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Freeway crash risks evaluation by variable speed limit strategy using real-world traffic flow data

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ABSTRACT

The primary objective of this study is to evaluate the real-time crash risk of freeways by using real-world traffic flow data. The crash risk expressed as the potential crash likelihood is assessed under variable speed limit (VSL) and without VSL, in which both spatial correlation between different sites and temporal similarity are contained. Traffic flow data of Whitemud Drive network (WMD) in Canada is used to perform the relevant analysis, including VSL implementation analysis, traffic flow similarity analysis, crash risk and congestion analysis. Analytical results demonstrate that the average traffic flow under VSL schemes 1, 2, 3 and 4 are highly correlated from spatial-temporal perspective. The crash likelihoods and congestions under these VSL schemes are greatly improved. The best VSL control scheme, the most dangerous area and time, together with the most congested station of WMD are eventually determined. Subsequently, a *t*-test is employed to examine the significance of these results. *t*-Test results suggest that the improvement degree between crash risk and congestion under the best VSL control scheme show a difference, i.e., the best VSL control scheme can reduce the crash risk of moderate risk area more than high risk area, while it may have a larger melioration on the most congested area than the relatively uncongested area. Finally, these results are considered to have the potential reference in the mitigation of WMD traffic issues.

1. Introduction

The past decades have witnessed a rapid increase in road crash risks that related to actual crash accidents or potential crashes. Generally speaking, these risks may not only contribute to the casualties and loss of property, but also cause a serious congestion. Because the travel speed in freeways is so high that once an incident occurs, the vehicle speed upstream may be sharply dropped, which will result in a traffic collapse. According to the federal highway administration of the United States, traffic accidents account for about 25% of the traffic congestions (Federal Highway Administration, 2005). Hence, the crash risk of road network has become a critical problem with considerable implications in recent years. How to effectively evaluate the risk is of vital importance for reducing the potential crash of freeways, which will play an indispensable role in the modern traffic management system. Crash risk evaluation of freeways get involved in identifying the potential risk locations and analyzing the impact of these risks on freeway networks. An efficient evaluation of crash risk can help the road managers to grasp the overall operation of the traffic condition and provide a basis for preventing traffic accidents or congestions.

Several studies have been conducted on the crash precursor of freeways. Islam and El-Basyouny (2015) performed a before-after safety evaluation with the object to evaluate the safety effects of reducing residential posted speed limit (PSL). Result showed that PSL reduction was found effective in reducing crashes. Kwak and Kho (2015) developed crash risk prediction models for identifying crash precursors based on loop detector data. The genetic programming was used to predict and evaluate the crash risk. The Model results showed that the traffic flow characteristics leading to crashes are differed by segment type and traffic flow state. Xu et al. (2016) investigated the predictability of crash risk models that were developed by using high-resolution traffic data. The predictability was defined as the crash probability given the crash precursor model. The conclusion suggested that crash risk modeling should focus on improving the predictability of crash risk models, not the prediction accuracy. Fang et al. (2016) utilized the eigenvectors of freeway loop data spatiotemporal schematic to predict the real time

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crash. The eigenvectors and eigenvalues of the spatiotemporal schematics were extracted to represent the traffic flow situation before the crash occurrence, and then a logistic model was used to identify the precursors. Results showed that both the eigenvectors and eigenvalues can significantly impact the accident likelihood.

Recently, artificial intelligence (AI) is gradually used in the evaluation and prediction of road safety. Halim et al. (2016) studied the AI technique for improving driving safety and predicting the vehicle crash, in which statistical methods were used to predict the accidents. Several machine learning methods were increasingly carried out as well in crash risk evaluation (Yu and Abdel-Aty, 2013; Sun and Sun, 2014; Qu et al., 2017; You et al., 2017; Basso et al., 2018). For example, Yu and Abdel-Aty (2013). proposed a support vector machine (SVM) approach for evaluating the real-time crash risk, and the model's predictive abilities that barely involved in other models were investigated. Sun and Sun (2014) adopted Bayesian method to analyze the accident risk and then evaluate the predictability of crash risk. Finally, the method was proved to be feasible. Qu et al. (2017) studied freeway rear-end crash potential predictors by using SVM technique. The relationship between rear-end crash occurrences and traffic conditions was explored through using historical loop detector data. Finally, it was confirmed that the SVM technique in rear-end crash prediction analysis has superior performance. You et al. (2017) presented an optimized crash prediction model on freeways with over-sampling techniques based on SVM. The results indicated that SVM classifiers improved the prediction accuracy. Basso et al. (2018) developed accident prediction models based on disaggregate data that were captured by free-flow toll gates with automatic vehicle identification. Three methods (i.e., Random Forest, SVM and Logistic Regression method) were proposed to identify the strongest precursors of accidents. The result showed that the best model accurately predicted 67.89% of the accidents with a low false positive rate of 20.94%.

Goodall (2017) analyzed the secondary crash occurrence of freeways, and integrated incident timelines and traffic volumes. Results showed that 9.2% of all vehicle crashes were secondary to another incident and that 6.2% of these crashes were tertiary to another primary incident. Wang et al. (2016) identified the secondary accidents based on traffic shock waves, and the study associated a secondary accident with its primary accident and the shock waves from it. Results showed the secondary accidents in California interstate freeway accounted for 1.08% of the total crashes, and this was much lower than the result of Goodall et al.

As an emerging method of traffic control, VSL control is increasingly popular in traffic management. VSL can improve both the congestion and crash risk of freeways. Plenty of studies have been presented in the regard of VSL to improve congestion (Bertini et al., 2006; Lu et al., 2011; Pu et al., 2012; Yang et al., 2013; Sun et al., 2014; Cao et al., 2015; Yang et al., 2015; Li et al., 2017). However, compared with the issue of VSL to relieve traffic congestion, the safety problem under VSL control might be more noteworthy. Because the traffic safety is directly related to people's vital interests (e.g., injuries, deaths, or loss of property), and this is supposed to be more important than people's interests in traffic congestion (e.g. delay increase, emissions increase, etc.). Several literatures revealed that significant efforts have been conducted to evaluate the potential and real-time crash risk (Lee et al., 2006; Abdel-Aty et al., 2006; Allaby et al., 2007; Abdel-Aty et al., 2009a; Mannering, 2009; Yu and Abdel-Aty, 2014). The afore-mentioned studies on VSL mostly aimed at single traffic congestion or crash risk. The integrated researches of the two aspects are relatively limited, and the relevant literatures are less than that of single study of traffic congestion or crash risk. For instance, Khondaker and Kattan (2015) presented a VSL control algorithm for simultaneously maximizing the mobility (this aimed to improve congestion), safety (this aimed to improve crash risk) and environmental benefit in a connected vehicle environment, total travel time (TTT) and time to collision (TTC) were used to measure the mobility and safety respectively. Their result indicated that VSL control can achieve a 20% reduction of TTT and 6%–11% improvement of TTC. Wang and Cheng (2017). studied the control and setting locations of variable speed limit signs, and the accident rate reduction (this aimed to improve crash risk) and traffic congestion improvement were the main objectives. Lyu et al. (2017) established a comprehensive VSL control model for reducing both travel delay (this aimed to improve congestion) and potential crash risk at freeway work zones. The objective was to minimize the operational cost by reducing the total travel delay and potential crash rate. Abdel-Aty et al. (2009b) proposed the application of VSL to improve safety and efficiency of freeways. The VSL algorithms were applied to analyze the crash risk and travel time, and it was found that VSL was effective to reduce crash risk and average travel time in some certain cases.

As discussed above, several aspects were relatively limited. For example, almost no researcher has comprehensively analyzed both the potential crash and congestion from spatial-temporal perspective, i.e., previous studies only studied a single aspect of traffic congestion or crash, or the analysis of crash risk and congestion is performed based on a single spatial (Korter, 2016) or temporal (Michalaki et al., 2016) perspective. In the meantime, the crash risk evaluation conducted in previous studies are primarily based on the simulation data, and these evaluations were limited compared with the researches that based on real-world data. Accordingly, the study conducted in the current paper fills these knowledge gaps. This study evaluates both congestion and crash risk from the spatial-temporal perspective. The actual traffic flow data was used to evaluate the impact of VSL control on congestion and crash risk. The results may be more objective and practical in comparison with those similar studies conducted in previous researches. Moreover, a *t*-test is employed to analyze the significance of the result, which makes it more convincing.

The remainder of this paper is structured as follows. Section 2 introduces the study corridor. Section 3 lists the data source. Section 4 presents the crash risk model. Section 5 describes the VSL implementation and traffic flow similarity. Section 6 proposes the evaluation of crash risk and congestion of WMD based on spatial-temporal perspective, and the *t*-test is also contained in this section. Section 7 makes a discussion about the results. Finally, section 8 shows a brief review of this paper and proposes the future research direction.

2. Study corridor

Whitemud Drive (WMD) is the study corridor of this paper, and it is an urban freeway in Edmonton, Alberta, Canada. The total length of WMD is about 28 km, and the basic speed limit was 80 km/h (it was the static posted speed limit). As the experiment road, WMD was equipped with loop detectors in its mainline and ramps. The specific study segment is the westbound direction of WMD, which is located between 122 St and 159 St (see Fig. 1). The length is about 11 km, and comprised of 12 ramps, 9 loop detector stations, and 7 video cameras. In addition, the directional average annual daily traffic (AADT) was up to approximately 100,000 vehicles. The 9 loop detector stations were all located on the mainline of WMD, and each of which consisted of dual-loop detector groups in each travel lane. These detectors and cameras measured traffic flow data every 20 s. Besides, the existing VSL control was adopted to alleviate traffic congestion at peak hours, and the data records under VSL control spans from 16:00 to 19:00 with different speed limits (i.e., 30 km/h to 80 km/h). The speed limits for other periods were 80 km/h. Fig. 1 shows the basic composition of the study corridor. In this paper, we only analyze the mainline of WMD, i.e., the stations of VDS 1018, VDS 1026, VDS 1028, VDS 1030, VDS 1032, VDS 1035, VDS 1036, VDS 1016, and VDS 1007.

3. Data source

The original data is obtained from a data sharing website called Open ITS, and the real-time data only contains the traffic flow, speed,