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Predicting driver's lane-changing decisions using a neural network model

Jian Zheng *, Koji Suzuki, Motohiro Fujita

Graduate School of Engineering, Nagoya Institute of Technology, Nagoya, Aichi 466-8555, Japan

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ABSTRACT

Lane changing has a significant impact on traffic flow characteristics and potentially reduces traffic safety. However, literature relating to lane changing is not comprehensive, largely owing to the inherent complexity of lane changing and a lack of large-scale data to analyze such behavior. In an effort to cope with these obstacles, this study adopts a neural network (NN) model to capture the complexity of lane changing, and large-scale trajectory data are employed for model estimation and validation. For comparison purposes, a multinomial logit (MNL) model that was frequently accepted as a framework for lane changing in previous studies is also built. Although for non-lane-changing samples, both models perform well in model estimation and validation processes, for lane-changing samples, there are significant differences in their performance. The NN model is able to correctly predict 94.58% of left lane-changing samples and 73.33% of right lane-changing samples in the model estimation process, whereas the percentage correctly predicted by the MNL model is only 13.25% and 3.33%, respectively. While the accuracy of both models noticeably drops in the model validation process, prediction results in the NN model are still acceptable. Finally, the impact of heavy vehicles on driver's lane-changing decisions is quantitatively evaluated using the sensitivity analysis of the proposed NN model.

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1. Introduction

Owing to the ability to capture the complexity of traffic systems, traffic simulation has become one of the most widely used approaches for traffic planning, traffic design, and traffic management. Various traffic simulation software packages are currently available in the market, and they are utilized by thousands of consultants, researchers, and public agencies [1–4]. With the popularity of traffic simulation, the car-following and lane-changing models, two of the most significant components in traffic simulation, have naturally attracted a lot of attention from traffic researchers [5–8].

According to previous studies, lane changing has a significant impact on traffic flow characteristics owing to the inference effect on surrounding vehicles [9]. In addition, lane changing is also viewed as a key trigger in freeway breakdown [10,11], and it potentially reduces freeway safety [12,13]. To describe such driving behavior more accurately, over the past two decades, several lane-changing models have been developed [14–20]. However, compared to the car-following model, literature relating to lane changing is less comprehensive. This may be owing to two reasons: the inherent complexity of lane changing and the absence of large-scale data to analyze such behavior. Unlike car following, lane changing is influenced not only by preceding and following vehicles in the same lane but also by leading and lagging vehicles in adjacent lanes [21]. Besides, driver's decisions to change lane are also affected by driver characteristics (age, gender, driving experience) and driving

* Corresponding author. Address: Gokiso-cho, Showa-ku, Nagoya, Aichi 466-8555, Japan. Tel./fax: +81 52 735 7962.
E-mail address: zhengjian1112@gmail.com (J. Zheng).

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attitudes (aggressive or conservative driver) [22,23]. As a result, the prediction of driver's lane-changing decisions is extremely complicated. On the other hand, models should be estimated and validated by field data [24]. However, most of the previous lane-changing models were proposed without rigorous estimation and validation, largely owing to a lack of available data [14,15,17].

In an effort to cope with the obstacles affecting the modeling of lane changing, in this study, a neural network (NN) model is adopted to capture the inherent complexity of lane changing, and large-scale trajectory data are used for model estimation and validation. Specifically, this study makes the following contributions. (1) A detailed analysis of left and right lane changes is conducted, which suggests that the left and right lane changes are asymmetric and incentivized by different motivations. (2) A NN model that can completely account for the impact of surrounding vehicles on lane-changing decisions is developed. In addition, the proposed NN model clearly outperforms a multinomial logit (MNL) model, which was frequently adopted as a framework for lane changing in previous studies, both in model estimation and validation processes. (3) The impact of heavy vehicles on driver's lane-changing decisions is quantitatively evaluated using the sensitivity analysis of the proposed NN model.

The paper is composed of eight sections. Section 2 discusses the specification of our model, and is followed by the introduction and analysis of trajectory data in Section 3. Model estimation and validation are presented in Sections 4 and 5, respectively. The application of the proposed model is demonstrated in Section 6. Sections 7 and 8 are devoted to further discussions and conclusions.

2. Model specification

Depending on the purpose, lane changing is categorized as being either mandatory or discretionary [14]. Typically, mandatory lane changing is executed when the driver must leave the current lane to maintain the desired route. Discretionary lane changing refers to cases in which the driver changes lane to improve driving conditions, such as overtaking slow vehicles, passing large/heavy vehicles, and avoiding traffic near an on-ramp. In addition, lane-changing maneuvers are different for different types of vehicles (heavy vehicle or car) [20,21]. In this study, we only discuss the discretionary lane changing of cars. In fact, the proposed methodology can also be applied to heavy vehicles or mandatory lane-changing vehicles by defining them as subject vehicles.

The subject vehicle and its surrounding vehicles are illustrated in Fig. 1. Note that in this study, not only are the nearest lead and lag vehicles in the current and adjacent lanes considered but also the nearer lead and lag vehicles. To facilitate model specification, the following variables are employed:

L_{id} = ID of the current lane for the subject vehicle,
V = instantaneous speed of the subject vehicle,
$T_{lead}^{nearest}$ = type of the nearest lead vehicle,
$RV_{lead}^{nearest}$ = relative speed between the nearest lead vehicle and subject vehicle,
$SG_{lead}^{nearest}$ = space gap between the nearest lead vehicle and subject vehicle,
T_{lead}^{nearer} = type of the nearer lead vehicle,
RV_{lead}^{nearer} = relative speed between the nearer and nearest lead vehicles,
SG_{lead}^{nearer} = space gap between the nearer and nearest lead vehicles.

Accordingly, $T_{lag}^{nearest}, RV_{lag}^{nearest}, SG_{lag}^{nearest}, T_{lag}^{nearer}, RV_{lag}^{nearer}, SG_{lag}^{nearer}$ are variables with respect to the subject vehicle, the nearest, and nearer lag vehicles.

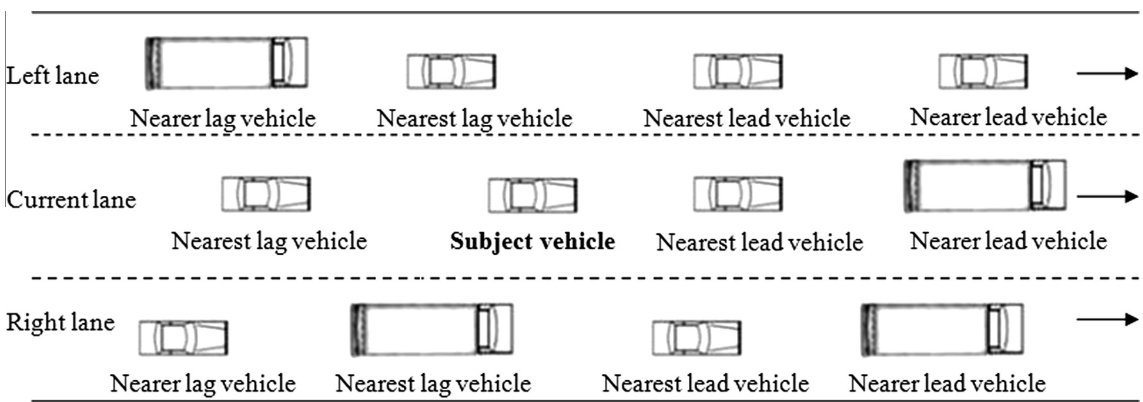

Fig. 1. Illustration of the subject vehicle and its surrounding vehicles.

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