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Proactive vehicle emissions quantification from crash potential under stop-and-go traffic conditions

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ABSTRACT

Driving behavior from vehicle interactions, such as acceleration, deceleration, and stop-and-go, is highly associated with traffic environment and safety conditions. This study is intended to investigate the connection between traffic environment and safety, more specifically, vehicle emissions and crash potential occurring in freeway traffic. Individual vehicle trajectory data collected from the US-101 freeway are used to investigate the relationship. Vehicle emission and crash potential indices are derived to characterize traffic environment and safety conditions, respectively, and relate those indices using correlation and regression. The resultant findings reveal that vehicle emissions are positively correlated with crash potentials in a statistically significant relationship. The methodological process for vehicle emissions and crash potential estimation developed in this study is expected to be used to monitor vehicle emissions from traffic conflict potential. Correspondingly, the methodological process is also to evaluate traffic control technology and policy implementation for improvement of transportation system efficiency with the goal of transportation emissions reduction.

1. Introduction

Transportation greenhouse gas emissions accounted for almost one-half of the increase in total U.S. greenhouse gas emissions between 1999 and 2006 (US DOT, 2010a). According to the Environmental Protection Agency (EPA), transportation was already the second largest emitting sector of carbon dioxide (CO_2) greenhouse gases behind electricity generation in 2012 (USEPA, 2012). Correspondingly, the environmental effect on public health of transportation CO_2 emissions, accounting for 95% of transportation greenhouse gas emissions, has received growing interest (USEPA, 2012, 2014).

One of the primary causes of transportation CO_2 emissions is traffic congestion; the congestion costs for time and fuel consumption increased from 24 billion dollars in 1982 to 121 billion dollars in 2011 (Schrank et al., 2012). Especially, non-recurring congestion from unexpected vehicle crashes substantially contributes vehicle CO_2 emissions, totaling half of all traffic congestion, through stop-and-go driving behavior patterns. The stop-and-go driving behavior is also combined with another important problem: the increase of crash potential in transportation system networks (USDOT, 2006).

To reduce vehicle emissions by a relevant amount, a report by the U.S. Department of Transportation (DOT) presented four major groups of strategies: introducing low-carbon fuel, increasing vehicle fuel economy, improving transportation system efficiency, and reducing carbon-intense travel activity (USDOT, 2010a). Unlike the other strategies, the transportation system efficiency strategy to reduce vehicle CO_2 emissions has significant co-benefits in the form of time-savings to travelers and reduced costs to shippers and on a local basis (USDOT, 2010b). Accordingly, the U.S. DOT report evaluated highway operation and management technologies such as signal coordination, freeway ramp metering, and real-time traveler information as its transportation system efficiency strategy (USDOT, 2010a).

Nevertheless, there are no criteria for deciding the applicability of the U.S. DOT's transportation system efficiency strategy implementation in the field to reduce vehicle emissions. That is, a transportation system is exposed to a variety of irregular congestion from unexpected crash occurrences and the resultant vehicle emissions.

Interestingly, vehicle emissions and crashes are triggered by the same cause, namely, driving behavior such as abrupt acceleration or deceleration during car-following or lane changes. For both vehicle emission reduction and safety improvement in a transportation system, it is more effective to avoid non-recurring congestion by monitoring crash potentials, identify the relationship between vehicle emissions and crash potential, and proactively implement transportation system efficiency improvement

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technologies. This proactive process particularly contributes to vehicle emission reduction in freeways because freeway crashes account for 72% of non-recurrent congestion (Skabardonis et al., 2003).

From these perspectives, an attempt to quantitatively associate vehicle emissions with crash potential should be conducted to complete the proactive process for vehicle emissions reduction. To employ the proactive activities aforementioned, first of all, an understanding of driving behavior patterns that increase vehicle emissions and crash potential is essential.

Hence, this study aims to provide a numerical methodology of forecasting vehicle emissions from crash potentials using vehicle trajectory data and to quantitatively support the U.S. DOT's transportation system efficiency strategies for vehicle emission reduction. To accomplish these goals, four major tasks were performed using individual vehicle trajectory data: (1) development of a driving behavioral model, (2) crash potential estimation, (3) estimation of vehicle emission, and (4) statistical analysis.

In this study, individual vehicle trajectory data obtained from the US-101 freeway, which is a part of the NGSIM project, are used for driving behavior model development. Based on individual vehicle trajectory data, this study derives a rear-end crash potential estimation model that was developed by Oh and Kim (2010). Regarding vehicle emissions estimation, a motor vehicle emission simulator (MOVES), recently published by the U.S. Environmental Protection Agency (EPA), is adopted (USEPA, 2009). During the estimation process for vehicle emissions and crash potential, vehicle emission index (VEI) and crash potential index (CPI) are derived. Finally, statistical analyses, including correlation and regression approaches, are conducted to explore the statistical significance of the relationship between VEI and CPI.

2. Literature review

Based on the goals of this study, first, high-resolution traffic data capable of representing individual vehicle movements must be analyzed for the scientific and systematic investigation of driving behavior patterns. Vehicle trajectory data provide such information and are thus very useful for analyzing driver behavior and vehicle interactions. Particularly, the Federal Highway Administration (FHWA) has released vehicle trajectory datasets as part of the Next Generation Simulation (NGSIM) project, from which several traffic engineering studies have been conducted. Dominant approaches can be classified into two groups: to identify the factors affecting vehicle interactions and to model microscopic traffic events such as car-following (Hamdar and Mahmassani, 2008; Kesting and Treiber, 2008; Talebpour et al., 2011) and lane changing (Toledo and Zohar, 2007; Choudhury et al., 2007; Thiemann et al., 2008).

Particularly, the use of micro-simulation modeling for conflict analysis has been popularized for evaluating experimental changes to existing road networks. As an initial stage of conflict analysis by simulation modeling, a study by Bachmann et al. developed a revised definition of conflict to address the issues of unrealistic conflict situations, and investigated the evaluation of a truck-only highway in Canada to observe the effects on traffic conflicts (Bachmann et al.,2011). Their study found that car lane-change conflicts increased because of the cars' increased maneuverability and presence on the truck-free highway even though providing a separate highway for trucks did reduce truck-related conflicts. During the conflict analysis, the vehicle trajectory data were used to quantify traffic conflict potential in previous studies at a more detailed analysis level. Oh and Kim and Meng and Weng proposed methods to estimate rear-end crash risks (Oh and Kim, 2010; Meng and Weng, 2011). Laureshyn et al. (2010) proposed a theoretical framework using surrogate safety measures obtained from trajectory data. Yang and Ozbay estimated traffic conflict risks for merging vehicles (Yang and Ozbay, 2011). Kuang et al. (2015) also proposed a probabilistic causal model to measure the rear-end crash risk using collision risk index reflecting freeway traffic state to a traffic speed disturbance. Similarly, Li et al. evaluated driving risk based traffic characteristics of freeway interchange entrance area in particular. As a result, they found that the speed difference and crash risk become decreasing with the increasing of the front car on acceleration lane (Li et al., 2013).

Moreover, vehicle emissions and measurements representing the environmental impacts of transportation-related operations and control strategies (Wu et al., 2010; Park et al., 2011; Tao et al., 2011) and policies (Lee et al., 2009; Lee, 2011) have been estimated based on vehicle trajectory data. Unlike macroscopic emission estimations based on aggregated representative link speeds, microscopic emission models based on vehicle trajectories produce more accurate estimates (Lee, 2011).

Even though some previous studies have used vehicle trajectories, we are not aware of any study that relates vehicle emission with crash potential by using vehicle trajectories, which is the major focus of this study. In a recent study, Silva et al. attempted to measure injury severity and vehicle emissions (Silver et al., 2012). However, the authors dealt with estimations for crash potential and vehicle emissions separately by each crash case without any consideration of vehicle interactions in the traffic stream and numerical connection between them. Thus, few studies have explored the numerical estimation method to measure vehicle emissions and crash potential and relate them based on individual vehicle trajectory data.

3. Data

A vehicle trajectory dataset on a 640-m segment of US-101 from the NGSIM project was used in this study (FHWA, 2005). This dataset obtained vehicle trajectories, collected from 7:50 a.m. to 8:35 a.m. on Wednesday, June 15, 2005, that exhibited stop-and-go behavior, including frequent acceleration and deceleration. The highway segment of US-101 includes five mainline lanes and an auxiliary lane for an on- and off-ramp, as depicted in Fig. 1.

To conduct more reliable emission estimations, detailed vehicle class information was obtained by manual examination of the US-101 data. Vehicles on the video were re-categorized based on the FHWA scheme. Additionally, a vehicle age distribution proposed by Bai et al. (2009) was applied in emission estimation. Table 1 presents descriptive statistics for section speeds of the US-101 segment.

4. Methodology

To complete the objective of this study, both vehicle emissions and crash potential must be quantitatively estimated. An overview of the proposed estimation framework is presented in the following subsections.

4.1. Framework of proposed estimation methods

This study intends to explore the relationship between vehicle emissions and crash potential, which is invaluable as it represents the first attempt to relate the impact of crash risk on the environmental conditions of the transportation system. This study also intends to provide numerical methods for traffic efficiency strategy implementation to proactively avoid non-recurring congestions from traffic crashes resulting in vehicle emission