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Impact of connected vehicles on mitigating secondary crash risk

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ABSTRACT

Reducing the risk of secondary crashes is a key goal for effective traffic incident management. However, only few countermeasures have been established in practices to achieve the goal. This is mainly due to the stochastic nature of both primary and secondary crashes. Given the emerging connected vehicle (CV) technologies, it is highly likely that CVs will soon be able to communicate with each other through the ad-hoc wireless vehicular network. Information sharing among vehicles is deemed to change traffic operations and allow motorists for more proactive actions. Motorists who receive safety messages can be motivated to approach queues and incident sites with more caution. As a result of the improved situational awareness, the risk of secondary crashes is expected to be reduced. To examine whether this expectation is achievable or not, this study aims to assess the impact of connectivity on the risk of secondary crashes. A simulation-based modeling framework that enables vehicle-to-vehicle communication module was developed. Since crashes cannot be directly simulated in micro-simulation, the use of surrogate safety measures was proposed to capture vehicular conflicts as a proxy for secondary crash risk upstream of a primary crash site. An experimental study was conducted based on the developed simulation modeling framework. The results show that the use of connected vehicles can be a viable way to reduce the risk of secondary crashes. Their impact is expected to change with an increasing market penetration of connected vehicles.

1. Introduction

Traffic crashes on highways not only induce delays, but also additional safety issues in terms of secondary crashes (SCs). The risk of having another crash in the presence of an earlier crash can be six times higher than the ones without an earlier crash (Tedesco et al., 1994). If the earlier crash presence on road for an additional minute, the likelihood of having a SC will increase by 2.8% (Owens et al., 2009). The occurrence of SCs further prevents incident responders from reaching crash sites timely and exposes road users to higher crash risk. In total, it was estimated that these SCs accounted for approximately 20% of all crashes and 18% of fatalities on US freeways (O'Laughlin et al., 2002; Owens et al., 2010). In addition, SCs contributed up to half of the congestion in urban area (Sarker et al., 2017). These crashes can result in millions of dollars of comprehensive

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costs associated with congestion, property damages, injuries, and/or fatalities (Pigman et al., 2011). Thus, reducing the risk of SCs is a critical concern for traffic incident management (TIM) agencies (Yang et al., 2013; Yang et al., 2014).

Despite the importance, there are still very few countermeasures that have been effectively deployed to reduce the number of SCs (Yang et al., 2013; Yang et al., 2014). In practices, many TIM agencies have adopted the quick clearance legislation and programs for preventing secondary crashes (Carson, 2008). However, due to the random nature and dynamic characteristics of crashes, it is often difficult to clear crashes in a short period of time in many actual circumstances. For example, it may take several hours to remove a serious crash in rural area involving a heavy truck carrying hazardous materials. Factors such as time of day, lanes closed, environment conditions, etc. also affect the clearance time (Nam and Mannering, 2000; Giuliano, 1989). Therefore, it is very challenging to implement any practical solutions targeting on SCs.

Given the emerging connected vehicle (CV) technologies, it is highly likely that many vehicles will soon be able to connect with each other through the vehicular ad-hoc networks. In particular, the U.S. Department of Transportation recently issued a proposed rule that would further accelerate the use of CV technologies throughout the U.S. light vehicle fleet. The rulemaking would enable vehicle-to-vehicle (V2V) communication technology on all new light-duty vehicles. The V2V communication enables information sharing and is envisioned to change the way of traffic operations. It will provide 360-degree situational awareness on road and all informed drivers can make better decision in response to abnormal conditions downstream and approach queues and incident sites with more caution. Thus, in case of crash conditions, the risk of secondary crash is also expected to be reduced. To examine whether such benefit is achievable or not, extensive evaluations of the innovative CV technologies are needed before widely deployed on road.

The main objective of this paper is to examine the safety benefits of deploying CVs for mitigating the risk of SCs. This allows us to investigate the feasibility of using CVs to reduce SCs and assess the magnitude of potential benefits under different market penetration rates. We intend to achieve the objective by developing a simulation-based framework for modeling the CV environment and analyzing the SC risk with an improved surrogate safety measure. The study findings will help design appropriate TIM strategies for preventing SCs with the application of CVs.

The remainder of the paper is organized as follows. The next section discusses up-to-date research focused on SCs. The third section presents the proposed methodology followed by the description of experimental study in the fourth section. The fifth section presents the test results and discussion. The final section concludes the paper with more perspective of this work.

2. Literature review

Existing studies on SCs mainly focused on three aspects, including (a) identification of SCs, (b) analysis of the characteristics of SCs, and (c) risk modeling of SCs.

First, a few studies have made efforts on developing specific approaches for identifying potential SCs given the occurrence of a primary crashes. For example, the static approaches have been introduced since 1990s (Raub, 1997a; Raub, 1997b). Such approaches require fixed spatial and temporal thresholds (e.g., one mile and crash clearance time + 15 min) to define the impact area of a primary crash. Any crashes occurred within the defined impact area of the primary crash will be classified as SCs (Raub, 1997b). Despite the variation of the spatiotemporal thresholds, many later studies adopted similar approaches to identify SCs (Latoski et al., 1999; Jalayer et al., 2015; Tian et al., 2016). Due to the subjectivity of defining the spatiotemporal thresholds, these static approaches have been questioned. This motivated tremendous efforts on developing a number of dynamic approaches such as queuing model-based approaches (Sun and Chilukuri, 2005; Zhan et al., 2009; Sun and Chilukuri, 2010; Zhang and Khattak, 2010), shockwave-based approaches (Zheng et al., 2014; Sarker et al., 2015; Wang et al., 2016), and data-driven approaches (Yang et al., 2013; Yang et al., 2014; Orfanou et al., 2011; Chung, 2013; Park and Haghani, 2016; Yang et al., 2017). Many of these approaches can largely improve the accuracy of the identification by dynamically updating the progression of the incident impact area. However, the need of additional datasets associated with incidents and/or traffic data from various sensors and computation resources remains a challenge for implementing them widely.

Second, with the support of various approaches for identifying SCs, many studies were able to successfully extract these special crashes and examine their characteristics specifically (Yang et al., 2013; Jalayer et al., 2015; Hirunyanitiwattana et al., 2006; Zhan et al., 2008; Carrick et al., 2015; Vlahogianni et al., 2010). For example, Zhan et al. (2008) examined the characteristics of SCs on freeways in Florida based on corridors, time, lane closures and incident types. Likewise, two studies (Hirunyanitiwattana et al., 2006; Kopitch et al., 2011) analyzed the characteristic of SCs for highways in California. With the improved identification algorithm, Yang et al. (2013) analyzed the SCs on the New Jersey Turnpike by mining the detailed incident records. Using Geographic Information System (GIS), Tian et al. (2016) filtered the SCs by three spatiotemporal criteria and investigate the SC frequency, types, severity, and contributing factors. These descriptive analyses revealed important characteristics of SCs, for example, the majority of SCs were found to be rear-end crashes. These information is valuable when developing countermeasures for preventing SCs.

Third, based on the identified SCs and their corresponding characteristics, a few studies have also statistically modeled the contributing factors that affect the risk of SCs. For example, logit models have been developed by several studies to examine the likelihood of SCs considering the features associated with primary crashes (Latoski et al., 1999; Zhan et al., 2009; Zhan et al., 2008; Kopitch et al., 2011; Karlaftis et al., 1999; Khattak et al., 2012). These models mainly focused on analyzing