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Impacts of speed variations on freeway crashes by severity and vehicle type

Pushpa Choudhary[a], Marianna Imprialou[b], Nagendra R. Velaga[a,*], Alok Choudhary[c]

[a] Transportation systems engineering, Department of Civil Engineering, Indian Institute of Technology (IIT) Bombay Powai, Mumbai 400 076, India
[b] School of Civil & Building Engineering, Loughborough University Loughborough LE11 3TU, United Kingdom
[c] School of Business and Economics, Loughborough University Loughborough LE11 3TU, United Kingdom

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ABSTRACT

Speed variations are identified as potentially important predictors of freeway crash rates; however, their impacts on crashes are not entirely known. Existing findings tend to be inconsistent possibly because of the different definitions for speed variations, different crash type consideration or different modelling and data aggregation approaches. This study explores the relationships of speed variations with crashes on a freeway section in the UK. Crashes split by vehicle type (heavy and light vehicles) and by severity mode (killed/serious injury and slight injury crashes) are aggregated based on the similarities of the conditions just before their occurrence (condition-based approach) and modelled using Multivariate Poisson lognormal regression. The models control for speed variations along with other traffic and weather variables as well as their interactions. Speed variations are expressed as two separate variables namely the standard deviations of speed within the same lane and between-lanes over a five-minute interval. The results, similar for all crash types (by coefficient significance and sign), suggest that crash rates increase as the within lane speed variations raise, especially at higher traffic volumes. Higher speeds coupled with greater volume and high between-lanes speed variation also increase crash likelihood. Overall, the results suggest that specific combinations of traffic characteristics increase the likelihood of crash occurrences rather than their individual effects. Identification of these specific crash prone conditions could improve our understanding of crash risk and would support the development of more efficient safety countermeasures.

1. Introduction

Speed and speed variations are considered to be among the most important crash contributory factors. Several ITS applications such as Variable Speed Limits (VSL) or cooperative systems are designed to provide speed harmonization anticipating that this will lead to lower crash rates (Farah and Koutsopoulos, 2014; Strömgren and Lind, 2016). However, studies considering speed variations as a contributory factor are relatively low in number and their results are varying (Kockelman and Ma, 2007; Quddus, 2013; Shi et al., 2016). Some of the studies find speed variations to be positively associated with crashes (Quddus, 2013; Tanishita and Van Wee, 2016; Wang et al., 2018) while others find non-significant relationships between speed variations and crash risk (Kockelman and Ma, 2007). Others also report changes in the effects of speed after including speed variance in models (Garber and Gadiraju, 1989).

The often-conflicting results of the existing studies may be related to the multiple definitions used to express speed variations, the differences in modelling approaches or data quality and pre-processing methods. All these suggest that further exploration of this contributory factor is needed. Current advances in crash modelling can be proved useful in the examination of the impact of speed variations on crashes. Recently, crash data aggregation has been found to be highly influential on the estimated coefficients of time-varying variables such as speed and traffic flow (Imprialou et al., 2016a, b; Xu et al., 2018; Yu et al., 2018). When crashes are aggregated according to the similarities of the traffic conditions just before their occurrence, modelling results appear to be more reliable than in traditional location-based approaches (Imprialou et al., 2016b). Additionally, research has shown that independent variables in crash modelling have unique effects on different crash types and these are more accurately estimated when the correlations between the examined crash types are taken into consideration (i.e. multivariate count models) (Huang et al., 2017; Lord and Mannering, 2010).

Although there are many multivariate crash prediction models that examine crashes by severity, there is a very limited number of studies

* Corresponding author.
E-mail addresses: pushpachoudhary@iitb.ac.in (P. Choudhary), M.Imprialou@lboro.ac.uk (M. Imprialou), n.r.velaga@iitb.ac.in, velaga@civil.iitb.ac.in (N.R. Velaga), A.Choudhary@lboro.ac.uk (A. Choudhary).

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that divides crashes by the involved vehicle types and none of them focuses on heavy goods vehicles. This paper analyses the effects of speed variations along with other traffic and weather variables on different types of crashes and specifically by vehicle types (heavy and light vehicles) and by severity type (killed/serious injuries and slight injuries; Property Damage Only (PDO) crash data were not available and therefore this crash type was excluded from the analysis). Multivariate Poisson lognormal regression models are used to develop the relationships that are applied on a dataset aggregated with the condition-based approach.

2. Literature review

The impact of traffic characteristics on crash frequency and severity has been widely studied in the literature and has offered useful insight into the development of effective mitigation measures. Speed has received a lot of research attention, but the findings regarding its relationship with crash rates are inconsistent (Aarts and Van Schagen, 2006). It is clear that higher speed is associated with higher crash severity, but the impact of speed on crash frequency is not clearly defined yet. Some studies suggest a positive relationship between speed and crash frequency (Imprialou et al., 2016a, b; Kloeden et al., 2002; Taylor et al., 2000); however, others have shown a negative or an insignificant relationship (Kockelman and Ma, 2007; Quddus, 2013; Stuster, 2004). There is also a common belief that speed does not necessarily lead to more crashes as long as there are no extreme speed differences between vehicles on a roadway section. These differences that are typically referred to as speed variations and have been identified as a potentially significant contributory factor; however, their exact effect on crashes remains inconclusive (Aarts and Van Schagen, 2006; Kockelman and Ma, 2007; Quddus, 2013; Solomon, 1964). There have been significantly fewer studies focusing on speed variations than on speed and other traffic, geometric or environmental variables (Quddus, 2013). This is may be partially because speed variations are not directly measurable and may be hard to be computed unless the available traffic data are highly spatially and/or temporally aggregated.

The effects of speed and its variations were initially studied by Solomon (1964) in a case-control study that suggested that vehicles moving much faster or slower than the modus speed were exposed to higher crash risks introducing the theory “Variance kills”. Some subsequent studies reported that speed variation is so highly influential for triggering crashes that it makes the effect of mean speed negligible, suggesting that “Variance kills, not speed” (Garber and Gadiraju, 1989). This was in line with the findings by Quddus (2013) who found that speed variation is associated positively with the crash rates but, the average speed is not. However, it contradicts the outcomes of other studies that find both speed and speed variance to be significant factors for predicting crash frequency (Levy and Asch, 1989; Tanishita and Van Wee, 2016). Studies on real-time crash prediction have shown negative associations of average speed with crashes, while a positive relationship between speed variation and crashes (Abdel-Aty et al., 2012; Wang et al., 2016, 2015a; Xu et al., 2016; Yu and Abdel-Aty, 2014). Moreover, the effects of speed and speed variations seemed to be related to other traffic variables such as flow (Abdel-aty and Pemmanaboina, 2006; Xu et al., 2016). For instance, Abdel-aty and Pemmanaboina (2006) mentioned that high-speed variation coupled with high occupancy and low variation in volume leads to higher likelihood of a crash, while, Xu et al. (2016) showed that, high-speed variance in high-density traffic flow leads to higher crash risk.

The inconsistencies among the results may be related to the differences between analytical methods and also with the definition of speed variations. Speed variation has been represented by multiple different measures such as differences in speed at individual vehicle level (Kloeden et al., 2002; Solomon, 1964), differences at section level traffic characteristics (Quddus, 2013), the difference between the 90th to the 50th percentile of speeds in each lane (Golob et al., 2004), speed differences between and across lanes (Kockelman and Ma, 2007) and others.

The differences in results could also be related to different crash types. For instance, Kweon and Kockelman, (2005) showed that the effects of speed variation were dependent on crash severity and that specifically slight-injury crashes were associated with high-speed variance. Current crash prediction modelling suggests that separate models for different crash types are not adequate; and therefore, multivariate modelling approaches came into application (e.g. Huang et al., 2017; Imprialou et al., 2016b; Lord and Mannering, 2010; Martensen and Dupont, 2013). Though there are various studies on crash contributory factors by severity levels, there are very few studies focusing on crashes by vehicle type and these are mostly focused on urban environments without making a distinction between heavy and light vehicles (Huang et al., 2017). Whereas, it has been known that due to their unique characteristics (weight, size, stopping distances etc.) heavy vehicles’ crash contributory factors should be investigated separately (Wei et al., 2017). Moreover, as per authors’ best knowledge, there is no study on investigating the effects of speed variation on heavy vehicle crashes.

Other than speed, traffic volume is one of the most studied factors in crash rate predictions (Aarts and Van Schagen, 2006; Garber and Ehrhart, 2000). Weather conditions could also affect crash risk (e.g. Abdel-aty and Pemmanaboina, 2006; Wang et al., 2015b; Xu et al., 2016). Typically rainy weather is found to be associated with higher crash rates in most of the previous studies (Abdel-aty and Pemmanaboina, 2006; Lee et al., 2003), possibly because, the wetness of pavement reduces friction, making stopping distances longer (Abdel-aty and Pemmanaboina, 2006).

This study explores further the relationships of traffic characteristics with crash rates with a special focus on the impact of speed variations (defined as speed differences within and between-lanes). Freeway crashes are split by vehicle types (heavy and light vehicle crashes) and severity (killed or serious and slight injury) and are fitted using multivariate count models. In order to achieve a more accurate representation of the conditions just before crashes, data are aggregated following a condition-based approach (Imprialou et al., 2016b).

3. Data collection and preparation

To analyse the impact of speed variations on crashes, traffic and weather data have been employed. The study area was decided to be a section of the South-North motorway M1 (Junctions 1–24 (Fig. 1), located between London and East Midlands Airport) that is one of the most important and busy motorways in England that links London with the North of the country. The length of the study area is 175 km per direction and most of its links include three running lanes in each direction. The crash data for three years (from 2013 to 2015) was obtained from the National Road Accident Database of the United Kingdom (STATS 19) (Department for Transport, 2011). Among others, the data included information on severity, involved vehicle types, time, date and location of the crashes. During the study period, there were 1075 fatal and injury crashes in total, of which 11.25% resulted in killed or seriously injured casualties (henceforth: KS crashes) and 88.75% in slight injuries (henceforth: SL crashes). As the study area belongs to the Strategic Road Network of England, that carries almost two-thirds of England’s freight, 15.90% of all crashes had at least one commercial vehicle with weight over 3.5 tones involved i.e. heavy vehicles (henceforth these crashes will be referred to as HV-crashes). The rest of the crashes (84.10%) were between mainly passenger vehicles or vans with weight 3.5 tonnes or less i.e. light vehicles (henceforth: LV-crashes)[1].

[1] In the present study, a crash is defined as HV-crash if the crash includes at least one heavy goods vehicle. Whereas, LV-crashes are the crashes that involve at least one light vehicle but excluding the crashes which include heavy goods