Accident Analysis and Prevention 120 (2018) 1–12

Contents lists available at ScienceDirect

Accident Analysis and Prevention

journal homepage: www.elsevier.com/locate/aap

Investigating factors of crash frequency with random effects and random parameters models: New insights from Chinese freeway study

Qinzhong Hou[a,b], Andrew P. Tarko[b], Xianghai Meng[a,*]

[a] School of Transportation Science and Engineering, Harbin Institute of Technology, 150090, China
[b] Center for Road Safety, Lyles School of Civil Engineering, Purdue University, West Lafayette, IN 47907, US

ARTICLE INFO

Keywords:
Freeway safety
Crash frequency
Random parameters model
Negative binomial model
Geometric
Design
Pavement condition

ABSTRACT

In response to the rapid economic growth in China, its freeway system has become the longest in the world and likely will continue to expand. Unfortunately, the safety issues on freeways in China have grown as well and are of great concern to Chinese transportation authorities and drivers. While many proven safety countermeasures developed and implemented by other countries are available for reference, they may be not fully transferrable to China due to the differences in driving cultures and conditions. As a result, an investigation of China's unique safety factors and effective relevant countermeasures are urgently needed.

The study presented in this paper thoroughly investigated the factors contributing to freeway crashes in China based on detailed crash data, traffic characteristics, freeway geometry, pavement conditions, and weather conditions. To properly account for the over-dispersion of data and unobserved heterogeneity, a random effects negative binomial (RENB) model and a random parameters negative binomial (RPNB) model were applied, along with a negative binomial (NB) model. The analysis revealed a large number of crash frequency factors, including several interesting and important factors rarely studied in the past, such as the safety effects of climbing lanes. Moreover, the RENB and RPNB models were found to considerably outperform the NB model; however, although the RPNB exhibited better goodness-of-fit than the RENB model, the difference was rather small. The findings of this study shed more light on the factors influencing freeway crashes in China. The results will be useful to highway designers and engineers for creating, building, and operating safe freeways as well as to safety management departments for developing effective safety countermeasures. The study presented in this paper also provides additional guidance for choosing relevant methods to analyze safety and to identify safety factors.

1. Introduction

Traffic crashes result in 1.2 million fatalities and up to 50 million injuries annually according to the *WHO Global Road Safety Report* (WHO, 2015). Numerous studies on road safety were conducted in the past few decades to investigate the factors contributing to crashes and to identify effective safety countermeasures; and thanks to the recent advancements in data collection and modeling methodologies, an increasing number of safety factors are better understood and new safety improvement measures are being implemented. However, road crashes are complex events that involve a large variety of factors with multi-faceted interactions, making it challenging to fully understand them. Advancing improved methodologies for road safety analysis and applying them to crash analysis continues to be investigated.

Freeways play a crucial role in transportation and economic development. Unfortunately, Chinese freeways are experiencing a considerable amount of road safety problems that are drawing attention and concern from the government and motorists. Crashes are problems unto themselves, but they also reduce the operational performance of the entire transportation system. Safe, highly efficient freeways are a priority for government agencies/road authorities, especially in countries with large freeway systems such as China.

The China freeway network became the world's largest freeway system in 2011 after surpassing by length the U.S. interstate highway system. Between 1999 and 2016, the total length of the freeway network in China grew 13 times and reached 131,000 km (MOT, 2016). This rapid growth of freeway mileage has been accompanied by a high crash rate (3.7 crashes/km/year in 2008–2012 period based on the eight freeways studied in this paper).

The safety concerns must be addressed in a timely manner as the national freeway network is scheduled to further expand to 150,000 km by 2020 according to the *13th Five-year Plan of Modern Transportation*

* Corresponding author.
E-mail addresses: houqinzhong@126.com (Q. Hou), tarko@purdue.edu (A.P. Tarko), mengxianghai100@126.com (X. Meng).

https://doi.org/10.1016/j.aap.2018.07.010
Received 23 January 2018; Received in revised form 27 June 2018; Accepted 2 July 2018
0001-4575/

System in China (State Council, 2017). In addition, the *National Highway Plan* (2013–2030) (NDRC, 2013) includes connecting the China freeway network with cities having a population of 200,000 and larger, which implies the impending construction of additional service freeways.

The study presented in this paper was motivated by the need to identify new safety factors and to confirm the known factors, which include traffic volume and its composition, freeway geometry, pavement conditions, and weather conditions. This study also aimed to provide new insight into safety factors that deserve additional investigation, such as speed limits for passenger cars and trucks, freeway interchanges, and service area segments. To accomplish these objectives, alternative negative binomial models with random effects and random parameters were estimated and compared.

Data representing 22,791 crashes that occurred on 1,689 km of freeways were collected in an average four-year period and supplemented with data pertaining to the traffic conditions, freeway geometry, pavement conditions, and weather conditions. Good quality detailed data were utilized to analyze the crash frequency factors on the studied freeways with a negative binomial (NB) model, a random effects negative binomial (RENB) model, and a random parameters negative binomial (RPNB) model. This paper continues in the following manner. First, the published literatures relating to this study are briefly discussed. Then, the data collection and preparation for modeling are presented, followed by a description of the methodology used in this study. The results are discussed next; and finally, the conclusions from the presented study and future research topics are summarized.

2. Literature review

Due to the vast number of studies relevant to the subject in this paper, the literature review here focuses on the relatively recent studies on crash frequency factors and new methods of crash frequency analysis.

2.1. Factors affecting crash frequency

Crash frequency has been reported in numerous past studies to increase with increases in traffic volume (Abdel-Aty and Radwan, 2000; Anastasopoulos and Mannering, 2009; Donnell and Mason, 2006; Lao et al., 2014; Ma et al., 2017) and the percentage of trucks or heavy vehicles (Abdel-Aty and Radwan, 2000; Buddhavarapu et al., 2013; Hosseinpour et al., 2014). The posted speed limit also has been found to significantly affect crash frequency with many studies concluding that higher speed limits are associated with higher frequency of crashes (Donnell and Mason, 2006; Yu et al., 2013), while other studies argued that higher speed limits can be associated with decreased crash frequency due to better roadway conditions and geometric characteristics that allow these high speed limits (Lao et al., 2014; Hosseinpour et al., 2014).

The freeway cross-sectional geometry was found to be correlated with crash frequency. For example, freeway segments with narrow shoulders, narrow medians, and reduced longitudinal barrier offsets experienced increased crash frequency (Abdel-Aty and Radwan, 2000; Ahmed et al., 2014; Donnell and Mason, 2006; Zou and Tarko, 2016). The safety effect of adding lanes also is debatable. Some researchers asserted that adding lanes increases the opportunity for lane changing, thus resulting in more crashes (Abdel-Aty and Radwan, 2000; Ma et al., 2017; Naik et al., 2016), while others argued that adding lanes is safety-beneficial as it reduces both the traffic density and potentially dangerous interactions between vehicles in high-traffic conditions (Ahmed et al., 2014; Yu et al., 2013, 2015). Although the safety effects of installing climbing lanes for freeways have rarely been investigated, the existing few studies targeted on safety of climbing/passing lanes for two-lane roads based on either reported crashes (Weber and Jährig, 2010; Carlson, 2009) or micro-simulation conflicts (Cafiso et al., 2017) could still provide some knowledge for this research subject. They all confirmed the safety benefits of installing passing/climbing lanes.

The horizontal and vertical alignments play an important role in road safety. A longitudinal grade increases the crash frequency (Ahmed et al., 2014; Fu et al., 2011; Ma et al., 2017; Montella and Imbriani, 2015; Yu et al., 2015). The relationship between horizontal curvature and crash frequency remains a subject of studies in order to better understand this relationship. Some studies concluded that sharp curves experience more crashes (Abdel-Aty and Radwan, 2000; Ahmed et al., 2014; Donnell and Mason, 2006; Hosseinpour et al., 2014; Ma et al., 2017). Other studies indicated that readable road curves increase the caution by drivers and promote adequate and safe behavior of reduced speeds (Anastasopoulos and Mannering, 2009; Rusli et al., 2017; Yu et al., 2013).

With regard to road pavement, studies have shown that good road surface conditions can decrease crash frequency and is an effective way to reduce crash severity in general (Abdel-Aty et al., 2009; Anastasopoulos and Mannering, 2009; Park et al., 2017). On the other hand, deep rutting of pavements was connected with increased crash frequency (Anastasopoulos and Mannering, 2009; Buddhavarapu et al., 2013). Previous studies also indicated that pavement friction improvements could significantly reduce the crash frequency, especially under wet pavement conditions (Anastasopoulos and Mannering, 2009; Mayora and Piña, 2009). Past studies produced mixed results on the safety effect of the international roughness index (IRI). Some researchers declared that increasing the IRI caused adverse safety effects (Anastasopoulos and Mannering, 2009; Anastasopoulos et al., 2012), while others presented the opposite effect and championed the risk compensation mechanism (Buddhavarapu et al., 2013).

Weather may also play a role in crash occurrence. Adverse weather conditions, such as rain, fog, poor visibility, strong wind, etc., may increase the probability of crash significantly to those already on the road. Aggregate annual weather data were available in the past and were widely used in previous studies (Chang and Chen, 2005; Young and Liesman, 2007). Thanks to the availability of disaggregate weather data, the recent trend in safety studies is to consider the weather conditions at the time of a crash as more relevant than the weather conditions averaged over long periods (Ahmed et al., 2014; Naik et al., 2016; Yu et al., 2013, 2015). However, this new opportunity is available only in countries with reliable data collected by high-density weather stations and comprehensive data storage systems.

2.2. Methodology of crash frequency analysis

A negative binomial (NB) model (also called the Poisson-Gamma model) was applied in many previous studies (Abdel-Aty and Radwan, 2000; Donnell and Mason, 2006; Garach et al., 2016; Montella and Imbriani, 2015; Shankar et al., 1998). The requirement of iid error components is violated if there are variables that introduce dependence among the error components if these variables are omitted from the model. In order to account for this limitation, a random effects negative binomial model (RENB) was used by many researchers (Caliendo et al., 2013; Hosseinpour et al., 2014; Ma et al., 2017; Naznin et al., 2016), who found it to be more suitable than the conventional NB model. In the RENB model, the joint effects of the unobserved variables are assumed to follow certain distributions along the spatial and temporal dimensions.

The conventional NB model with fixed parameters may fail to capture the possible variability of the individual effects associated with the variables across observations, which may lead to biased parameter estimation and incorrect inferences (Washington et al., 2010). The RENB model also may be insufficient if the variability of the effects does not follow the constrained spatial-temporal structure assumed for the random effects. A random parameters negative binomial (RPNB) model is an extension of the RENB model and has been advocated in recent years as an alternative approach by many studies (Anastasopoulos and Mannering, 2009; Chen and Tarko, 2014; Rusli et al., 2017; Truong