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Developing an algorithm to assess the rear-end collision risk under fog conditions using real-time data

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ABSTRACT

This study aims to propose a new algorithm to evaluate the rear-end collision risk under fog conditions considering reduced visibility. The proposed algorithm compares the safe stopping distance of the leading and following vehicles. According to the relationship between clearance distance between the two consecutive vehicles and visibility distance, the car-following maneuver is divided into different situations and the algorithms to calculate the safe stopping distances are suggested correspondingly. The visibility distance is collected by a new visibility detection system with adaptive learning modules and the clearance distance is obtained from a vehicle-based detector. By comparing the safe stopping distances of the following and leading vehicles, the potential rear-end collision can be identified. Subsequently, statistical tests are conducted to analyze rear-end collision risk and compare the different impact of reduced visibility on the collision risk for different vehicle types and lanes. Furthermore, random parameters logistic and negative binomial models are estimated by using individual vehicle data and aggregated traffic flow data, respectively, in order to explore the relationship between the potential rear-end crash and the reduced visibility together with other traffic parameters. The results suggest that the proposed algorithm works well in evaluating rear-end collision risk under fog conditions. It is found that reduced visibility has significant impact on the rear-end collision risk and the impact vary by the different vehicle types and by lane. Further, it is concluded that the driving maneuver of the leading and following vehicles can affect the rear-end collision risk. It is expected that the proposed algorithm can be implemented in a Traffic Management context to improve road safety under fog conditions. Specifically, it is suggested to implement the proposed algorithms in real-time and integrate it with ITS technologies such as Variable Speed Limit (VSL) and Dynamic Message Signs (DMS) to enhance traffic safety when the visibility declines. This car following algorithm could also be extended to adapt for the advent of Connected Vehicles in Fog conditions.

1. Introduction

Fog is a weather condition that reduces visibility of the driving scene, which can cause a serious problem for traffic operation and safety. Usually, fog forms during the late night and early morning, which can increase crash severity (Al-Ghamdi, 2007). The crash data suggest an over-representation of fog crashes in crash fatalities. In the period of 2011–2016, nearly 11,600 fog-related crashes occurred in Florida. Nearly 1.53% of the fog-related crashes are fatal crashes while the proportion of fatal crashes for the total crashes

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is only 0.43%. Besides, the possibility of multiple vehicle involved crashes could be increased due to the reduced visibility (Abdel-Aty et al., 2011). For example, a fog-related crash with 70-vehicle pileup happened on I-4 in Polk County in January 2008, which caused five deaths and many injuries (Hassan et al., 2011). Therefore, it is necessary to devote efforts to understand the impact of fog on traffic safety and propose appropriate countermeasures to enhance the safety under fog conditions.

Traditionally, traffic safety analyses are conducted based on historical crash data and identify roadway- and traffic-related factors contributing to the crash risk using statistical methodologies. Hence, the traditional method could suffer from problems such as small samples, underreporting, and misclassification. The problems could become even worse for fog crashes since the events are very rare. In addition, it would be difficult to rapidly evaluate the recent treatments due to the lack of after-treatment crash data, which require observations of a long period (several years) (St-Aubin et al., 2013). Considering the limitations of the traditional safety analyses, various studies have been conducted using individual vehicle data (e.g., vehicle speed and headway) to evaluate traffic safety (Oh and Kim, 2010; Son et al., 2011). Compared with the literature about traffic safety under clear conditions, traffic safety under fog conditions has attracted much less attention, especially studies based on individual vehicle data. Although some researchers have developed methods to investigate the traffic safety under fog conditions, the methods were proposed based on simplified conditions. Hence, the corresponding conclusions may be limited and biased.

This research aims to contribute to the literature by proposing a new algorithm to evaluate traffic safety under fog conditions and apply it to explore the impact of the reduced visibility together with other traffic parameters on safety.

2. Literature review

In the previous research, only few studies have focused on the effect of fog on traffic crashes by using the historical crash data. Coding (1971) suggested that fog-related crashes were more likely to involve multiple vehicles. Edwards (1996) pointed that fog-related crashes were very rare and highly seasonal. It was found that speed remained a major contributing factor in many of multiple pileup crashes in fog (Edwards, 1998). Wanvik (2009) analyzed the effect of road lighting on fog-related crashes based on historical crash data in Netherlands and concluded that the effect of lighting was significant and underestimated in safety research. Abdel-Aty et al. (2011) conducted a comprehensive analysis of fog-related crashes in Florida. The authors found that the fog-related crashes tend to result in more severe injuries and involve more vehicles. They also concluded that head-on and rear-end crashes were the two most common crash types under fog condition.

Compared to the limited research about the impact of fog on traffic safety, a lot of efforts have been made to investigate the change of driver behavior during fog based on driving simulator studies. By using driving simulator data, Broughton et al. (2007) observed reduced headway distance under fog condition. The authors suggested that the headway distance reduced because the drivers wanted to seek visible cues since the scenery and roadway condition became obscure in fog. Caro et al. (2009) observed similar results of the reduced headway distance and they explained that the adjustment could be a way for drivers to achieve a perceptual control benefit. Ni et al. (2010) investigated the age-related differences in car following behavior in simulated fog condition. The authors found that older drivers would like to maintain closer headway distance (21% closer) compared to young drivers, indicating older drivers were at higher risk especially under heavy fog. Saffarian et al. (2012) found that drivers would feel risky under fog situation and they preferred to follow the leading vehicle as a guide instead of overtaking it. Yan et al. (2014) examined the effect of fog on speed control behaviors based on a driving simulator experiment. It was found that drivers would reduce their speeds significantly under fog condition. Wu et al. (2017a, 2017b, in press-a, in press-b) investigated the impacts of fog warning system on driving behavior under fog condition using the driving simulator. The authors found that the warning system may affect drivers' speed choice before they entered fog area. However, the effect of the warning system on drivers' final speed in the fog area is not significant.

Although drivers may reduce their speed under fog condition, they may still not have enough space to decelerate since drivers tend to reduce their headway distance, which may increase the rear-end collision risk (Shi and Tan, 2013). Thus, it would be necessary to evaluate the rear-end collision risk under fog condition and investigate the effects of reduced visibility together with traffic parameters on the rear-end collision risk. One of efficient methods to analyze the crash risk is to analyze the crashes based on the historical data. However, this approach may be limited since the fog-related crashes are very rare and the real-time traffic data are difficult to obtain. For example, only 0.32% of crashes occurred in Florida during the period 2011–2016 are fog-related crashes and the number of fog-related crashes that have available roadway and traffic data could be even smaller. The possible solution to overcome this issue is developing algorithm to calculate surrogate measures to evaluate the traffic safety. In previous studies, different surrogate measures have been calculated including time-to-collision (Oh and Kim, 2010), stopping distance index (Oh et al., 2006, 2009), modified time to collision (Ozbay et al., 2008), and individual vehicle speeds and headways (Hourdos et al., 2006). These earlier studies demonstrated the advantages of surrogate safety measures for traffic safety analysis. However, the algorithm of surrogate measures cannot be directly adopted for safety evaluation under fog condition since most of them were developed for clear condition without the consideration of the reduced visibility under fog condition.

Recently, Peng et al. (2017) assessed the impact of reduced visibility on traffic crash risk by calculating time-to-collision under fog condition. The authors calculated time-to-collision using the visibility distance to replace the actual clearance distance (the distance between the rear bumper of the leading vehicle and the front bumper of the following vehicle) when the visibility distance is less than the clearance distance. Li et al. (2014) used the same approach to develop an algorithm to evaluate the crash risk when they developed a variable speed limit strategy during inclement weather conditions. Although the reduced visibility was considered, the car-following process has been simplified. Specifically, it was assumed that the leading vehicle kept the same speed until the driver of the following vehicle can see the leading vehicle. Thus, it may lead to the inaccurate results regarding the traffic safety under fog condition.