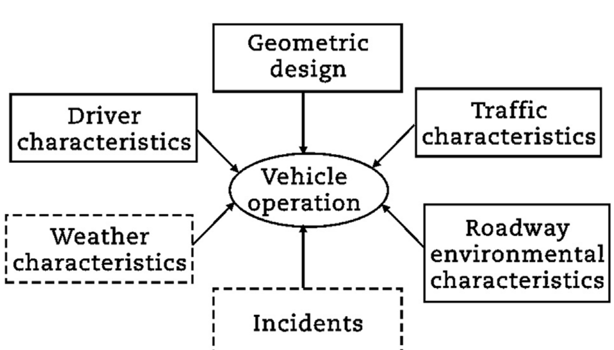

Fig. 1 – Relationship between vehicle operation and ESC.

acceleration, and the percentage of idle time. Kuhler and Karstens (1978) suggested adding acceleration statistics, the mean length of a driving period, and the proportion of different operating modes. Later, Watson et al. (1983) established the importance of positive kinetic energy (PKE) for explaining the observed variance in fuel consumption and pollutant emissions. Matzoros and Van Vliet (1992) added a creeping mode to account for short accelerations and decelerations when estimating time spent in different operating modes.

Ericsson (2000) broadened previous inquiries by considering different street types, driver gender, and traffic conditions. Using factorial analysis, she found that street type had the largest influence on vehicle operation. In subsequent research, Ericsson (2001) studied how 16 independent variables impacted vehicle operation; 9 of them turned out to be significant for fuel consumption and emissions, including 4 variables related to acceleration and power demand, 3 associated with gear changing behavior, and 2 describing speed bins.

Using a hierarchical tree approach, Hallmark et al. (2002) found that queue position, grade, downstream and upstream volume, the percentage of heavy duty vehicles, and posted speed limits affect vehicle operation at signalized intersections. More recently, Brundell-Freij and Ericsson (2005) reported that junction density, speed limit, street function, and neighborhood type are all statistically significant for explaining vehicle operation. Lederer et al. (2005) studied the effect of on-ramp geometric and operational factors on vehicle operation using linear regression and hierarchical tree-based regression methods; grade had the greatest impact on vehicle operation followed by ramp curvature, length of curvature, and traffic volume.

To improve current practice, Nesamani et al. (2007) developed a regression model to refine the link speed obtained from travel forecasting models using ESC variables. This improved emission estimation but their model cannot predict vehicle operation on a link.

Our work departs from the above cited literature not only by the breadth of the ESC variables we are considering but also by our methodology because previous studies relied either on factor analysis (Ericsson, 2000) or on regression with or without hierarchical tree analysis (Hallmark et al., 2002; Lederer et al., 2005; Nesamani et al., 2007, 2009).

More specifically, our paper makes two contributions. First, to better understand the impact of ESC variables on vehicle operations we consider the joint impact on vehicle operation of a large set of ESC, including vehicle constraints, individual driving style, characteristics of the surrounding traffic, and physical characteristics of the roadway and its environment.