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Time-dependent drivers' merging behavior model in work zone merging areas

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ABSTRACT

This study investigates the drivers' merging behavior in work zone merging areas during the entire merging implementation period from the time of starting a merging maneuver to that of completing the maneuver. With the actual work zone merging traffic data, we propose a time-dependent logistic regression model considering the possible time-varying effects of influencing factors, and a standard logistic regression model for the purpose of model comparison. Model comparison results show that the time-dependent model performs better than the standard model because the former can provide higher prediction accuracy. The time-dependent model results show that seven factors exhibit time-varying effects on the drivers' merging behavior, including merging vehicle speed, through lane lead vehicle speed and through lane lag vehicle speed, longitudinal gap between the merging and lead vehicles, longitudinal gap between the merging and through lane lead vehicles, types of through lane lead and through lane lag vehicles. Interestingly, both the through lane lead vehicle speed and the through lane lag vehicle speed are found to exhibit heterogeneous effects at different times of the merging implementation period. One important finding from this study is that the merging vehicle has a decreasing willingness to take the choice of "complete a merging maneuver" as the elapsed time increases if the through lane lead vehicle is a heavy vehicle.

1. Introduction

Widespread traffic growth has prompted the need for roadway improvements, such as maintenance and reconstruction of the existing roadway system. It should be pointed out that work crews usually close a part of existing traffic lanes in work zone in order to protect their safety. Because of lane drops, vehicles in a merge lane have to merge into the adjacent through lane before entering the work zone area (Weng and Meng, 2011). However, the increased merging maneuvers could increase the number of traffic conflicts that further lead to higher collision risk.

In general, the drivers' merging behavior is highly correlated with the collision risk, especially in work zone merging areas. In order to obtain an accurate estimate of the collision risk, it is of great importance to propose an appropriate model to describe the merging behavior in work zone merging areas. Many researchers (e.g., Kita, 1999; Toledo et al., 2009) have developed parametric models to predict the drivers' merging choices. Among these models, most are the gap acceptance based models with an assumption that a driver will only take a lane change if the adjacent lag and lead gaps are acceptable (Yang and Koutsopoulos, 1996; Lee, 2006; Toledo et al., 2009). However, this assumption is inconsistent with the reality that

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vehicles may still change lanes when only the adjacent lag gap or the adjacent lead gap is accepted (Gundaliya et al., 2008). To avoid this inconsistence, Treiber and Kesting (2009) presented a general lane-changing model MOBIL that took into account the degree of "passive" cooperativeness among drivers via a politeness factor. In the MOBIL model, a pushy driver is still able to initiate a lane change when either the adjacent lead gap or the adjacent lag gap is accepted. In addition, some other researchers (e.g., Meng and Weng, 2012) built non-parametric models to describe the vehicle merging behavior.

In order to take into account the sequential lane-changing/merging process, some other models (e.g., Ahmed, 1999; Oliver and Pentland, 2000; Smith et al., 2003; Meng and Weng, 2011) have also been developed to describe the sequential lane-changing behavior. However, these models could not fully explain the time-varying relationship between the lane-changing/merging behavior and influencing factors. This is because the effects of influencing factors on the drivers' merging behavior may vary with different times. When a model contains time-dependent response and explanatory variables, it is able to account for possible time-varying effects of influencing factors on the merging behavior. Therefore, there is a critical need to develop a time-dependent model to predict the sequential merging choices during the merging implementation period that is defined as the period from the starting time to the completion time of a merging maneuver.

2. Literature review

So far, a number of parametric models have been developed to describe the drivers' lane-changing/merging behavior. For example, game-theory based models (e.g., Kita, 1999; Talebpour et al., 2015) have been developed to predict the lane-changing/merging choices. Among these parametric models, most models are the gap acceptance models with an assumption that a driver will take a lane-changing if both the adjacent lag and lead gaps are acceptable (e.g., Lee, 2006; Toledo et al., 2007, 2009). However, their model assumptions are inconsistent with reality because vehicles still take lane changes when only the adjacent lag gap or the adjacent lead gap is accepted according to the real-world observations. To avoid this inconsistency, some other researchers (e.g., Kita, 1993) attempted to develop logit models for predicting the lane-changing decisions. Considering more influencing factors, Weng and Meng (2011) and Jia et al. (2011) developed logistic models to determine merging choices in work zone merging areas and urban expressway merging sections, respectively. Mao et al. (2013) presented a dynamic lane-based signal merge control model to advise drivers' merging behavior with the objective of maximizing work zone throughput under heavy traffic conditions. Park et al. (2015) developed logistic regression models for discretionary lane changing under congested traffic.

Apart from parametric statistical approach, many researchers also built non-parametric models such as tree-based models and artificial neural network models, which can provide higher prediction accuracy for merging choices. For instance, Hunt and Lyons (1994) predicted drivers' lane-changing decisions using neural networks on dual carriageways. Moridpour et al. (2013) developed a lane-changing model using fuzzy logic for describing the lane-changing behavior of heavy vehicles. Meng and Weng (2012) built a non-parametric model to predict the merging behavior at work zones using the classification and regression tree approach. Hou et al. (2014a, 2014b) modeled the mandatory lane changing behavior using Bayes classifier and decision trees.

In order to take into account the sequential lane-changing/merging process, many researchers presented various models to predict the series of merging choices. For example, Ahmed (1999) proposed a behavioral based model to replicate the real-time lane changing behavior. Oliver and Pentland (2000) used hidden Markov models (HMM) to recognize the lane change state. Smith et al. (2003) used four states to reflect the severity level of lane-change behavior according to relative longitudinal distance and speed. McCall et al. (2007) used the latitudinal position and head motion to infer lane-change intent. Meng and Weng (2011) developed Cellular Automata models incorporating the sequential lane-changing behavior. Wan et al. (2015) proposed a combined sequential decision-making model to describe the sequential vehicle merging behavior at freeway merging areas.

Nonetheless, the lane-changing/merging behavior models mentioned above still could not fully explain the time-varying effects of influencing factors on the lane-changing/merging behavior. This is because we require repeatedly collecting data for the merging vehicle before the completion of a merging maneuver in reality. It is reasonable to assume that the effects of influencing factors may vary with different times. In order to account for the possible time-varying effects, time-dependent models are suitable models for binary responses taken over time when the response and explanatory variables are time-dependent (Hu et al., 1998; Lai and Small, 2007; Lalonde et al., 2013). In addition, the above discussion clearly indicates that the literature regarding vehicle merging behavior during the merging implementation period, which is defined as the period from the stating time to the completion time of a merging maneuver is rather limited. Talebpour et al. (2015) assumed that drivers constantly monitor the situation during the lane-changing maneuver and their behavior changes over the course of lane change. However, these studies did not report how the effects of influencing factors (e.g., merging speed, lead vehicle speed, vehicle type) are changed with the time elapsed.

Therefore, there is a critical need to develop a time-dependent model to describe the complex merging behavior during the merging implementation period.

3. Objectives and contributions

This study aims to develop a time-dependent logistic regression model to describe the drivers' merging behavior considering the possible time-varying effects of influencing factors. The actual merging trajectory data will be used to calibrate the