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In-depth analysis of drivers' merging behavior and rear-end crash risks in work zone merging areas

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ABSTRACT

This study investigates the drivers' merging behavior and the rear-end crash risk 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 merging traffic data from a work zone site in Singapore, a mixed probit model is developed to describe the merging behavior, and two surrogate safety measures including the time to collision (TTC) and deceleration rate to avoid the crash (DRAC) are adopted to compute the rear-end crash risk between the merging vehicle and its neighboring vehicles. Results show that the merging vehicle has a bigger probability of completing a merging maneuver quickly under one of the following situations: (i) the merging vehicle moves relatively fast; (ii) the merging lead vehicle is a heavy vehicle; and (iii) there is a sizable gap in the adjacent through lane. Results indicate that the rear-end crash risk does not monotonically increase as the merging vehicle speed increases. The merging vehicle's rear-end crash risk is also affected by the vehicle type. There is a biggest increment of rear-end crash risk if the merging lead vehicle belongs to a heavy vehicle. Although the reduced remaining distance to work zone could urge the merging vehicle to complete a merging maneuver quickly, it might lead to an increased rear-end crash risk. Interestingly, it is found that the rear-end crash risk could be generally increased over the elapsed time after the merging maneuver being triggered.

1. Introduction

Various routine road maintenance and improvement activities, such as pothole patching, roadside tree-trimming and repairing damage to roads, are necessary to maintain a good level of service in an urban road system. Hereafter, a work zone is defined as a stretch of roadway where road maintenance or construction activities are operated. Note that work crews usually close a part of existing traffic lanes in work zone in order to protect their safety. However, the lane closure could increase the number of traffic conflicts which further lead to higher rear-end crash potential. It was reported that the accident rates are increased by 20–50% during road construction or maintenance periods (Hall and Lorenz, 1989; Garber and Woo, 1990; Zhao, 2001). In addition, the rear-end crash is found to be the major accident type in work zones, whereas the majority of work zone rear-end crashes occur in work zone merging areas (Srinivasan et al., 2007). Therefore, effective countermeasures should be taken in order to mitigate the rear-end crash risk in work zone merging areas. A comprehensive understanding of the relationship between the rear-end crash risk and its influencing factors could help prioritize these countermeasures.

In general, the drivers' merging behavior is highly correlated with the rear-end crash risk, especially in work zone merging areas. In order to obtain an accurate estimate of the rear-end crash risk, it is of great importance to propose an appropriate model to describe the merging behavior in work zone merging areas. Numerous parametric models have been developed to predict the drivers' merging probability. For example, Kita (1999) proposed a game theory model to calculate the merging probability using the maximum likelihood estimation technique. 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;

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Toledo et al., 2009). However, this assumption is inconsistent with the reality that vehicles may still change lanes when only the adjacent lag gap or the adjacent lead gap is accepted. To avoid this inconsistency, Weng and Meng (2011) developed a logit model to estimate the merging probability. In order to improve the estimation accuracy, Meng and Weng (2012) further built a non-parametric model using the classification and regression tree approach to determine the merging probability in work zone merging areas. Nonetheless, one assumption that a merge maneuver is completed within 1 s is implicitly made in both studies. This is inconsistent with the field observation that it takes more than 1 s (averagely 5.52 s as per our survey) for a vehicle to complete a lateral movement in work zones.

Selecting an approximate rear-end crash risk estimation approach is the second key step towards producing an accurate estimate of rear-end crash risk. Using historical accident records, many researchers have already developed a number of rear-end crash risk models, including the conditional logistic regression model (Harb et al., 2008), the ordinal probit model (Barua and Tay, 2010), the modified negative binomial regression model (Kim et al., 2007), and so on. Considering the drawbacks of historical accident data, recent studies have attempted to use surrogate safety measures (SSM), which utilize the real-time vehicle trajectory data to estimate crash risk (Oh and Kim, 2010). For example, Gettman and Head (2003) considered the deceleration rate, maximum speed and maximum speed standard deviation as three surrogate safety measures to estimate traffic accident risks. Cunto and Saccomanno (2008) employed the deceleration rate to avoid the crash (DRAC) to evaluate the individual vehicle risk. Weng and Meng (2014) selected the time to collision (TTC) as the surrogate safety measure to measure the rear-end crash risk. Gao et al. (2013) analyzed the freeway work zone safety using two safety surrogate measures (SSM) including the TTC and DRAC. These relevant existing literature provides adequate supports that TTC and DRAC can yield reliable and accurate results.

Although many researchers (e.g., Srinivasan et al., 2007) suggested that more concerns should be addressed on the work zone merging area because of the higher rear-end crash risk, little efforts have been made to examine the driver behavior and rear-end crash risk in work zone merging areas. Furthermore, the effects of influencing factors such as the elapsed time after a merging action being triggered, vehicle type, and remaining distance to work zone on the drivers' merging behavior and rear-end crash risk in work zone merging areas have not been fully examined. Therefore, this study aims to model the driver merging behavior and rear-end crash risk during the entire merging process at work zone merging areas considering more influencing factors.

The rest of this paper is organized as follows. Section 2 elaborates the detailed objectives and potential contributions of this study. Section 3 gives the methodology to build the drivers' merging behavior model and calculate the rear-end crash risk. Section 4 describes data used for the model calibration. The model results and impact analysis are presented in Section 5. Section 6 concludes with future directions of work.

2. Objectives and contributions

The objective of this study is to investigate the drivers' merging behavior and rear-end crash risk of the merging vehicle during the entire merging implementation period in work zone merging areas. To achieve this objective, we will first develop a probit model to calculate the probability that a merging vehicle can complete its merging maneuver at the current time. Subsequently, the TTC and DRAC-based rear-end crash risk are computed between the merging vehicle and its neighboring vehicles. Finally, we will examine the effects of influencing factors including the vehicle type, time elapsed after a merging action being triggered, the remaining distance to work zone and merging speed on the rear-end crash risk.

It should be pointed out that, different with the study of Weng et al. (2014), the focus of this study is on the rear-end crash risk in work zone merging areas rather than in activity areas. Therefore, the methodology and influencing factors are significantly different between these two studies. For example, there is no need to integrate the driver merging behavior model into the rear-end crash risk estimation model in Weng et al. (2014) because there are few merging maneuvers in work zone activity areas. However, the work zone merging behavior has to be taken into account in this study because of a large number of merging maneuvers in work zone merging areas. In addition, the time elapsed after a merging action being triggered and remaining distance to work zone were not considered in Weng et al. (2014). In general, the contributions of this study are three-fold. First, this study makes an initial attempt to investigate the drivers' merging behavior varies during the entire merging implementation period. Second, this study is a pioneering work to examine the impacts of time elapsed after a merging action being triggered, vehicle type and remaining distance to work zone on the drivers' merging behavior and rear-end crash risk. Third, the results and suggestions of this study could be helpful for traffic engineers to take effective counter-measures to mitigate the rear-end crash risk in work zone merging areas.

3. Methodology

3.1. Drivers' merging behavior model

The presence of work zone usually causes a reduction of one or more lanes. Therefore, vehicles traveling in a lane that is partially closed because of work zone activities ultimately have to merge into the adjacent through lane. Hereafter, the lane that is partially closed is defined as the merge lane. A vehicle traveling in the merge

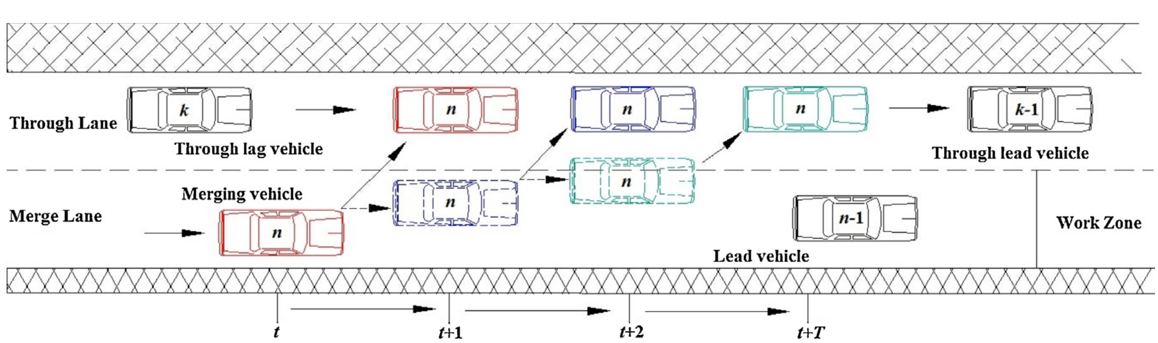

Fig. 1. Merging vehicle and its possible movement choices.