Accident Analysis and Prevention 111 (2018) 86–93

Contents lists available at ScienceDirect

Accident Analysis and Prevention

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

Correlates of fatality risk of vulnerable road users in Delhi

Rahul Goel[a,*], Parth Jain[b], Geetam Tiwari[c]

[a] MRC Epidemiology Unit, University of Cambridge, United Kingdom, UK
[b] Civil Engineering, Shiv Nadar University, Gautam Budh Nagar District, India
[c] Transportation Research and Injury Prevention Programme (TRIPP), Indian Institute of Technology Delhi, New Delhi, India

ARTICLE INFO

Keywords:
Delhi
Vulnerable road users
Road deaths
India
Population
Density
Grade separators

ABSTRACT

Pedestrians, cyclists, and users of motorised two-wheelers account for more than 85% of all the road fatality victims in Delhi. The three categories are often referred to as vulnerable road users (VRUs). Using Bayesian hierarchical approach with a Poisson-lognormal regression model, we present spatial analysis of road fatalities of VRUs with wards as areal units. The model accounts for spatially uncorrelated as well as correlated error. The explanatory variables include demographic factors, traffic characteristics, as well as built environment features. We found that fatality risk has a negative association with socio-economic status (literacy rate), population density, and number of roundabouts, and has a positive association with percentage of population as workers, number of bus stops, number of flyovers (grade separators), and vehicle kilometers travelled. The negative effect of roundabouts, though statistically insignificant, is in accordance with their speed calming effects for which they have been used to replace signalised junctions in various parts of the world. Fatality risk is 80% higher at the density of 50 persons per hectare (pph) than at overall city-wide density of 250 pph. The presence of a flyover increases the relative risk by 15% compared to no flyover. Future studies should investigate the causal mechanism through which denser neighborhoods become safer. Given the risk posed by flyovers, their use as congestion mitigation measure should be discontinued within urban areas.

1. Introduction

Indian cities have witnessed an exponential growth of vehicles during the previous two decades or so, contributed largely by motorised two-wheelers (MTW) (Pucher et al., 2007; MoRTH, 2012). Coincident to this, burden from road traffic injuries in India has also been rising, and the number of deaths have more than doubled from 1991 through 2011 (Mohan et al., 2015). According to the official sources, there were more than 140,000 road deaths in year 2013-14 (NCRB, 2015). When expressed as the number of road deaths per 100,000 persons, fatality risk in India is 2–4 times higher than high-income settings such as the UK, Germany, France and Canada (MoRTH, 2012).

A majority of the victims are men in age-group 15–59 years (Gururaj, 2008; Mohan et al., 2009; Hsiao et al., 2013). Pedestrians, cyclists, and MTW riders have the largest share. The three road-user categories, with no rigid barrier protecting them against traumatic forces, are often termed as vulnerable road users (VRU) (Peden et al., 2004). Globally, VRUs account for around 46% of all road deaths (WHO, 2015), while in India this share is much higher.

According to Million Death Study, a national-level mortality survey in India, VRUs accounted for 68% of all road deaths during the period 2001–2003 (Hsiao et al., 2013). A study conducted in six Indian cities with population ranging between 1–2 million reported that the proportion of VRU fatalities for years 2008 through 2011 varied from 84% to 93% (Mohan et al., 2016). This proportion is much lower in high-income countries and is as low as 22% in the Americas (WHO, 2015). There are multiple factors contributing to these differences, such as road design, provision of safe infrastructure for pedestrians and cyclists, traffic management, and the enforcement of speed and alcohol limits. Apart from these, the major underlying difference is how people travel in these settings.

According to Census 2011, close to one-third of the workers (30%) in Indian cities walk to work, 17% cycle, a quarter (25%) use some form of public transport (bus, autorickshaw or train), more than one-fifth (22%) use MTW and only 5% use cars (Census-India, 2016). As a result, 69% of the workers can be categorised as VRUs during their commute trips. If we consider walking involved in either ends of a public transport trip, the proportion of work trips involving VRU reach up to 94%.

When trips of all purposes are considered, data from various cities in India show that the share of non-motorised modes is even higher (Arora et al., 2014; RITES, 2008; Goel, 2017). As a result, a large proportion of road users are exposed to high injury risk through collisions with high-

* Corresponding author.
E-mail addresses: rahulatiitd@gmail.com, rg574@medschl.cam.ac.uk (R. Goel).

https://doi.org/10.1016/j.aap.2017.11.023
Received 30 August 2017; Received in revised form 30 September 2017; Accepted 17 November 2017

powered motorised vehicles such as cars, buses, and trucks. This is in complete contrast with high-income settings where a large proportion of trips are carried out in cars. For instance, 86% of the work trips in the US (2009; McKenzie and Rapino, 2011), 64% in the UK (2011; Gower, 2013) and 62% in the Netherlands (2007; MOT, 2009) were carried out using cars. As a result, in case of a crash, the road users in these settings have much higher protection.

Road transport in India also differs in the form of motorisation from their western counterparts. Increasing motorisation is not resulting in reduction of VRUs on roads, as MTW remains a preferred mode of private transport. While MTW in India account for more than two-thirds of private motorised fleet (MoRTH, 2012), their share in western settings such as the USA, UK, Germany and France, is only 3–10% (EEA, 2003; USDOT, 2015).

A large number of crash-level epidemiological studies have been carried out in India to understand the causal mechanism of crashes or the injury severity (Garg and Hyder, 2006). However, epidemiology of crashes using ecological models is lacking. In this study, we present a spatial analysis of VRU fatalities in Delhi to assess their geographic variation with respect to built environment, demographic factors, and traffic characteristics. We restricted our analysis to fatal crashes as number of injury crashes reported by police are highly underreported in India (Gururaj, 2008; Mohan et al., 2009; Mohan et al., 2015). Delhi being the capital of India and the seat of federal government has an active police department and is a dense urban area. Therefore, underreporting of traffic deaths in a setting like Delhi is highly unlikely.

2. Literature review

Crash rates have been established to have a positive association with the speed of vehicles (Nilsson, 1981; Cameron and Elvik, 2010). In addition to the probability of a crash, speed of vehicles is also a determinant of severity level of injuries (OECD/ECMT, 2006; Aarts and Van Schagen, 2006). How fast vehicles travel on road is a function of built environment (Ewing and Dumbaugh, 2009) and road design features (Török, 2011; Fitzpatrick et al., 2001), among other factors such as speed limit (Fitzpatrick et al., 2001), or traffic conditions (Török, 2011). Given these links of crashes with speed and that of speed with built environment, many studies have found association between crash rates and built environment (Ewing et al., 2003).

There are other factors which result in higher number of crashes such as through increasing the exposure to risk, increasing the chances of a crash, or increasing the severity of injury. Higher exposure to risk is a function of economic and demographic factors and mode of travel. Higher crash occurrence is associated with lack of law enforcement by police and lack of safe infrastructure for pedestrians and cyclists, and higher severity level can result from lack of forgiving vehicle front to protect pedestrians in a collision, use of seat belts by cars occupants and helmets by MTW riders and cyclists (Peden et al., 2004).

A large number of studies have carried out area-level crash modelling to quantify the association of road traffic injuries with built environment and traffic characteristics as well as population characteristics. Such models, after accounting for confounding variables, estimate the independent effects of different built environment variables, such as, type of junctions, intersection density, type of roads, speed limit, road widths, and road curvature. With this knowledge, built environment can be modified in ways which can increase the safety of road users. The sensitivity of safety to those modifications is given by the coefficients of the regression models.

Most of the area-level modelling studies have been carried out in settings from highly motorised developed countries—US, Canada, UK, and Australia. For instance, studies from cities/states in the US include San Francisco, California (LaScala et al., 2000; Wier et al., 2009), Tucson, Arizona (Ladron de Guevara et al., 2004), Pennsylvania (Aguero-Valverde and Jovanis, 2006), Hawaii (Kim et al., 2006), Charlotte, North Carolina (Pulugurtha et al., 2013), California (Chakravarthy et al., 2010), San Antonio, Texas (Dumbaugh et al., 2013), New York city (DiMaggio, 2015), Manhattan (Narayanamoorthy et al., 2013), New Jersey (Demiroluk and Ozbay, 2014), and Hillsborough and Pinellas counties of Florida (Siddiqui et al., 2012; Xu et al., 2017), from those in Canada include Toronto (Hadayeghi et al., 2003), Greater Vancouver region (Lovegrove and Sayed, 2006) and British Columbia (MacNab, 2004), those in UK, London (Quddus, 2008), England (Graham and Glaister, 2003; Noland and Quddus, 2004), and England and Wales (Jones et al., 2008), and in Australia, Melbourne (Amoh-Gyimah et al., 2016). Among low-and middle-income countries (LMICs), the only study reported is by Wang et al. (2016) in which they modeled pedestrian crashes in Shanghai city.

The areal unit of analyses used by various studies also varied and included counties (Aguero-Valverde and Jovanis, 2006; Demiroluk and Ozbay, 2014), census tracts (LaScala et al., 2000; Chakravarthy et al., 2010; Narayanamoorthy et al., 2013; DiMaggio, 2015), census statistical area levels (Amoh-Gyimah et al., 2016), wards (Graham and Glaister, 2003; Noland and Quddus, 2004; Quddus, 2008), traffic analysis zones (TAZ) (Hadayeghi et al., 2003; Pulugurtha et al., 2013; Siddiqui et al., 2012; Wang et al., 2016; Xu et al., 2017), city blocks (Dumbaugh et al., 2013) or grids (Kim et al., 2006).

The modeling has been carried out using non-spatial models (Hadayeghi et al., 2003; Graham and Glaister, 2003; Noland and Quddus, 2004; Kim et al., 2006; Pulugurtha et al., 2013; Lovegrove and Sayed, 2006; Wier et al., 2009; Chakravarthy et al., 2010; Dumbaugh et al., 2013), spatial models (LaScala et al., 2000; MacNab, 2004; Narayanamoorthy et al., 2013; Demiroluk and Ozbay, 2014; DiMaggio, 2015; Wang et al., 2016), as well as both (Quddus, 2008; Aguero-Valverde and Jovanis, 2006; Siddiqui et al., 2012; Amoh-Gyimah et al., 2016; Xu et al., 2017). Spatial models have accounted for spatial correlation using traditional econometric models, such as spatial autoregressive models (Quddus, 2008; LaScala et al., 2000) or spatial error models (Quddus, 2008) or using more recently developed hierarchical Bayesian modelling which include specifications of error terms for uncorrelated heterogeneity as well as spatial heterogeneity (MacNab, 2004; Aguero-Valverde and Jovanis, 2006; Quddus, 2008; Siddiqui et al., 2012; Wang et al., 2016; Amoh-Gyimah et al., 2016; Xu et al., 2017).

It is noteworthy that even though a major share of global road traffic injury burden is contributed by LMICs, their representation in such studies is almost absent. In Indian cities, most roads do not have posted speed limits, and when they do, police rarely enforces those. As a result, speed chosen by drivers is likely to be much more associated with traffic conditions, road design features and other built environment factors. This underscores the importance of built environment as risk factor for crashes in Indian cities. Other factors which set Indian cities apart from their high-income counterparts are lack of safe infrastructure for non-motorised modes, heterogeneous mix of traffic, low level of car-based travel and a high share of MTW. The contrasting contexts of on-road traffic mix, built environment, demographics, and level of traffic enforcement between India and high-income countries warrant an area-level crash study in an Indian city.

3. Case study city—Delhi

Delhi is the capital city of India and one of the most heavily motorised large cities in India. Among the cities with population more than 10 million, it has the highest ownership of cars, with more than one in every 5 households owning a car (Guttikunda et al., 2014). Delhi along with its contiguous cities have grown rapidly over the last two decades. The population of the region more than doubled from 10 million in 1991–22 million in 2011, with Delhi contributing 16.7 million to the latter. Over the same period, the number of registered vehicles have increased by more than 300%. Public transport (PT) is served through a combination of road– and rail–based modes. These include buses, intermediate public transportation such as cycle rickshaws, electric