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Assessing rear-end crash potential in urban locations based on vehicle-by-vehicle interactions, geometric characteristics and operational conditions

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ABSTRACT

Rear-end crashes are one of the most frequently occurring crash types, especially in urban networks. An understanding of the contributing factors and their significant association with rear-end crashes is of practical importance and will help in the development of effective countermeasures. The objective of this study is to assess rear-end crash potential at a microscopic level in an urban environment, by investigating vehicle-by-vehicle interactions. To do so, several traffic parameters at the individual vehicle level have been taken into consideration, for capturing car-following characteristics and vehicle interactions, and to investigate their effect on potential rear-end crashes. In this study rear-end crash potential was estimated based on stopping distance between two consecutive vehicles, and four rear-end crash potential cases were developed. The results indicated that 66.4% of the observations were estimated as rear-end crash potentials. It was also shown that rear-end crash potential was presented when traffic flow and speed standard deviation were higher. Also, locational characteristics such as lane of travel and location in the network were found to affect drivers' car following decisions and additionally, it was shown that speeds were lower and headways higher when Heavy Goods Vehicles lead. Finally, a model-based behavioral analysis based on Multinomial Logit regression was conducted to systematically identify the statistically significant variables in explaining rear-end risk potential. The modeling results highlighted the significance of the explanatory variables associated with rear-end crash potential, however it was shown that their effect varied among different model configurations. The outcome of the results can be of significant value for several purposes, such as real-time monitoring of risk potential, allocating enforcement units in urban networks and designing targeted proactive safety policies.

1. Introduction

Traffic safety performance is relied on measuring crash frequency and thus road safety analysis has traditionally been undertaken using crash data. It has been shown that rear-end crashes are one of the most frequently occurring types; 3.98 million rear-end crashes were reported in the U.S. roadways in 2013, which accounted for the 34% of the total reported crashes, and resulted in 2200 fatalities (National Safety Council, 2015). From this perspective, the identification of contributing factors to rear-end crashes, such as human behavior, roadway characteristics or environmental conditions, and the investigation of their impact on these type of crashes is of practical importance in order to develop effective countermeasures for improving network safety levels. Rear-end crashes are defined as a type of crash where the rear side of a vehicle is hit by the front side of the following vehicle (Singh 2003).In car-following situations vehicles interact with adjacent vehicles and it has been identified that crashes are potentially raised when interactions between vehicles become unstable (Oh and Kim, 2010).Rear-end crashes are usually attributed to insufficient spacing between consecutive vehicles; the proper distance kept between consecutive vehicles should provide the driver of the following vehicle time to recognize a potential hazard ahead and engage in an appropriate action (such as braking, or lane changing) if needed. Generally, drivers can minimize the risk of being involved in a rear-end crash by maintaining an adequate space cushion that is appropriate for the driving conditions (Abdel-Aty and Abdelwahab, 2004).

Traditional rear-end crash analysis has focused on identifying factors that contribute to rear-end crash counts by developing models using aggregated traffic data, geometric characteristics and crash data collected over a prolonged time period. However, in addition to long periods of time required for collection, crash data are often faced with reliability, quality and quantity problems. Therefore, the use of alternative indicators to crashes, known as surrogate measures, have been widely used in road safety analysis to reflect road safety. In this point of

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view, identifying rear-end potentials with the use of surrogate measures in the network which could potentially lead to rear-end crashes, would be a proactive measure toward mitigating transportation problems in the network.

The objective of this study is to estimate real-time rear-end crash potential in urban networks, and to identify the effect of various traffic parameters on this potential. This paper introduces a thorough investigation of car-following decisions (speed and time headway) and vehicle-by-vehicle interactions through disaggregated loop detector data, aiming to systematically reveal the underlying patterns and the contributing factors of possible rear-end crashes. The scope of this paper stands for the extrapolation and adaptation of the extensive and thorough research related to crash risk potential that has been mainly focusing on highways, to the more complex case of signalized and congested urban networks by using real data typically collected in Traffic Control Centers (here, from the urban network of Nicosia, Cyprus). Several traffic parameters at the individual vehicle level, locational characteristics and operational conditions are introduced, and assessed. Traffic volume and vehicle speed are collected from inductive loop detectors, along with individual vehicle information such as time of arrival, vehicle type and lane of travel. Rear-end crash potential is estimated based on stopping distance calculation and subsequently four distinctive cases of rear-end crash potentials are developed (a) no rear-end crash potential, (b) rear-end crash potential when the leading vehicle is stationary; (c) rear-end crash potential when the leading vehicle is braking; (d) rear-end crash potential where the distance kept is not sufficient to avoid a collision with the leading vehicle in the next 10 s if no action is taken. An exploratory analysis is employed to observe the effect of location (lane width, lane of travel, location in the network), traffic parameters (traffic flow, average speed, moments of speeds) and vehicle configuration (vehicle type, leading/following type) on rear-end crash potential. A preliminary statistical investigation of the above variables with respect to driving behavior and crash potential is followed by a model-based analysis. In particular, alternative Multinomial Logit (MNL) regression models are developed to identify the significance of the aforementioned parameters on the rear-end crash potential, proving detailed and robust functional form explaining risk driving behavior. The extensive datasets used in this study are based on more than 400,000 vehicles and the experimental setting in terms of the model structure, selection and analysis, offers valuable results for monitoring and policy-making purposes in realistic urban traffic systems. The results of the above described analytical approach contribute important exploratory and explanatory insights on both the design as well as the operational traffic characteristics that effect crash risk potential in congested signalized urban networks, possibly valuable for controlling/management purposes, an objective that exceed the scope of the present study.

The structure of the paper starts with a presentation of the relevant research background on rear-end crash investigation. Then the methodological approach is presented, offering the analytical framework that the following experimental results are based on. In the final section, the results are discussed in detail while several directions for future research are given.

2. Background

Significant research effort has been undertaken to analyze the characteristics and contributing factors of rear-end crashes. A number of studies investigating rear-end crashes, with different perspectives (e.g. crash propensity, injury severity, car-following decisions etc.), and modelling techniques has been presented in recent years. Kim et al. (2007), developed a modified negative binomial regression model to estimate rear-end risk using Washington State data, reporting among others that urban areas have an increased rear-end crash probability. Yan et al., (2005) used binary logistic models to investigate rear-end crashes at signalized intersections utilizing Florida traffic accident data, in order to identify the risk factors related to traffic environment, driver characteristics and vehicle type. Also, the generalized estimating equations were used by Wang and Abdel-Aty (2006) to model rear-end frequencies at signalized intersections, showing high correlations between the longitudinal and spatially correlated rear-end crashes. Ahmed and Abdel-Aty (2013), used a machine learning technique, namely, Stochastic Gradient Boosting (SGB), in order to develop a framework for real-time risk assessment on a freeway in Colorado. The general estimates system (GES) databases were used by Abdel-Aty and Abdelwahab (2004) to study the effect of the lead vehicle's size on the rear-end crash configuration, by developing nested logit models in order to estimate the probabilities of four types of rear-end collisions. Shi and Abdel-Aty (2015), utilized a Microwave Vehicle Detection System (MVDS) consisting of 275 detectors and developed a methodology of data mining and Bayesian inference techniques to implement real-time crash prediction models.

Furthermore, several studies have investigated the connection between crash risk and operational characteristics (mainly traffic flow). A study conducted by Golob and Recker (2004), examined how the types of urban freeway accidents are related to traffic flow using accident data and corresponding loop detector data. This study found that median traffic speed and temporal variation in speed are strongly related to the type of collision. Christoforou et al. (2011) proposed a framework of multivariate probit models to assess the effects of traffic variables on crash type, and findings showed that crash type can almost exclusively be defined by the prevailing traffic conditions shortly before the crash occurrence. Xu et al. (2013), utilized the sequential logit model to link crash likelihood at different severity levels, and showed that traffic flow characteristics contributing to crash occurrence vary across different crash severity levels. It is evident that traditionally research has focused on the macroscopic measurements of total counts of crashes and total flows to develop safety functions. However, an increased interest over time has been on individual vehicle interactions and behavioral analysis relationship with crashes. Hu et al. (2004), proposed a probabilistic model to predict traffic accidents based on 3-D model-based vehicle tracking. Hourdos et al. (2006), established a relationship between quickly evolving real-time traffic conditions and crash likelihood, by utilizing a state-of-the-art infrastructure which allowed the video capture of 110 live crashes. Oh and Kim (2010) proposed a methodology to estimate rear-end crash probabilities by using vehicle trajectories obtained from video surveillance mechanisms. In this study a statistical methodology was developed to estimate rear-end crash potential using time-to-collision (TTC) measures. Kim et al. (2016) explored the association of crash propensity and micro scale driving behavior by integrating rear-end crash data experienced in a freeway with micro-scale driving behavioral data gathered by an in-vehicle sensing system. The findings of this study showed that 85% of all rear-end crashes occurred within 2000 feet of the on-ramp gore and a strong association between rear-end crash rates and the propensity of hard deceleration exists. These studies concretely offer evidence on the relationship among traffic conditions and crash risk, valuable both for strategic planning as well as for real-time applications. In the last decade real-time crash prediction has also been an active field in safety research. In real-time safety analysis, the use of dynamic traffic data enables researchers to investigate crash likelihood over a short period of time. Real-time analysis assumes that the occurrence of a crash is because of a short-term turbulence right before the crash, and this turbulence can be identified by real-time data (Wang et al., 2017a,b). For example Abdel-Aty et al. (2012) examined the relationship between visibility-related crashes and real-time traffic data using two data sources, namely loop detectors and Automatic Vehicle Identification (AVI) sensors. The study showed that the average speed along with the coefficient of variation in speed at 5–10 min prior to a crash significantly affects the likelihood of visibility related crashes. Similarly, Ahmed et al. (2014) used real-time weather data collected from airport stations to investigate the viability of this type of data in real-time crash

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