How does the built environment influence pedestrian activity and pedestrian collisions at intersections?

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ABSTRACT

This paper studies the influence of built environment in the vicinity of an intersection on pedestrian activity and collision frequency. For this purpose, a two-equation model to represent pedestrian activity and collision occurrence is formulated and validated using data from 509 signalized intersections in the City of Montreal. Among other results, it was found that the built environment (BE) in the proximity of an intersection has a powerful association with pedestrian activity but a small direct effect on collision frequency. In accordance with previous studies, pedestrian activity and traffic volume are the main determinants of pedestrian collision frequency at signalized intersections. In addition, our results show that a reduction of 30% in the traffic volume in each of the studied intersections would greatly reduce the average risk of pedestrian collision (-50%) and the total number of injured pedestrians (-35%) in the area under analysis. The presence of arterials and urban highways has a double negative effect on pedestrian safety (major arterials are negatively related with pedestrian activity and positively associated with traffic volume).

1. PROBLEM STATEMENT AND OBJECTIVES

Every year, a large number of pedestrians are killed or seriously injured in crashes involving motor vehicles. In Canada, for instance, between the year 2002 and 2006, 1,829 pedestrians were killed comprising approximately 13% of total road user fatalities. In addition, around 23,920 were seriously injured. To address this problem, local government and urban transportation agencies, not only in Canada but also in other countries around the world, have identified the safety and mobility of pedestrians as high priorities. To this end, investments are constantly allocated through different safety improvement programs. However, the development of cost-effective safety improvement programs requires modeling tools to guide decision makers.

In the past decade, considerable research effort has been directed towards addressing road safety issues of motorized modes with relatively few dealing with NMT. However:

- There is a lack of empirical studies that have simultaneously investigated the complex relationships between built environment (BE), pedestrian activity and accident occurrence in urban intersections. Despite that few studies have investigated the impact of BE, a limitation of these studies is the direct association of BE variables with pedestrian collision frequency without specifying whether BE patterns affect collision risk by affecting directly pedestrian activity, the number of pedestrian accidents or both.
- Most previous works on pedestrian safety concern US urban areas. Transferability of US evidence to the Canada context may not be adequate given socio-cultural, urban form and mobility pattern differences.
- Despite the fact that pedestrian volumes are an essential element in road safety analysis; few transportation agencies collect pedestrian data from a large number of sites on a regular basis. Among other reasons, this is due to the fact that site-specific pedestrian count studies are expensive and time-consuming. To address this lack of data, a simple and efficient way is to develop prediction built-environment models based on a sample of intersections in an urban area (Pulugurtha and Repake 2008; Schneider, Arnold et al. 2009). In spite of this, very little empirical evidence exists in the literature following this approach. One of the few studies is the recent work done by Pulugurtha and Repaka (2008)
- Most empirical studies involve a relatively small number of intersections in their analysis.

Objectives

Accordingly the aim of this paper is two-fold:

1) To propose a framework to integrate the impact of built environment on both pedestrian activity and safety at signalized intersections.

2) To develop and evaluate a two-equation model for predicting pedestrian activity and collision frequency at signalized intersections in Montreal.

2. CONCEPTUAL FRAMEWORK

For a given intersection, a conceptual framework showing the potential relationships between built environment, pedestrian activity and safety status is presented in Figure 1. This conceptual framework is inspired and supported by previous research (Feng 2001; Harwood, Torbic et al. 2008; Clifton, Burnier et al. 2009; Elvik 2009; Ewing and Dumbaugh 2009). The elements of this framework and their relationships are discussed as follows:

- Built environment and geometry design
- Risk exposure: Vehicle traffic counts and pedestrian volumes
- Safety outcomes: collusion frequency and consequences

Model

For a particular intersection, the two-equation model is then defined as:

$$(i) \quad P = f(\alpha; BE, \varepsilon_P)$$

$$(ii) \quad A = f(\beta; V, P, G, \varepsilon_A) \qquad (1)$$

Where,

- P - Pedestrian activity (in an hourly-base period) at a given intersection
- A - Pedestrian accident frequency (in yearly-base period)
- BE - Built environment attributes in the proximity of an intersection including: L - land use types, D - demographic characteristics, T - transit supply, R - road network infrastructures),
- G - Geometry design characteristics
- V - Motor vehicle volumes (daily average)
- α, β - vectors of regression parameters
- $\varepsilon_P, \varepsilon_A$ – Unobserved heterogeneities

3. DATA FOR EMPIRICAL ANALYSIS

- Accident data, pedestrian and traffic counts

- Data for this analysis is provided by Direction des transports du Montreal and Direction de Santé Publique du Montreal:
- All injured pedestrians for whom an ambulance was sent on the island of Montreal over a five year period (from 1999 to 2003) were included in the study.
- 509 signalized intersections were available with pedestrian and traffic volumes for the year 2003. Pedestrian volume data were collected by the City of Montreal from three different periods: peak morning, noon period, and peak afternoon. Traffic volumes were also available for the same intersections represented by the average annual daily traffic (AADT).

- Built environment (BE): land use, demographics, transit and road network

BE variables in the vicinity of each intersection are generated using GIS data obtained from various sources. To take into account the impact of buffer dimension, different buffer sizes were tested including 50, 150, 400 and 600 meters. The list of BE variables is provided in Table 1:

Table 1. Built environment variables

Category	BE Variables
Land Use	Commercial, residential, industrial (m^2), number of jobs, number of schools, etc.
Demographic	Population, workers, children, seniors,
Transit system characteristics	Presence of metro station, number of bus Stops, km of bus route, etc.
Road network Characteristics	Number of streetsegments, intersections, proportion of major roads, road Length (km), km of highway, arterial road and local road, etc

4. MODELING RESULTS

Based on the conceptual model specification defined in Eq. 1, a regression modeling analysis is then carried out to investigate the relationship between BE, pedestrian activity and accident occurrence at the signalized intersections. To address the multicolinearity issue, an exploratory analysis is first carefully done to identify serious problems of correlation between BE factors. Pedestrian activity and accident frequency models are then developed to account for heterogeneity. The results are provided in Tables 2 and 3:

Table 2. Log-liner model for pedestrian activity

Variables	Buffer	Parameter estimates: Coefficient		Sig.	Elasticities
Intercept		4.115	(0.022)	***	
Population	400m	0.071	(0.022)	**	0.30
Commercial	50m	0.192	(0.026)	***	0.20
No. jobs	400m	0.173	(0.027)	***	0.28
No. schools	400m	0.146	(0.071)	***	0.20
Metro station	400m	0.329	(0.014)	***	0.28
No. bus stops	150m	0.108	(0.261)	***	0.37
% of major arterials	400m	-0.858	(0.323)	**	-0.19
Ave. street length	400m	1.036	(0.076)	**	0.50
Intersection indicator[1]		0.348	(0.184)	***	0.29
Goodness-of-fit		$R^2 = 0.55$			

[1] 4-legged intersection = 1 and 3-legged intersection = 0
**: Statistically significant at 5%,
***: Statistically significant at 1%

- Pedestrian activity model

- Table 2 shows the parameter estimates for the log-linear model. Eight variables have statistically significant effects on pedestrian activity. These variables have a positive effect, except the proportion of major arterials being the only factor negatively associated to pedestrian activity.

- Table 2 also shows the elasticities associated to each explanatory variable calculated at the point of means. From these elasticities, one can see that a 100 percent increase in the population is associated with a 30 percent increase in the pedestrian activity. An augmentation of 100 percent of commercial area also represents a 20 percent in pedestrian volumes at intersections. A metro station increases the pedestrian activity by 30 percent. Interestingly, an increase of 100 percent in the proportion of major arterials is associated with a decrease of 20 percent in pedestrian activity.

Pedestrian collision frequency model

- For the modeling of pedestrian collision frequency, two negative binomial modeling settings were attempted including the standard negative binomial (NB1) model with fixed dispersion parameter and generalized negative binomial (NB2) allowing observed heterogeneities in the dispersion parameter.
- In Table 3, one can see that both pedestrian and traffic volumes are positively and statistically significant as expected. The size of these parameters is in the range of those reported in the literature.
- From the model with BE variables, one can observed that some BE variables are statistically significant including commercial area, number of bus stops and schools - all other variables are non-significant at the 5% level. In addition, parameter estimates of pedestrian volume and AADT are importantly reduced with the incorporation of these variables. In spite of, the model fit is only slightly improved. This suggests that most of the impact of BE occurs through their association with pedestrian activity and/or traffic volume.
- Traffic is by far the major determinant of pedestrian accident frequency (with a regression coefficient of 1.15 for NB1 model, for instance). In terms of elasticities, one can observe that a reduction of 100 percent in the current traffic condition will represent a decrease of 90-120 percent in the number of pedestrian collisions.
- The importance of pedestrian activity is also confirmed with a regression parameter of 0.45 in the NB1 model. Another interesting finding is the negative sign of the number of schools. This can be related to speed limits and/or some calming measures that may be applied around schools.
- Finally, to test the potential correlation between the error terms in Eq. 1 $(\mathrm{cov}(\varepsilon_P, \varepsilon_A) \neq 0)$, a bivariate Poisson regression model was also attempted (Karlis and Ntzoufras 2005). Since no evidences of error correlation were identified, the results are not reported in this paper.

Table 3. Pedestrian collision frequency model

Variables	Parameter estimates: Short model (without BE) NB1				Extended model (with BE) NB2				GNB2	
Mean										
Intercept	-14.790	***	-14.590	***	-11.636	***	-11.661	***		
ln AADT	1.152	***	1.122	***	0.906	***	0.900	***		
ln pedestrian volume	0.447	***	0.461	***	0.263	***	0.280	***		
Intersection indicator	0.404	***	0.412	***	0.431	***	0.435	***		
Commercial (50m buffer)	-	-	-	-	0.145	***	0.143	***		
No. bus stops (50m buffer)	-	-	-	-	0.160	***	0.151	***		
No. schools (150m buffer)	-	-	-	-	-0.234	***	-0.225	***		
Alpha										
Constant	0.414	***	-1.027	**	0.323	**	-0.923	*		
ln AADT	-		9.757	**			8.437	-		
AIC	*1406.9*		*1413.1*		*1381.8*		*1381.4*			

[1] 4-legged intersection = 1 and 3-legged intersection = 0
**: Statistically significant at 5%,
***: Statistically significant at 1%,

SOME POLICY IMPLICATIONS

Different practical implications can be supported from our analysis:

- A strong link between BE and pedestrian activity was confirmed at the intersection level. However, the direct impact of the surrounding built environment (ex. land use patterns) on collision frequency seems to be marginal, traffic volume and pedestrian activity being the main determinants of collision occurrence.
- Urban policies aiming to increase population density, land use mix, transit supply and road network connectivity may have a double benefit: a direct increase in pedestrian activity (increase in walkability) and indirect decrease in the risk of pedestrian collision. However, with no supplementary strategies, the total number of injured pedestrians would increase with pedestrian activity.
- The more motor vehicles at intersections, the higher the individual risk is. In addition to their beneficial effect on noise and emissions, strategies to reduce traffic volume would lower both the individual risk of pedestrian collision and the total number of injured pedestrians - a reduction of 30% in the traffic volume would greatly reduce the average pedestrian risk (-50%) and the total number of injured pedestrians at the study intersections (-35%). It is noteworthy that major roads seem to have a double negative effect on pedestrians, being positively associated with traffic volume and negatively related with pedestrian activity. Such results support the idea of retrofitting urban major roads into complete streets (Laplante and McCann 2008).

6. CONCLUSIONS AND FUTURE WORK

This work aims to understand how built environment (BE) affects both pedestrian activity and collision frequency. In doing so, two major contributions have been made. First, a model framework has been developed to jointly analyze pedestrian activity and safety at the intersection level. This modelling framework is useful for the identification of effective pedestrian safety actions, the prediction of pedestrian counts when lacking data, and the appropriate design of new developments encouraging walkability.

In accordance with previous studies, our results show that some BE characteristics have a powerful association with pedestrian activity including population, commercial land use, number of jobs, number of schools, presence of metro station, number of bus stops, percentage of major arterials and average street length. The reported influence of BE on pedestrian collisions at intersection, however, seems largely mediated through pedestrian activity and traffic volume. Our study also provides some additional evidence that traffic volume is the primary cause of collision frequency at the intersection level. A reduction in traffic volume would be associated with great improvements in pedestrian safety. Finally, an original validation procedure measured the prediction capability of our models. Our future efforts will concentrate on examining the validity of these findings across a wider spectrum of intersections and longer periods of pedestrian data collection. The disaggregated analysis will also make it possible to include intersection geometry characteristics (ex. road width). A simultaneous modeling approach will be further explored to evaluate the potential effect of error correlation and improve prediction capacity.

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