JOURNAL OF TRAFFIC AND TRANSPORTATION ENGINEERING (ENGLISH EDITION) 2016; 3 (3): 226–235

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journal homepage: www.elsevier.com/locate/jtte

Original Research Paper

Incorporating vehicle mix in stimulus-response car-following models

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ARTICLE INFO

Article history:
Available online 14 May 2016

Keywords:
Car-following
Stimulus-response
Acceleration/deceleration
Vehicle mix
Driver response time lag

ABSTRACT

The objective of this paper is to incorporate vehicle mix in stimulus-response car-following models. Separate models were estimated for acceleration and deceleration responses to account for vehicle mix via both movement state and vehicle type. For each model, three sub-models were developed for different pairs of following vehicles including “automobile following automobile,” “automobile following truck,” and “truck following automobile.” The estimated model parameters were then validated against other data from a similar region and roadway. The results indicated that drivers' behaviors were significantly different among the different pairs of following vehicles. Also the magnitude of the estimated parameters depends on the type of vehicle being driven and/or followed. These results demonstrated the need to use separate models depending on movement state and vehicle type. The differences in parameter estimates confirmed in this paper highlight traffic safety and operational issues of mixed traffic operation on a single lane. The findings of this paper can assist transportation professionals to improve traffic simulation models used to evaluate the impact of different strategies on ameliorate safety and performance of highways. In addition, driver response time lag estimates can be used in roadway design to calculate important design parameters such as stopping sight distance on horizontal and vertical curves for both automobiles and trucks.

1. Introduction

A car-following model is a mathematical expressions that emulate drivers' behavior following another vehicle in a single lane. Studies on the car-following model started in the early 1950s (Pipes, 1953; Reuschel, 1950). Reuschel and Pipes were independently inspired by the vehicle separation law of the California Vehicle Code, which states that “A good rule for following another vehicle at a safe distance is to allow yourself the length of a car (about fifteen feet) for every ten miles per hour you are traveling.” They developed safe distance model as a linear function of speed assuming that drivers reacted instantaneously to the actions of a leading vehicle. Forbes

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Peer review under responsibility of Periodical Offices of Chang'an University.
http://dx.doi.org/10.1016/j.jtte.2016.05.002

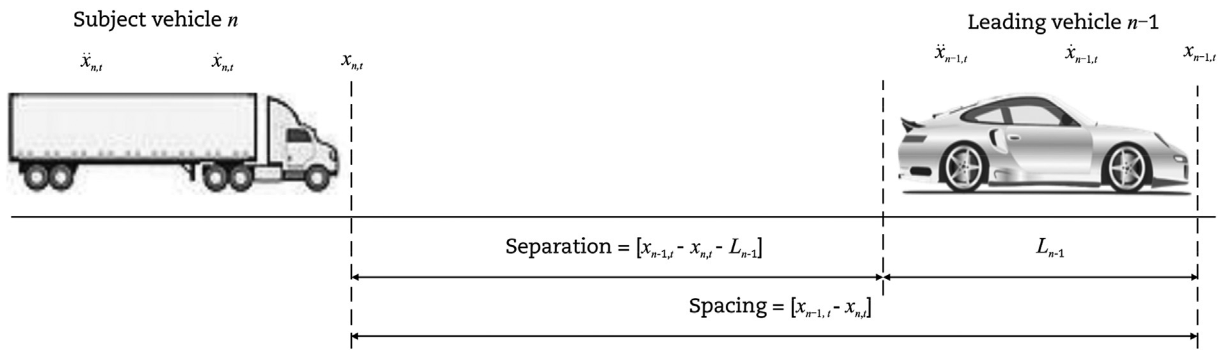

Fig. 1 – Definitions and notations.

(1963) modified the model by incorporating a driver reaction time.

In 1958, researchers associated with the general motors (GM) developed a series of five stimulus-response car-following models. The concept of the GM models was similar to those of Reuschel, Pipes, and Forbes but assumed that driver response was a function of a stimulus and driver sensitivity. Stimulus was defined as the relative speed between the two following vehicles and driver sensitivity was assumed to be a function of vehicle speed and spacing. Gazis et al. (1961) generalized the models by further improving the driver sensitivity term. This resulted in a nonlinear model that had the driver sensitivity term proportional to the speed of the following vehicle and inversely proportional to vehicle spacing.

Ozaki (1993) and Subramanian (1996) modified the GM model by separating acceleration and deceleration responses. Subramanian determined that drivers reacted faster under acceleration response than deceleration response which is counter intuitive. Deceleration is a response related to safety, therefore, one would expect a faster response time. Ahmed (1999) improved Subramanian's model by adding traffic density in the sensitivity term and assumed nonlinearity in the stimulus term. Similarly, Toledo (2003) re-estimated parameters of Subramanian's model. For acceleration response, results of both Ahmed and Toledo showed that acceleration increased with speed and decreased with vehicle spacing, which was unexpected. For the deceleration model, they both removed speed from the models as it was statistically insignificant. Having a deceleration model that does not incorporate speed is unrealistic.

To address limitations of the generalized GM model reviewed above, numerous studies have attempted to improve the structure to reasonably replicate car-following behavior (Alvarez et al., 2003; Bonsall et al., 2009; Brackstone et al., 2009; Mehmood and Easa, 2010; Newell, 2002; Siuhi and Kaseko, 2013; Wang et al., 2004; Winsum and Brouwer, 1997; Xin et al., 2008). Other studies have attempted to improve car-following particularly in modeling driving behavior, traffic safety, and psychology (Dowling et al., 2004; Wang et al., 2010a,b). Most recent studies have devoted effort and emphasis to understand drivers' decision making while following another vehicle in the same lane (Wang et al., 2011; Winsum and Brouwer, 1997).

Drivers' decision making of the subject vehicle following the leader vehicle depends on many factors including vehicle separation, differential speed, and characteristics of traffic stream (Ranney, 1994; Winsum and Heino, 1996). Due to many reasons, sometimes drivers make unconscious and/or unexpected responses which are not responses related to the actions of the leading vehicle (Siuhi, 2009; Siuhi and Kaseko, 2013). As a result, emulating driving behavior on drivers' awareness under different driving conditions still motivates researchers (Bonsall et al., 2009; Sukthankar, 1997; Wang et al., 2010a,b).

In summary, existing GM-like stimulus-response car-following models still have one major shortcoming; they fail to account for vehicle mix. The models assume that drivers have similar driving behavior regardless of the type of vehicle being driven and/or followed, which is unrealistic. In reality, drivers behave differently depending on type of vehicle being followed and/or driven. For example, large trucks generally block the ability of drivers of automobiles to see beyond them due to their large dimensions. Thus, drivers of automobiles traveling behind trucks may behave more differently than when traveling behind other automobiles. Likewise, trucks have low acceleration/deceleration capabilities than automobiles and try to compensate these limitations by keeping longer vehicle separation than automobiles.

To address this shortcoming of the GM-like stimulus-response car-following models, the objectives of this paper were:

1. To develop and estimate a set of stimulus-response car-following models that incorporate vehicle mix such as automobiles and trucks. Models estimated were for acceleration and deceleration responses for different types of vehicles being driven and/or followed,
2. To evaluate whether estimated model parameters were different for different types of vehicles being driven and/or followed, and
3. To evaluate spatial transferability of the estimated model parameters.

2. Generalized stimulus-response car-following model

This paper uses the following definitions and notations in describing the car-following models. Consider two following vehicles traveling from left to right as shown schematically in