Safety Science 130 (2020) 104847

Contents lists available at ScienceDirect

Safety Science

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

Pedestrian safety models for urban environments with high roadside activities

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ARTICLE INFO

Keywords:
Road accident
Pedestrian safety
Road side activities
Crash frequency
Crash severity
Pedestrian crash

ABSTRACT

Virtually every traveller starts and ends as a pedestrian. Therefore walking, an essential part of a non-motorised transport mode, is very important especially in urban settings. To achieve safe walkable environments, practical tools are needed by transport professionals to assess and mitigate the influence of development on pedestrian safety, including pedestrian-vehicle accidents. Therefore, a better assessment of the risks faced by pedestrians is important to achieve a safer walking environment and to reduce the risks.

In spite of the importance of roadside activities in urban areas, it appears that there are no sufficient studies which have given attention to them and investigated their influence on pedestrians' safety. As a consequence, this study developed models to assess pedestrian safety and capture the effect of pedestrian and roadside activities' intensity. The study found that the number of bus stoppings per unit of time, parking, pedestrian crossing and violations' volume, the traffic speed variation, the number of intersecting side roads, in addition to through and intersecting traffic volume, were among the significant risk factors related to the pedestrian crash risk. These factors were then linked with the risk of a pedestrian crash using generalized regression models of which the Poisson model seem to be the most satisfactory.

1. Introduction and background

Pedestrians are considered as the most vulnerable road users because of their fragility and slow movement. They have a higher risk of road crash potential than motorised vehicle occupants (Zhang et al., 2014). In addition, pedestrian fatalities accounting for about 23% of total traffic deaths globally (WHO, 2018). In 2016 for instance, 5320 pedestrians' fatalities were reported in Europe (excluding Lithuania and Slovakia) accounting for 2% of total traffic deaths (European Commission, 2018). Pedestrians tend to travel more in urban areas, where the traffic accident hazards are higher than those in inter-urban areas (Elvik et al., 2009). For example, around 76% of pedestrian deaths in the United States and 70% in the European Union were in urban areas (WHO, 2013).

However, pedestrian casualties seem to be mostly preventable and established intervention measures are available. Yet, successful interventions to make walking safer and protect pedestrians need an understanding of the causes and nature of the risk factors related to pedestrian-vehicle crashes (WHO, 2013), especially in areas of higher road and roadside activities, where pedestrian activities, traffic volume and traffic speed variations are greater compared to other area settings (Zegger et al., 2002; Clifton and Kreamer-Fults, 2007; Zheng et al., 2010).

In general, there are a number of factors affecting pedestrians' safety including intersection and roadway characteristics, pedestrian volume, traffic volume and speed (Zeeger et al. 2005; Wang and Abdel-Aty, 2008; Elvik et al., 2009; Derry et al., 2010; Al-omari and Obaidat, 2013; Wang, Quddus, and Ison, 2013). In addition, speed variation, land uses and pedestrian and roadside activities also affect pedestrians' safety.

The Highway Safety Manual (HSM), published by the American Association of State Highway and Transport Official (AASHTO) in 2010, provides users analytical tools to identify locations of the higher risk of accidents and assist to quantify the potential factors contributing to traffic accidents and countermeasures to improve safety. The methodology consists of three basic parts; Safety Performance Function (SPF) to establish the relation between crashes and exposure, Crash Modification Factors (CMFs) which is adjust the model to site specific conations, and the Calibration factor (C) to adjust the results to account for local differences. In the HSM methodology, CMFs were developed to quantify the change in expected average crash frequency as a result of geometric or operational modifications to a site that differs from base conditions.

Several studies found that speed variation has an important effect on accident risk and attempted to quantify its influence on accident

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https://doi.org/10.1016/j.ssci.2020.104847
Received 30 December 2019; Received in revised form 23 April 2020; Accepted 20 May 2020

frequencies. It is a problem that has a more significant effect on accident frequencies than speed itself (Solomon, 1964; Lave 1985; Garber and Gadiraju, 1989; Garber and Ehrhart, 2000; Zheng et al., 2010; Quddus, 2013).

Speed variability which is refers to speed variance may be attributed to drivers' behaviour. For example, some drivers simply may wish to drive faster than others; while other reasons could be associated with different traffic conditions (e.g. varying levels of traffic flow), or a combination of the two (Taylor et al., 2000).

Quddus (2013) investigated the relationship between speed variation, average speeds and accident rates using a range of motorways and A-class road sections around London. The study results showed that 1% increase in speed variation may lead to a 0.3% increase in crash frequency.

Recently, the use of loop detector data has improved the ability to study the effect of speed variation in a more accurate and well-controlled manner. The collected data from loop detectors can be used to construct traffic characteristics at a given site. It then becomes possible to determine if the period immediately before an accident occurred was characterized by a larger speed variance than other periods (Elvik, 2014). Using this method and data resource, Zheng et al. (2010) has shown that speed variation influences accident risk.

The relationship between speed variation and safety are not as well established as the relationship with speed limits and average speed. Its theoretical base may be linked to the interaction between the expectations of drivers and vehicles. The higher the traffic speed variation, the more overtaking manoeuvres and consequently, the more situations with increased risk (Finch et al., 1994). Also, for the road user, larger speed variations may create more unexpected situations due to increased differences between the expected traffic speed and the actual speed, which may lead to collisions (Jonsson, 2005). In this regard, Domenichini et al. (2018) demonstrated through a pilot study in Florence, in Italy, that to protect pedestrians it is necessary to reduce both the driving speed and speed variance and comply with the operating speed limit. This may be achieved by multiple engineering treatments aimed at all road users.

In terms of land uses, Chapman (1978) performed a detailed investigation to examine the road and environmental factors associated with accidents rates across 4 towns in Southern England. Accidents rates were compared along the road sections passing through different land uses on each side of the study area. The study showed that a notably higher accident rates associated with sections of road passing through shopping areas. The accident rates were found to be over twice the average along road sections adjacent to at least one side of shopping development compared with other land uses. Although the accident rates were relatively higher for all road users, pedestrians and cyclists were particularly vulnerable. McGuigan (1982) conducted study in Lothian region to determine the relationship between accident rates, roadside development and traffic and reported that there are significant relationships between accidents and adjacent roadside development. The analysis showed that accident rates vary according to the types of the adjacent land uses, and higher accident rates were associated with roads passing through shopping development. Another work by Lawson (1986) on Birmingham radial routes indicated the effect of land uses and roadside development on the differences of accidents at different locations. The results showed that there were high numbers of accidents along the roads adjacent to shops and confirmed the findings of earlier studies of Chapman (1978) and McGuigan (1982). Also, there were significantly more pedestrian accidents on roads passing through shopping areas than on roads passing through other forms of land use.

More recently, Jonsson, (2005) stated that land use comes second in order of importance after traffic flow as an explanatory factor for most traffic accident types. Also, Wedagama et al. (2006) reported that pedestrian accidents in the city centre area are linked to retail and commercial land use. This is consistent with other studies which highlighted the proportion of commercial land use as significant predictors of pedestrian injury crashes (Wier et al., 2009). In addition to commercial land uses, the presence of schools and higher fractions of industrial land use were found to have a significant impact on vehicle–pedestrian crashes (Harwood et al., 2008; Ukkusuri et al., 2012).

Many studies indicated the effect of roadside activities on pedestrian safety. Crossing in front of a parked vehicle, crossing from an incorrect location, unsafe entering/exiting a vehicle, walking, playing, working on the road edge and improper parking are reported to be among the factors affecting pedestrian safety. For example,

Ukkusuri et al. (2012) indicated that areas which have a greater number of public transport stops and schools, are more likely to have higher crash risks. Also, roadside activities in commercial areas, public transport hubs and stops and schools may influence pedestrians to commit crossing violations, to cross against the lights, or not at the crossing facilities (Cinnamon et al., 2011). Violators, in turn, could face higher risks of encountering traffic conflicts or crashes (Koh et al., 2014) and King et al., 2009 showed that the crash risk per crossing violation may be approximately eight times greater than that of a legal crossing.

Quistberg et al. (2015) examined the relationship between bus stops and pedestrians' crashes in urban Lima, Peru. The study reported that the presence of a bus stop in an intersection was threefold more likely to result in a pedestrian crash. Also, Harwood et al. (2008) found that the presence of bus stops within 300 m have a significant relationship to vehicle pedestrian accidents. However, these studies used the presence of bus stop as an indicator, while bus stops could have different bus stoppings frequencies. With regard to roadside interaction, Hauer et al. (2004) found that the presence of parking showed a significant contribution towards the crash risk.

Al-omari and Obaidat (2013) reported that a significant share of pedestrian accidents occurred while walking on sidewalks, crossing in front of a parked vehicle, playing on the road, walking on the road, crossing at a zebra crossing, getting in or out of a vehicle, working on the road or pushing or towing a carriage. Additionally, Hosseinpour et al. (2014) indicated that roadside activities such as parking, bus stoppings and loading were positively associated with crash injury severity and that the potential of fatal crashes was 34% in road sections with high roadside activities that were not protected from through traffic.

Moreover, Verzosa and Miles (2016) examined the factors associated with the severity of traffic accidents involving pedestrians in Manila, in the Philippines, and found that the high flow of heavy vehicles along with the street vendors who share the road led to a hazardous environment for pedestrians. Also, they found that a large share of fatal crashes occurs close to public transport stations and stops.

The literature review presented above, found several factors and activities that could impose impact on pedestrian safety. However some other factors could affect pedestrian safety in environments with high roadside activities in urban areas: traffic speed variation; significant pedestrian crossing violations (i.e. those who cross from non-specified crossings or during the red interval); type and intensity of roadside activities, including bus stoppings, parking and un- parking events (Al-omari and Obaidat, 2013; Ukkusuri et al., 2012; Derry et al., 2010; Ma et al., 2010; Zheng et al., 2010; Harwood et al., 2008; Wedagama et al., 2006; Hauer et al., 2004; Al-Ghamdi, 2002; Taylor et al.,2000; Hunter et al., 1996). Although these factors are frequent in urban commercialised areas where dense road side and pedestrian activities take place, there have been comparatively fewer attempts to include them in appropriate models. For the purpose of this study, the road link of 100 m length was considered as unit of analysis.

2. Objective

The above factors albeit frequently considered in statistical analyses, there have been comparatively fewer attempts to include them in appropriate models. Therefore, it was felt necessary to examine the safety of pedestrians moving in urban road environments with high roadside activities through the development of a modelling approach which considers both the infrastructure, and traffic attributes and seeks to capture the effect of roadside activities on pedestrian safety.

3. Methodology

The research concerns the interaction between the pedestrians and the drivers of motorised vehicles in urban roads. It aims to determine the relationship between the characteristics of the road environment and the incidence of conflicts between pedestrians and the drivers of motorised vehicles which result in injury or death.

In order to investigate the significant contributing factors influencing pedestrian safety, the study will develop crash models for pedestrians moving in urban areas with high road and roadside activities. The first part involves selecting modelling approaches and the second part selecting study sites to perform the study process.

To investigate the significance of the contributory factors to pedestrian safety, a statistical approach was used to measure the variations of crash risk intensities across selected road sections. Generalised regression models (GLM) have been used because of their appropriateness to deal with count data and their ability to model simultaneous effects of multiple variables, including mixtures of continuous, count and categorical data (Myers et al., 2002; Lord and Mannering, 2010). In addition, such models enable the examination of the significance of their factors and the assessment of their contribution to crash frequency and severity (Chiou and Fu, 2013). There are a number of generalised regression models (GLM) to model crash frequency and the most common methods of which are Poisson, Negative Binomial and Zero-inflated Poisson regression (Carson and Mannering, 2001; Lee and Mannering, 2002; Wang et al., 2011; Qi et al., 2013).

The traffic accidents are likely to follow a Poisson distribution as they are rare events. (Washington et al., 2003). Therefore, pedestrian crash data was firstly modelled by assuming a Poisson distribution. The Poisson regression model assumes the mean and variance to be equal. However, over-dispersion could be encountered if the variance is greater than the mean (Washington et al., 2003; Lord et al., 2005). Thus, the use of the Poisson modelling method in such a case may result in biased estimates of variables' coefficients (Fu, 2015).

Alternatively, a Negative Binomial model may be considered as a suitable option to model crash frequency due its ability to deal with over-dispersion (Washington et al., 2003; Poch and Mannering, 1996).

However, another limitation may be encountered if crash data is under-dispersed, where the mean of crash events is greater than the variance. In modelling of crash events for a road section, some sections record zero accidents, but the likelihood of accidents occurring is still present. In the case of excess zero counts being present in data, the Zero-Inflated Generalized Poisson (ZIP) model could be an appropriate option (Shankar et al. 1997; Washington et al., 2003). All the three alternatives were considered and tested in the modelling process.

To make a selection between the Poisson and the NB models, the test of over-dispersion was used (Hardin and Hilbe, 2001), and a test proposed by Vuong (1989) was utilised to test the appropriateness of using the ZIP models over the other two models.

To examine how well the models fit the observations and perform with different data sets, two measures of evaluation were performed including the goodness of fit (GOF) assessment and field validation. The likelihood ratio, the standardised likelihood ratio and the Akaike information criteria (AIC) were used as GOF measures (Washington et al., 2003; Al-Matawah, 2008; Washington et al., 2010). For the model field validation, the actual crash frequencies observed in the validation sites were compared with the predicted crash frequencies estimated by the developed models.

4. Data description and collection

The second part involves selecting study sites and variables to perform the study process. Based on literature review, it was felt that a range of independent factors that may influence the potential of crash events and could be considered in the model developed in this work. These included:

- Traffic volume measured as annual average daily traffic (AADT),
- Traffic mean speed (V),
- Coefficient of speed variation (CV),
- Pedestrian crossing violations (PCV),
- Number of bus stoppings (BS),
- Pedestrian walking along (PAL),
- Pedestrian crossing volume (PC),
- Percentage of heavy vehicle traffic (HV),
- Intersecting traffic volume (INT),
- Number of intersecting side roads (SR),
- Roadside parking (P) and
- The number of Parking, un-parking, boarding and alight activities events (PBA).

Therefore, data associated with the above variables were collected as follows:

4.1. Road sites selection

The site selection process was mainly guided by the considered variables and determined by the presence of a wide range of commercial, educational and residential surrounding tracts, pedestrian and roadside activities, traffic flow conditions and the percentage of heavy vehicle, bus stops, on-street parking, and parking manoeuvres. A preliminary reconnaissance survey was conducted to identify the suitable road segments for potential inclusion in the study and to examine the potential interactions with traffic in the selected study environment.

Accordingly, twelve road segments from Birmingham' urban roads in the UK meeting the above criteria were chosen for model development, in addition to three other segments to provide data for testing the developed models. The selected road segments were within a 0.8–1.2 km length range. The selected sites were split into 100-metre sections making 117 sections in total. The suggested sample size was determined using the Highway Safety Manual (HSM) recommendations.

4.2. Data collection

Following the identification of the appropriate modelling factors and the road sections, the data collection process has been conducted based under the following headings:

- **Collision data statistics**

Vehicle-pedestrian crash data collection was undertaken to examine their relationship with the considered variables. The iRAP and HSM recommend a period of five years to be included (iRAP, 2016; AASHTO, 2010). In this study the decision was to include an eight-year period to include a sufficient frequency of traffic crashes and the crash data for the study sites are available and well maintained; furthermore, this would reduce the crash frequency variability from year to year (Hosseinpour et al., 2014). For this time span, every pedestrian crash recorded for the study sites was considered using the Department for Transport database (DFT, 2016a; DFT, 2016b). A pedestrian crash was defined as a crash involving at least a pedestrian and vehicle. As pedestrians are more fragile and the least physically protected road user (Downing et al., 2000; Eluru et al., 2008; Zhang et al., 2014), and causality injuries and fatalities are too scarce to be used for model development, the study utilized all pedestrian severity categories (i.e. fatal, serious, slight). Also, all pedestrian crash data including fatal, injury and slight crashes along the road segments were collected, including that at junctions. The pedestrian crash data collected for the study road sections counted 330 crash events in total.

- **Road characteristics**

With respect to the study objectives, the focus was more on traffic characteristics and pedestrian activities. However, roadway geometric design and attributes were also considered due to the difficulty of finding identical sites in terms of design to be selected for the study. For this purpose, an inventory survey was conducted along the selected road segments. Following the inventory and site visits, a range of road attributes were recorded for each 100-metre section.

- **Traffic volumes and Speed data collection**

The traffic volume data for the selected road segments was obtained from the Department for Transport (DfT, 2016a). Traffic speed data were obtained from the Birmingham City Council Transport Unit (Birmingham city council, 2016). The speed data for Birmingham city were provided for the years 2015–2016. The data was provided in the form of travel times for each link and then the traveling mean speed for any given link was calculated. Also, the standard deviation of travel times was provided and used to calculate the coefficient of speed variation. Elvik et al., (2004) highlighted that the strong correlation between speed mean and variance possibly make it difficult to separate the effects of speed variance and mean speed on crash events. To address this point, this study suggested using the coefficients of speed variation factor to measure the effect of speed variability with respect to mean speed. This variable was estimated by dividing the standard deviation over the average of the traffic speed at any given road link

- **Pedestrian and roadside activities' data collection**

Data collected about pedestrian and roadside activities, include; parking on roadsides; bus stopping activities; parking and un-parking to load and unload passengers; pedestrian walking along and crossing volumes; and pedestrian violations, which refers to pedestrians crossing out of allocated facilities or times.

The pedestrian volume and roadside activities for the study area were gathered by conducting a field inventory and observations along the selected sites. All counts were conducted during weekdays in October 2016 between 12 and 4p.m. for all road segments when the weather allowed. Before actual field data collections, a one-hour pilot survey was conducted in addition to site visits to check and select the data collection positions. Accordingly, the mobile observation technique was considered for roadside parking while the stationary counting technique was considered for other pedestrian and roadside activities. For the stationary counting, the length of the road sections (100 m) was found short enough to be surveyed by one surveyor. For bus stopping activities, the site visits showed that the data can be preferably collected using referencing photographs for each bus stop service timetables to count the number of bus stopping for each route

The data of the continuous variables and categorical variables from these roads are presented in Table 1 and Table 2 respectively.

4.3. Differences between road sections

To establish that the 100-meter sections represented different road conditions albeit being adjacent within each site, a preliminary reconnaissance survey was carried out. This showed a wide range of:

- Commercial, educational and residential land uses,
- Pedestrian and roadside activities,
- Traffic flow conditions and percentages of heavy vehicle, bus stops, on-street parking, and parking manoeuvres.

Thereafter, a further qualitative investigation was conducted to check that each of the 100-m sections within each individual site showed variations in the sections‘ attributes.

The investigation revealed that adjacent 100-meter sections within each road segment are characterised by differences as follows:

- Changes in the roadway configuration especially with regard to pedestrian crossing facilities and number of intersecting side roads;
- Different crash rates;
- Significant variations in speed variables (i.e. traffic mean speed and the speed variance); and
- The variability of active bus stops and the number of bus stopping activities between sections.

5. Result and discussion

5.1. Model building

To provide a more suitable model, the natural log transformation was applied to both traffic volume and intersecting traffic volume (El-Basyouny and Sayed, 2009; Wier et al., 2009; Miranda-Moreno et al., 2011).

In addition, the factors of intersecting traffic volume and number of side roads intersecting the analysed segment were included separately in the model estimation. This is due to the fact that intersecting volume and side roads are related, since in the event of no side road intersecting the considered road segment means no intersecting traffic flow at that segment. For that reason, the model was estimated using only the intersecting traffic. However, another model estimation was conducted, using the number of side roads instead of intersecting traffic volume as an alternative, in the case where no information was available to estimate the intersecting traffic volume.

The Poisson and NB model estimation results are shown in Table 3.

To select between the models, a test for the appropriateness of using Negative Binomial over the Poisson model was conducted firstly by checking the over-dispersion scale. This may be calculated by dividing the Pearson function value by the number of degrees of freedom. If the scale parameter exceeds 1 by a significant amount, it indicates over-dispersion in the data and in such a case, the NB method is appropriate for the model building. If the scale parameter ratio is larger than 2, then the use of the NB model may be required. If the scale parameter is closer to 1, it indicates that over-dispersion is not likely to be affecting the model fitting and the Poisson method provides an alternative method (Hardin and Hilbe, 2001). For this study, the calculated value of the scale parameter ratio was (1.011) which does not exceed the threshold of 2; and therefore the Poisson model was selected over the NB model.

Table 1 shows that the average of pedestrian-vehicle collision data mean per 100-meter segment for the considered segments is 2.75 over the study period and out of the 117 study segments, only 15 segments found with zero crash records. Despite the low number of road segments with zero crashes, the study considered to compare the Poisson fitted model with Zero-inflated Poisson (ZIP). Accordingly, the appropriateness of using the ZIP model over the other models was tested utilising a test proposed by Vuong (1989). The Vuong's value (V) is compared with the $z-$ Statistic where (V) is lower than $V_{critical}$ (1.96 for a 95% confidence level); the test does not support the selection process. Whereas large positive V greater than $V_{critical}$ supports the selection of the model 1 over model 2; whereas large negative values favour model 2.

For this study, the test compared Model 1-Poisson and Model 2 –ZIP and the results were as follows:

Vuong Test-Statistic (2.466) giving that Model 1 $>$ Model 2, with p-value 0.007; therefore the Poisson model (Model 1) is selected over

Table 1
Descriptive statistics of quantitative variables.

Variable	Description	Min.	Max.	Mean	Standard deviation
Crash data	Pedestrian-vehicle collision data 2009–2016 per 100-metre segments	0	11	2.75	2.283
AADT	Annual Average daily traffic	14,506	36,851	20,989	7330
Intersecting AADT	Intersecting Annual Average daily traffic	0	15,000	4098	3797
Heavy Vehicles	Annual Average daily heavy vehicle traffic	323	568	395	105
Heavy Vehicles Percentage (HV)	The percentage of Annual Average daily heavy vehicle traffic of the total annual average daily traffic	1.45	2.93	1.925	0.445
Operating Speed km/h	The statistical average of the real speed data	12	47	25.80	9.297
Coefficient of Speed Variation (CV)	The standard deviation over the average of the traffic speed	0.56	2.3	1.131	0.358422
Bus Stoppings	The number of bus stopping activities per time unit (hour)	0	54	14	16
Parking and Un-parking*	The number of parking/un-parking manoeuvres together with the boarding/alight passengers	81	450	239	125
Pedestrian Crossing	The number of pedestrians crossing the road	116	814	332	209
Pedestrian Alongside	The number of pedestrians moving along the road	186	1532	718	387
Pedestrian Violations	The number of pedestrians crossing the road segment freely either by not using the pedestrian crossing facilities or crossing out of the allocated time interval	64	257	135	66

the ZIP model (Model 2).

After conducting the tests, the Poisson model shown in Table 3 was selected over the NB and the ZIP models. Another Poisson model was developed, using as the independent variable the number of intersecting side roads (SR) instead of intersecting traffic volume. Table 4 shows the estimated model coefficients.

However, it should be noted that using the intersecting traffic volume variable for analysis could be more accurate because the intersecting side roads could have varied characteristics in terms of configuration, directions, width and number of lanes.

5.2. The significance of coefficients

For the best fitting of the model, only statistically significant independent variables were included (p-value < 0.05). Therefore, after an initial analysis any variable found insignificant was dropped before the model re-run. If more than one insignificant variable were present, the variable with the highest P-value were dropped firstly before conducting another re-run.

According to estimation results of the models (Tables 3 and 4), all significant independent variables are almost the same with relatively similar values; however, variables of the Poisson model with the intersecting traffic volume incorporate more significant effects.

The percentage of HV was not significant and excluded from the modelling process. This is may be because the percent of HV was relatively low and has small range between 1.49% and 2.93% for all included sections in the study. The number of pedestrian crossings was also found not to be significant. This is may be because another indicator included counting the number of pedestrian crossing violations. Also, this is possibly because of the similarity of these features along the selected sites as the primary intention was to measure the potential effect of traffic characteristics and pedestrian activities on pedestrian safety; and to control, as much as possible, the effect of roadway geometric design and attributes. The results for this factor could be different if a larger data set was available with a wider range of crossing facilities and other geometric features.

Traffic speed was found to be negatively associated with the crash frequency and showed only minor effect, possibly indicating less conflicts, more careful driving and better enforcement for roads with higher speed. This was also found by Al Kaaf and Abdel-Aty (2015) Furthermore, previous studies highlighted the significant effects of traffic speed on crash severity level rather than frequency (Wier et al., 2009).

The model fitting indicated that road segments with one-sided or

Table 2
Descriptive statistics of categorical variables.

Variable	Description	Observation	Frequency of observation
Speed Limit	Actual posted speed limit (20 mph and 30 mph)	20 mph	25
		30 mph	92
Bus Stops	Number of bus Stops (Counts; 0, 1 or 2 bus stops in the given 100-metre segment)	0 (no bus stop)	46
		1 bus stop	51
		2 bus stops	20
No. of Lanes	Number of lanes for each travel direction (1 for one-lane, 2 for two and more lanes)	1-lane	75
		2-lanes	42
Lane width	Narrow if lane width (< 2.75 m)	Narrow	115
	Medium if lane width (2.75 m-3.25 m)	Medium	2
Road Parking	No side parking, one-side parking or two-sides parking	No side parkin	55
		One-side parking	41
		Two-sides parking	21
No. of Side roads	Number of intersecting and minor access roads per 100-metre segment	No side road	29
	(Counts; 0, 1, 2 or side roads intersecting the given 100-metre segment)	1-side road	58
		2-side roads	28
		3-side roads	2
Median type	Indicator of the median arrangement to separate the two traffic directions flows (Centreline and Central hatching > 1 m)	Centreline	111
		Central hatching (> 1m)	6
Pedestrian crossing facility	Pedestrian crossing facilities for each road section (100-metre) (No facility, refuge only, signalised without refuge or signalised with refuge)	No facility	62
		Refuge only	9
		Signalised without refuge	34
		Signalised with refuge	12

Table 3
Statistical properties of models -Poisson and NB models.

Variables		Coefficients	Poisson Model		Negative Binomial Model	
			Estimated coefficient	p-value	Estimated coefficient	p-value
Constant		β_0	−9.848	0.005	−11.183	0.074
Traffic mean speed		β_1	−0.022	0.032	−0.027	0.162
Parking	No side parking	β_2	−0.611	0.004	−0.722	0.079
	One-side parking		−0.441	0.011	−0.442	0.213
	Two-side parking		0	.	.	.
Coefficient of speed		β_3	0.461	0.043	0.58	0.167
Parking-un-parking and boarding-alight (PBA)		β_4	−0.002	0.047	−0.002	0.222
Pedestrian crossing violations		β_5	0.008	< 0.001	0.008	0.028
No. of bus stoppings/Hr/Sec		β_6	0.015	< 0.001	0.016	0.049
Pedestrian along Vo		β_7	0.001	0.014	0.001	0.192
Number of pedestrian crossings		β_8	.	.	.	.
Percent of HV		β_9	.	.	.	.
Ln (AADT)		β_{10}	1.011	0.003	1.161	0.06
Ln (intersecting traffic volume)		β_{11}	0.042	0.03	0.049	0.183

Table 4
Statistical properties Poisson Model using number of intersecting roads.

Variables		Coefficients	Estimated coefficient	p-value
Constant		β0	−6.694	0.034
Traffic mean speed		β1	−0.019	0.054
Parking	No side parking	−0.533	0.009	.
	One-side parking	−0.367	0.029	.
	Two-side parking	.	.	.
Coefficient of speed		β3	0.532	0.017
Parking-un-parking and boarding-alight (PBA)		β4	.	.
Pedestrian crossing violations		β5	0.005	< 0.001
No. of bus stoppings/Hr/Sec		β6	0.013	0.001
Pedestrian along Vo		β7	0	0.094
Number of pedestrian crossings		β8	.	.
Percent of HV		β9	.	.
Ln (AADT)		β10	0.685	0.034
Number of side roads		β11	0.361	< 0.001

two-sided parking show a higher risk of pedestrian-vehicle crash compared with absence of road-side parking which compares well with Box (2002); Greibe (2003); Hauer et al. (2004); and Al-omari and Obaidat (2013).

The coefficient of speed variance affects crash frequency; suggesting that speed variation in a road segment increases accident frequency which is in agreement with Hunter et al. (1996), Taylor et al. (2000), Al-Ghamdi (2002), Koushki and Ali (2003), Elvik et al. (2009), Derry et al. (2010), Pulugurtha and Sambhara (2011), and Al-omari and Obaidat (2013).

In terms of roadside activities, the parking and un-parking activities at the roadside have negative effects on crash frequency; implying the crash frequency is slightly lower at segments with high parking and un-parking activities. This is possibly explained by the fact that more parking and un-parking manoeuvres make both pedestrians and drivers more aware and alert before committing to any movement and may lead to careful driving.

Pedestrian crossing violations and volume was found to have a statistically significant effect on accidents in this study. Previously, Brude and Larson (1993), Zegeer et al. (1985) and Zeeger et al. (2005) found that the increase of pedestrian crossing volume was associated with higher crash frequencies.

Bus stopping activities per hour per road segment were found to influence crash frequency, suggesting that a higher number of crashes occurs on segments accommodating more bus stoppings. Some previous studies investigated the effect of bus stops rather than the number of real bus stoppings activities and found a positive and significant relation, including Harwood et al. (2008); Miranda-Moreno et al. (2011); and Ukkusuri et al. (2012).

The AADT was found to be another significant variable for the developed models and as the traffic flow increased, crash numbers also increased. The reason for this may be that a higher traffic flow leads to more interactions between pedestrians and vehicles and possibly increases the exposure of pedestrians to risk. This is also supported by Garber and White (1996), Wang and Abdel-Aty, (2008), and Wier et al. (2009). For the intersecting traffic volume, Table 3 shows the higher the intersecting traffic volume is the higher the number of crash events and this is in agreement with Lyon and Persaud (2002), and Leden (2002).

For the model in Table 4, the number of intersecting side roads was found to be statistically significant and their number leads to an increased crash risk. This is likely because of the interacting traffic environment and intersections bring a higher risk for vulnerable road users with the interactions and possibly increase the exposure of the pedestrians to risk (see also Garber and White (1996) and Greibe (2003)).

To summarise, the results show that the variables found to be significant in the Poisson model of Table 3 (intersecting traffic volume) were: traffic mean speed (V), roadside parking (P), coefficient of speed variance (CV), the number of parking-un-parking and boarding-alight activities (PBA), number of pedestrian crossing violations (PCV), number of bus stoppings (BS), pedestrian walking along (PAL), traffic volume (AADT) and intersecting traffic volume (INT). As such, the variables found to be significant in the Poisson model in Table 4 (number of intersecting side roads (SR)) were essentially the same but the number of parking-un-parking and boarding-alight activities (PBA) were not considered and the number of intersecting side roads (SR) instead of the intersecting traffic volume (INT) were considered.

Consequently, the best fitting Poisson model (Model 1-Table 3) capturing the probability of a pedestrian-vehicle crash is as follows:

$$P(y_i) = 4.61 \times 10^{-5} \times AADT^{1.011} \times INT^{0.042} \times e^{\sum \beta 2 - 0.022V + 0.461CV - 0.002\mathrm{PBA} + 0.008PCV + 0.015BS + 0.001PAL} \tag{1}$$

where $\beta 2 = -0.611$ if no side parking in road segment; -0.441 if one side parking or zero for two side parking.

When using the number of intersecting side roads (SR) instead of the intersecting traffic volume (INT), the Poisson model (Model 3-Table 4) is given by:

$$P(y_i) = 12.39 \times 10^{-4} \times AADT^{0.685} \times e^{\sum \beta 2 - 0.019V + 0.532CV + 0.005PCV + 0.013BS + 0.361SR} \tag{2}$$

where $\beta 2 = -0.533$ if no side parking in road segment; -0.367 if one side parking or zero for two side parking.

5.3. Model testing and evaluation

Two measures of evaluation were considered, goodness of fit and field validation.

Table 5
Predicted and actual number of crash frequencies values for the validation road sections.

Site number	Observed crashes	Poisson Model (INT)		Poisson Model (SR)	
		Predicted crashes	Percentage correct %	Predicted crashes	Percentage correct %
1	4.77	3.93	82.39%	3.85	80.71%
2	4.17	3.47	83.21%	3.44	82.49%
3	5.80	5.58	96.21%	4.64	80.00%
Average of agreement			87.27%		81%

- **Goodness of fit (GOF) measures**

Tests were conducted to assess the goodness of fit (GOF) and examine how well the observed estimation data set fits the outputs from the developed models. The likelihood ratio, the standardised likelihood ratio and the Akaike information criteria (AIC) were used as GOF measures (Washington et al., 2003; Al-Matawah, 2008; Washington et al., 2010). To apply these measures, the model was fitted in a step-by-step procedure starting with the null model which contains only the constant value. At each following step, one variable was added and the GOF measures calculated. In this process, the smaller models with fewer variables were considered as nested in the full model which includes all variables.

For model 1 (Poisson Model -Table 3), the value of the likelihood ratio and the AIC were the smallest in the full model with all variables (117.7 and 425.7 respectively) comparing to the null model (226.4 and 514.35 respectively). Another indication for a better fit of the full model is the standardised likelihood ratio being closer to one. The results showed that the standardised likelihood ratio is 1.968 for the null model and decreases with every variable added to reach 1.121 for the full model indicating a better fit.

The same procedure was followed to perform the GOF measures for Model 3 (Table 4). The value of the likelihood ratio and the AIC were the smallest in the full model with all variables (102.9 and 406.8 respectively) comparing to the null model (226 and 514 respectively). For the standardised likelihood ratio, the results were 1.97 for the null model and decreases with every variable added to reach 0.961 for the full model indicating a better fit.

These results indicated that the full model (which included of all the significant variables) shows a better fit in comparison to the other nested models with fewer variables. These findings suggest that the full model is more accurate and represents better risk estimates.

- **Field validation**

To further test the developed models, a field validation was conducted using data collected from three additional road sections.

The actual crash frequencies observed in the validation sites were compared with the crash frequencies predicted by the developed models. There was a good agreement between the predicted and actual pedestrian-vehicle frequency crash data; which was 87.27% when using the intersecting traffic flow model and 81% for the intersecting side roads model. Table 5 shows the comparison results.

The other goodness of fit (GOF) measure was examined: The mean squared prediction error (MSPE) and the mean squared error (MSE) were used. The MSPE is defined as the sum of the squared differences between actual and predicted crash rates divided by the sample size while the MSE is defined as the sum of the square difference between predicted and actual crash rates divided by the sample size minus the number of model independent variables. The developed model performance can be estimated then by comparing the MSPE and MSE values. If the MSPE value is higher than the MSE value, this may indicate the potential of over-fitting to the estimation data or that some important variables were omitted (Oh et al., 2003)

For Model 1, the MSPE for crash rate per km per year was (0.412) for the verification data and significantly lower than that of the MSE (2.71) the model building. Also, for the Model 3, the MSPE for crash rate per km per year (0.91) for the verification data was slightly lower than the MSE (1.19) for the estimation data. Both developed models show MSPE values lower than MSE values, indicating acceptable goodness of fit with regard to the validation data set.

6. Conclusion and recommendations

This study developed a Poisson regression model to correlate pedestrian crash risk with parameters of road environments with high roadside activities. The study concluded that the number of bus stoppings per unit of time, parking, pedestrian crossing and violations' volume, the traffic speed variation, the number of intersecting side roads, in addition to through and intersecting traffic volume, were among the significant risk factors related to the pedestrian crash risk. The model provided realistic results and demonstrated that the Poisson regression may provide an appropriate option to analyse crash data as crashes are infrequent events and tend to be non-normally distributed and skewed. In addition to the roadway design elements, the study concluded that the planning and land-use types (i.e. commercial, educational, residential, industrial or mixed) can contribute to the risk of pedestrian crash occurrence. Some land-use factors such as population and density, land-use mixes and activities' location and intensity can influence risks for pedestrians. Additionally, the extent to which pedestrians' facilities are considered and provided by planning and land-use has a significant effect on the crash risk for pedestrians.

It is recommended that roadway design and land-use practices should aim not only to accommodate the pedestrian's needs to access services such as retail shops, hospitals, schools, social meeting places and public transport, but also to improve their safety. Therefore, a specific consideration to pedestrian safety is needed in land-use planning and road design.

The developed model could be a particularly useful tool for traffic planners and others with the ability to rank roadways with regard to pedestrians' crash risk. Also, it could be used in the process of evaluating existing roads and prioritizing the roads which are in need of safety interventions. Furthermore, this approach may provide a better understanding of the causes and nature of risk factors related to pedestrian crashes while moving in road environments with high roadside activities in urban areas.

The data sets for the models' fitting were collected from Birmingham' urban roads in the UK. However, the ultimate objective was to test the transferability of the model to developing countries. There are differences between the developed and developing countries and the latter have more severe problems with pedestrian road safety (WHO, 2018). Thus, the roads were selected in such a manner so that their conditions may be comparable and the models can therefore be transferred.

It is also felt that the investigation of the proposed risk factors and examination of their effect in developing countries might give a better insight into pedestrian road safety, especially in road links accommodating high roadside activities. Therefore, it would be desirable to further test and possibly calibrate the findings of this study in developing countries. This could be performed by selecting representative roads accommodating high pedestrian and roadside activities which are to some extent comparable with UK roads, in terms of road configuration, to test the model development and the effect of the variables.

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