RISK PERCEPTION OF PEDESTRIANS AT MIDBLOCK CROSSINGS IN BRAZIL

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ABSTRACT

Pedestrians face a greater risk of being injured on a traffic crash than vehicle occupants. In Brazil, they represent about 24% of all traffic fatalities. Risk perception techniques can be used in defining proactive countermeasures that take into account pedestrians' needs and behaviors. Our study evaluates the pedestrian safety at midblock crossings using modeling techniques to represent the relationship between risk factors and risk perception. It includes film simulation of pedestrian midblock crossings and data collection of road and crossing characteristics in the city of Porto Alegre, the southernmost state capital of Brazil. In controlled simulation conditions, pedestrians and experts rated twenty one midblock crossings after observing pictures and watching film clips. The regression model indicates that the perceived risk is influenced by a combination of interactive risk factors, such as the presence of busways and bus stops, road width, parking permission, presence of a marked crosswalk and traffic signal, and volume of pedestrians. The results of this study are very useful to improve the safety of pedestrians in Porto Alegre and are likely to be transferable to other cities in Brazil where traffic and transit operate under similar conditions.

Keywords: Pedestrians; Midblock crossings; Risk evaluation; Risk perception.

INTRODUCTION

Risk perception is a subjective assessment of the probability of occurring an unwanted event and the importance level of its consequences (Sjöberg et al., 2004). The perceived risk is related to how a person understands and experiences a specific event (Oltedal et al., 2004). Generally, individuals adapt their behavior and make decisions based on their perception of risk (Solvic, 1992; Wilde, 2001; Schneider et al., 2004; Sjöberg et al., 2004). When noticing that a specific situation would lead to adverse consequences, a rational individual would be motivated to behave in a such way to avoid the unwanted outcome (Lam, 2005). The study of risk perception can help to understand the legitimate concerns and dimensions that people associate with different risk sources and the potential trade-offs that people would make in setting life priorities (Renn, 1998; 2001).

Risk perception research began in the 1960's, concomitantly with the nuclear debate (Sjöberg, 2000). Since then, its principles and techniques have been applied to many study fields. In the transportation field, more specifically on road safety, risk perception techniques have been frequently used in studies that aim to understand how road users plan their behavior based on the perceived risk or to identify factors related to crash occurrence.

Risk perception studies can provide insight into the needs and behaviors of road users, and, consequently, contribute to the development of efficient countermeasures to reduce the number and/or severity of road crashes (Oltedal et al., 2004). For example, when a study indicates that the road users misperceive a specific road risk, it is possible to develop programs and policies to alert them about their personal vulnerability to the danger so that precautions can be taken (Will and Geller, 2004).

The critiques of using risk perception techniques on road safety management are related to the fact that road users are not able to assess the real risk, since people can underestimate or overestimate the dangers (Sjöberg et al., 2004). However, the outcomes of some studies debate these critiques. The results of a Norwegian research about how public accurately perceives differences in transportation risks indicated a positive correlation between statistically estimated risk and perceived risk (Elvik and Bjørnskau, 2005). In Israel, Rafaely et al. (2006) examined the differences in the perception of road safety for older and younger adults. The results showed that younger adults (mean age 24.7 years) and older adults (mean age 70 years) adequately assess the risk for their own age group, but they overestimated or underestimated the risk for other group.

The main advantage of risk perception techniques is the possibility of assessing road safety even when resources are scarce and reliable data is not available. This is one of the reasons that risk perception techniques have been widely applied for evaluating pedestrian risk (Diogenes, 2008). Furthermore, it is not always possible to identify the risk location or the risk factors related to pedestrian crashes using statistics data, since pedestrian crashes are rare and stochastic events. Risk perception studies can also provide a better understanding of the pedestrian behavior in different road environments (Hine, 1996). They can help in finding differences in the perceptions of people with specific traits so that appropriate education, enforcement, and engineering treatments can be appropriately targeted (Schneider et al., 2001; 2004).

Studies shows that risk perception techniques can point out dangerous crossings, even when the crash history has not been recorded. These techniques can also point out a crossing as low risk, even when pedestrian crashes were observed on that crossing. Risk perception can guide the development of proactive countermeasures that take into account users' needs and behaviors and are capable of reducing the possibility of a pedestrian crash (Schneider et al., 2001; 2004).

Risk perception studies are important in the process of mitigating the danger that pedestrians face every day. Pedestrians are the most vulnerable road users and are at a greater risk of being injured on a traffic crash than vehicle occupants. In developing countries, they represent the group of road users with the largest number of fatalities (Mohan et al., 2006). In Brazil, pedestrians accounted for 24% of all traffic fatalities reported in 2005. In Brazilian urban areas, where 35% of all trips are made on foot, (ANTP, 2004) pedestrians represented 40% of the reported traffic fatalities (DENATRAN, 2005).

Our study evaluates the pedestrian safety at midblock crossings using modeling techniques to represent the relationship between risk factors and risk perception of pedestrians at midblock crossings. It includes film simulation of pedestrian midblock crossings and data collection of road and crossing characteristics in the city of Porto Alegre, the southernmost state capital of Brazil. The evaluation comprises the identification of pedestrian high-crash locations, the selection of factors associated with pedestrian crash, and the development and analysis of a regression model that associates risk perception with selected risk factors. It also provides results that are valuable for improving the pedestrian safety management in Porto Alegre and that are likely to be transferable to other cities in Brazil where traffic and transit operate under similar conditions.

LITERATURE REVIEW

Researchers apply different methods to evaluate the risk of pedestrian crash, using either crash or non-crash based measures, including historical crash data, change in user behavior, conflict and avoidance maneuvers and ratings based on expert or/and user opinion (Carter et al., 2006). One of the most used methods in pedestrian risk analysis consists in identifying pedestrian crash patterns from historical data. Studies generally point out male pedestrians as those most frequently involved in pedestrian crashes and elderly and children as the most vulnerable pedestrians (Holubowycz, 1994; Campbell et al., 2004; Gårder, 2004; Martinez and Porter, 2004; Al-Madani and Al-Janahi, 2006; Diogenes, 2008).

Schneider et al. (2001) conducted a survey for gathering data on pedestrian and driver perception. In the survey, participants used a map of the campus area of the University of North Carolina, USA, for marking three locations that they believed had the highest risk of pedestrian crashes. Survey data was then compared to data obtained from reported pedestrian crashes. Results showed that road users only perceived as risky two of the four sites with the higher number of reported pedestrian crashes.

However, Schneider et al. (2001) pointed out some limitations of the analytic method used in the surveys: (i) survey maps may be difficult for participants to interpret, and lack of familiarity with maps of a local area can be a source of error; (ii) reported crashes may have occurred in a different context than the one evaluated by survey participants; (iii) the possibility of errors in reported and perceived data.

A survey was conducted among residents in six neighborhoods of a low income area in Johannesburg, South Africa, who related their perception of reasons and solutions for pedestrian safety problems. The study revealed that the risk perception of each community is associated to their housing and environmental conditions. Those participants who live close to a freeway, where occurs in average 10 pedestrian fatalities per year, perceived the lack of pedestrian crossing facilities as the main reason for pedestrian crashes. Other communities, participants indicated driver intoxication and driver recklessness as the leading cause of traffic injuries (Butcharta et al., 2000).

Landis et al. (2001) investigated pedestrian risk perception during a walking course in the Pensacola, Florida. Participants attributed a grade for roadway segments, reflecting their perception of safety and comfort. These grades were used for developing a level of service model. Results indicated that the presence of sidewalk and larger lateral separation from vehicles increases the pedestrian's comfort or sense of safety. When there is a barrier between pedestrians and motor vehicle traffic, such as on-street parking, line of trees, or roadside swale, pedestrians' sense of protection increases. On the other hand, higher vehicle volumes and higher traffic speeds are associated to a higher pedestrian discomfort.

Baltes and Chu (2002) also used risk perception techniques for modeling the level of service at midblock crossings. Results reveal 15 factors as significantly correlated with pedestrians' perceived quality of service. The study suggests that difficulty in crossing increases with vehicle volumes, vehicle speeds, crossing widths, and length of traffic signal cycles, and decreases with the presence of marked crosswalk, traffic signal, or wide restricted medians.

Petritsch et al. (2005) built a service level model for pedestrians at signalized intersections. The study shows that pedestrian risk perception is influenced by right-turn-on-red volumes for the street being crossed, permissive left turns from the street parallel to the crosswalk, vehicle volumes, speed of the vehicles, number of traffic lanes, pedestrian's delay, and presence of right-turn channelization islands.

Risk perception data was also used in the development of an index for assessing pedestrian safety at intersections in the United States. Pedestrian professionals watched the sites on a video clip and gave ratings to the crosswalks according to their perceived level of pedestrian safety. Then, a preliminary model was developed on the basis of crosswalk ratings. The model showed that an intersection is perceived as less safe when there are more through lanes on the main street, when the traffic speed is high, and when the intersection is on a commercial area. When there is a traffic signal or a stop sign the perception of safety increases. The final model incorporated data of conflicts and evasive maneuvers observed at the intersections and indicated that pedestrian safety decreases as the traffic flow increases (Carter et al., 2006; Zegeer et al., 2006).

In general, research on risk perception indicates that individuals deal with risks in a way that is not always consistent with the way scientists assess risk. However, it does not mean that the perceived risk is necessarily less rational than the risk estimated by scientists (Hampel, 2006). In addition, risk perception and pedestrian behavior are influenced by cultural aspects and environmental conditions (Renn, 1998; Hampel, 2006). Thus the results of previous risk perception studies cannot be used to assess pedestrian safety in most developing countries where weather, traffic flow and walking culture vary widely (Risser and Methorst, 2007). Moreover, the literature review indicates that risk perception has not yet been applied to evaluate mid-block crossings of pedestrians.

METHODOLOGY

The model to assess pedestrian safety at midblock crossings in this study was developed according to the following basic steps:

- Selection of a group of midblock crossings (study sites)
- Selection of risk factors and data collection procedures
- Collection of data on midblock crossing characteristics
- Collection of data on pedestrian risk perception
- Development of a regression model to represent the relationship between risk factors and perceived risk

Study Area

The city of Porto Alegre, Brazil has a population of 1,420,667 inhabitants and an area of 149 km^2 (IBGE, 2007). Car ownership is relatively high for Brazil, around 1 motor vehicle per 2.5 inhabitants (DETRAN-RS, 2006). Porto Alegre is one of the pioneer cities in Brazil for high-capacity bus transit and today there are approximately 50 km of busways implemented in the city (Lindau et al., 2008).

The Public Company for Transportation and Circulation (EPTC), which regulates and enforces transit and traffic in the city of Porto Alegre, maintains a detailed geo-referenced traffic crash database. According to this database, there were 12,799 pedestrian crashes in Porto Alegre during a nine-year period (1998-2006), which represents an average of 4 pedestrian crashes per day.

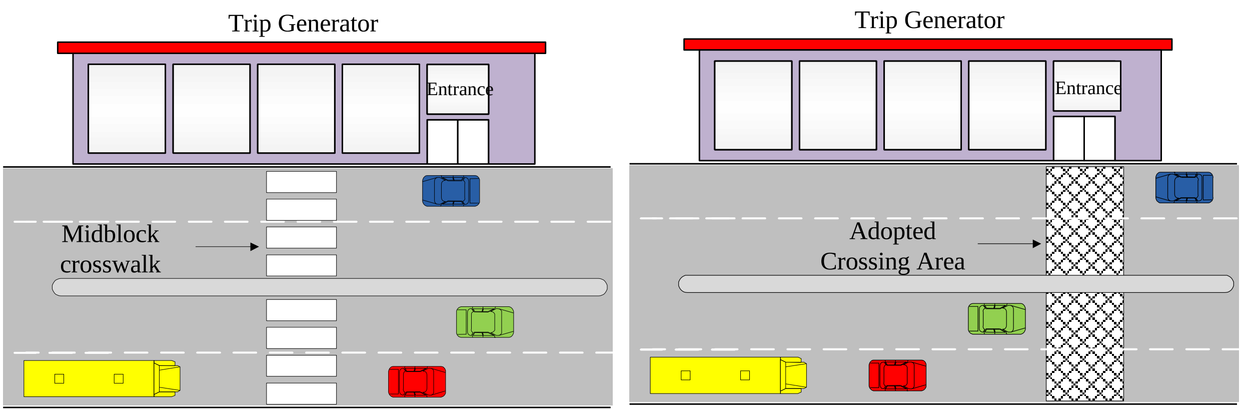
Crash database details include the address and date of the occurrence, the time of the day, weather conditions, pedestrian age and gender, vehicle characteristics, and severity level in most pedestrian crashes. The crash location is classified as occurring on intersections or road sections. According to this classification, 88% of the pedestrian crashes in Porto Alegre occur at road sections. In this study, we focus on crashes associated to midblock crossings.

Selection of Midblock Crossings

The study sites were selected according to the number of reported pedestrian crashes in the area. One of the reasons for establishing this selection criterion was the need for including, in the sample, locations where pedestrians tend to cross the road, independent of the existence of a crosswalk or a pedestrian overpass or underpass. By doing so it is possible to obtain information on factors that influence pedestrian risk perception at uncontrolled crossings. In addition, Brazilian traffic law establishes that pedestrians are legally allowed to cross a road on a pedestrian overpass or underpass, on a intersection with or without a marked crosswalk, on a marked crosswalk or at any point of a road where there is no crosswalk or pedestrian overpass or underpass on a distance smaller than 50 meters (Brazil, 2008).

The preliminary selection of midblock crossings consisted in identifying addresses in the database presenting the highest number of pedestrian crashes. These addresses were used in determining 25 selected locations that respond for 3% of all pedestrian crashes reported in Porto Alegre.

After the preliminary selection, field researchers visited the 25 selected midblock crossings and determined the limitations for collecting data on each spot. During the visit it was possible to notice that 8 locations had a length of more than 50 m, delimiting a road section and not a crossing. For these cases, site observations enabled the definition of a representative crossing area for the crashes' location (Figure 1): (i) when there was a midblock marked crosswalk, it was adopted as the crossing area; (ii) when there was no crosswalk, the adopted crossing area was delimited by the entrance of the building. Six sites were within the intersection influence area, located at street corners, and 11 corresponded to a midblock crossing, but not necessarily to a regular crosswalk.



(a) There is a midblock crosswalk: the crosswalk is the adopted crossing area

(b) There is not a midblock crosswalk: the area in front of the building entrance is the adopted crossing area

Figure 1 – Adopted crossing area in front of trip generator buildings.

Four sites were excluded from the analysis: (i) three addresses identify buildings with more than 350 m of length and corresponding road sections have more than one marked crosswalk; (ii) one site is located in a remote area where the researchers did not feel secure to collect data.

Once crashes registered for the opposite buildings were aggregated to the selected crosses, pedestrian crash rates of the 21 selected midblock crossings ended up ranging from 0.89 to 2.39 pedestrian crashes per year. On average, there were 1.39 pedestrian crashes per crossing per year. Furthermore, at all selected crossings, at least one pedestrian crash happened over the last three years.

Selection of Risk Factors and Data Collection Procedures

Many interactive factors can influence pedestrian safety and thus it is hard to develop a model taking all of them into account. In this context, just factors considered relevant for the study were selected. The selection of risk factors comprised an initial phase with the selection of factors based on the literature review and on the characteristics of selected crossings (Diogenes, 2008). The final classification of risk factors in four categories (Table I) took into the account the possibility of collecting data given that there was no data readily available.

Table I – Selected risk factors

Category	Risk Factors
Public transportation characteristics	Presence of busway transit system
	Presence of a bus stop (close to the crossing area, but not in at the busway)
	Distance from the crossing center to the closest bus stop (including bus stops in the busway system)
Road Features	Road width
	Number of traffic lanes
	Maximum number of crossing stages (e.g., if there is a median island, the maximum number of stages are 2; if there is a median busway with two refuge islands, the crossing will take 3 stages)
	Number of traffic directions (one or two ways)
	Presence of refuge island
	Parking permission
Road Pedestrian Facilities	Presence of a marked crosswalk
	Presence of a traffic signal
	Distance to the closest marked crosswalk or intersection
	Average sidewalk width
Pedestrian and Vehicle Flow Characteristics	Percentage of male pedestrians
	Percentage of elderly pedestrians
	Percentage of public transportation vehicles on traffic flow
	Pedestrian waiting time
	Pedestrian volume
	Vehicle volume

In order to simplify the data collection on the site, filmed images, visually analyzed by the researches, provided the characteristics of the pedestrian and the vehicle flows. Data related to other characteristics was collected *in loco*.

The crossings were filmed using a digital camera for a minimum period of one hour. To avoid any over- or under-estimation of pedestrian and vehicle volumes, the films were shot on weekdays and during off-peak hours. Ideally one should extrapolate the manual counts to estimate annual pedestrian and vehicle volumes. However, yearly volume patterns were not available.

Simulation was the methodology selected for gathering data on pedestrian risk perception. In this type of experiment, participants observe a representation of the midblock crossings and rate them on the basis of the video presentation. The main advantage of surveys based on controlled simulation conditions relies in exposing survey participant to identical conditions. Furthermore, each participant can review a greater number of crossings in a shorter time and at lower costs than the staged real-time field event which requires that each participant observe the crossings in real time (Landis et al., 2005).

A high quality digital film of each midblock crossing was recorded for being used in the controlled simulation conditions. Panoramic pictures of the crossing were also used in the simulation, in order to provide more information to the survey participants.

DATA COLLECTION

This section details the process and results of the collection of data on the physical characteristics of the pedestrian crossings and on risk perception.

Physical Characteristics

There is a busway road environment in 10 of the selected midblock crossings and 12 of the other crossings are close to a bus stop that is not part of the busway system. Only one crossing was neither close to a bus stop nor to a busway. The distance between the middle of the crossing and the closest bus stop ranged from 0 to 68.9 m (226.05 ft). Other data collected in the field are summarized below:

- Road width: ranged from 9.6 to 28.8 m (31.5 to 94.5 ft). Only 4 crossings had a width larger than 25 m (82 ft).
- Number of traffic lanes: ranged from 3 to 8 lanes.
- Maximum number of crossing stages: 5 crossings did not present a refuge island and had to be crossed in 1 stage, 14 in 2 stages, 1 in 3 stages, and 1 in 4 stages. Figure 2 shows an example of a crossing with 4 stages.
- Number of traffic directions: 16 crossings were on two-way roads.
- Presence of refuge islands: refuge islands occurred in 15 crossings.

- Parking permission: parking was allowed in 3 sites.
- Presence of a marked crosswalk: marked crosswalk existed in 9 crossings.
- Presence of a traffic signal: occurred only on 9 crossings with marked crosswalks.
- Distance to the closest marked crosswalk or intersection: ranged from 0 to 78.9 m (258.9 ft) and 8 crossings were located more than 40 m away (131 ft) of a marked crosswalk or intersection.
- Average sidewalk width: ranged from 2.4 to 6.5 m (7.9 to 21.3 ft).

The films were analyzed by the same person to assure data reliability. On average, one hour of film required 1.5 hours of analysis to fully characterize each direction of vehicle traffic. The percentage of public transit vehicles on the overall flow of motorized vehicles varied between 2.6 and 80.2% and total vehicle flow ranged from 242 to 4721 vehicles per hour.

The characterization of the pedestrian flow required, on average, 5 hours per crossing stage of film being analyzed. The pedestrian movements are erratic and demand more attention. Furthermore, not every pedestrian completes the crossing; some used the median as a sidewalk after crossing one stage of the road.

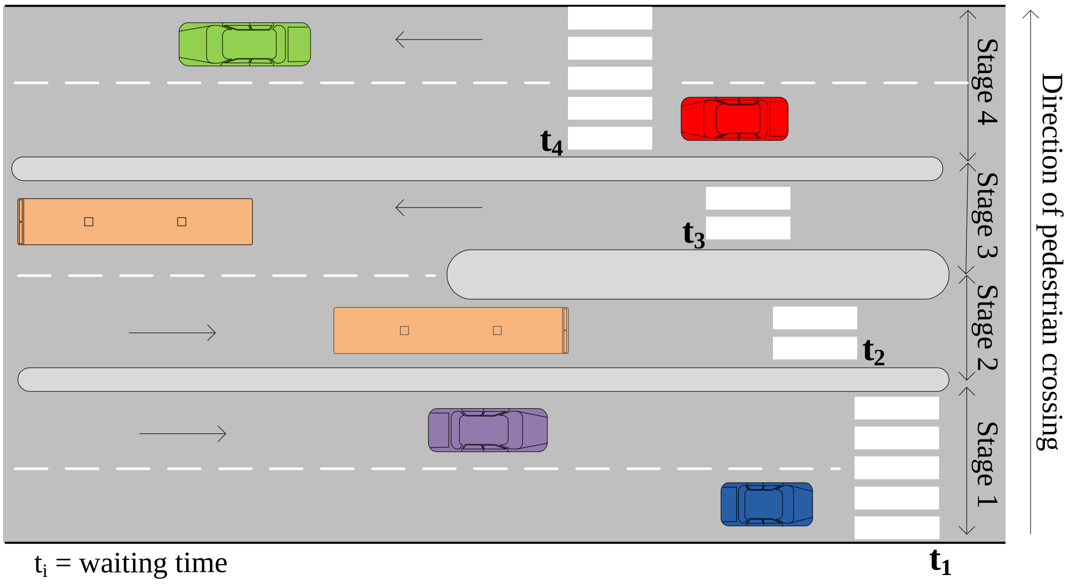


Figure 2 – Schematic drawing of the crossing.

The total waiting time for each pedestrian was calculated as the sum of the waiting time in each crossing stage. For example, in the crossing of Figure 2, that is typical of a site that has a median busway, the pedestrian waiting time is the sum of waiting times in each stage (∑ti). Waiting time per crossing presented very high variances (in some cases varying from 14 seconds to 176 seconds). Averages with high variances can generate important distortions in the formulation of the models and thus waiting time was excluded from model estimation.

A classificatory count of pedestrians was carried out during the analysis of the video. Pedestrians crossing only partially to board buses in median lanes, carrying children, and babies in strollers were included in the counts, since they are also exposed to motor vehicle crashes. The percentage of male pedestrians varied from 29.6% to 67.7%, and the percentage of elderly pedestrians from 15.2% to 24.8%.

Perceived Risk

A group of sixteen pedestrians of different ages and educational levels and eight road safety experts participated of the film simulation. The analysis of each midblock crossing was done in three stages. In the first stage, the participants watched a film of the crossing with a length of approximately 45 seconds. Then, they observed a panoramic picture of the respective crossing (example in Figure 3). Finally, they watched again the same film and rated the crossing according to their sense of safety, ranging from 1 (very dangerous) to 5 (very safe).

The Cronbach Alpha was calculated to evaluate the internal consistency of the survey instruments. The reliability of the survey is verified when Cronbach Alpha is greater than 0.55 (Fogliatto, 2004). In the risk perception survey of this study the Cronbach Alpha was 0.69.

Figure 3 – Example of a panoramic picture

Analysis of variance (ANOVA) was also performed to verify if there were differences in opinion between groups of participants (experts and pedestrians, males and females, vehicle owners and non vehicle owners). The results are presented in the Table II, Table III, and Table IV. The ratings of experts differed from the ratings of pedestrians just in 3 of the 21 evaluated crossings. The females rated five crossings as less safe than the males. The owners of motor vehicles judged only one crossing as safer than those that do not own a motor vehicle. These results led to the conclusion that the ratings of different groups can be considered homogeneous, with almost no statistically significant difference between them. Thus, the average rating for each intersection can be used in the development of a multilinear regression model.

Table II – ANOVA results (Pedestrians x Experts)

Adress	Pedestrian		Expert		F	Significance
	Mean	Standard Deviation	Mean	Standard Deviation		
Av. Assis Brasil 2834	2.31	0.704	2.50	0.926	0.31	0.585
Av. Bento Gonçalves 2948	3.94	0.772	2.75	0.886	11.46	0.003
Av. Bento Gonçalves 3031	3.44	0.964	2.75	0.886	2.85	0.105
Av. Borges de Medeiros 1945	3.13	0.719	3.75	1.035	3.01	0.097
Av. Independência 1184	1.56	0.727	1.38	0.518	0.42	0.523
Av. Independência 1206	1.81	0.750	1.38	0.518	2.18	0.154
Av. Ipiranga 5200	2.38	0.885	2.50	1.069	0.09	0.763
Av. João Pessoa 1831	2.50	0.894	2.75	0.707	0.47	0.499
Av. João Pessoa 2050	1.50	0.632	1.75	1.035	0.54	0.469
Av. Júlio de Castilhos 284	1.25	0.447	1.63	0.744	2.40	0.136
Av. Loreiro da Silva 1500	1.19	0.403	1.13	0.354	0.14	0.713
Av. Loreiro da Silva 1520	1.63	0.806	1.25	0.463	1.47	0.239
Av. Loreiro da Silva 2001	1.31	0.602	1.25	0.463	0.07	0.800
Av. Paulo Gama 110	1.00	0.000	1.25	0.463	4.89	0.038
Av. Praia de Belas 408	2.56	0.814	1.75	0.886	5.02	0.036
Av. Praia de Belas 422	4.25	0.683	4.25	0.463	0.00	1.000
Av. Protásio Alves 943	3.13	0.957	2.38	0.916	3.36	0.080
Av. Protásio Alves 1210	3.00	1.211	3.13	0.991	0.06	0.803
Av. Sertório 6600	3.60	0.632	3.63	0.518	0.01	0.925
R. Siqueira Campos 1300	2.00	0.816	2.63	1.061	2.56	0.124
R. Voluntário da Pátria 650	1.19	0.403	1.25	0.463	0.12	0.736

= significant difference of opinion between experts and pedestrians

Table III – ANOVA results (Female x Male)

Adress	Female		Male		F	Significance
	Mean	Standard Deviation	Mean	Standard Deviation		
Av. Assis Brasil 2834	1.90	0.568	2.71	0.726	8.721	0.007
Av. Bento Gonçalves 2948	3.50	0.850	3.57	1.089	0.030	0.864
Av. Bento Gonçalves 3031	2.50	0.850	3.71	0.726	14.167	0.001
Av. Borges de Medeiros 1945	3.20	0.919	3.43	0.852	0.394	0.537
Av. Independência 1184	1.30	0.483	1.64	0.745	1.620	0.216
Av. Independência 1206	1.30	0.483	1.93	0.730	5.616	0.027
Av. Ipiranga 5200	2.30	0.823	2.50	1.019	0.262	0.614
Av. João Pessoa 1831	2.60	0.699	2.57	0.938	0.007	0.936
Av. João Pessoa 2050	1.30	0.675	1.79	0.802	2.430	0.133
Av. Júlio de Castilhos 284	1.10	0.316	1.57	0.646	4.507	0.045
Av. Loreiro da Silva 1500	1.00	0.000	1.29	0.469	3.667	0.069
Av. Loreiro da Silva 1520	1.50	0.850	1.50	0.650	0.000	1.000
Av. Loreiro da Silva 2001	1.10	0.316	1.43	0.646	2.189	0.153
Av. Paulo Gama 110	1.10	0.316	1.07	0.267	0.057	0.813
Av. Praia de Belas 408	2.20	1.033	2.36	0.842	0.168	0.685

Av. Praia de Belas 422	4.20	0.632	4.29	0.611	0.111	0.742
Av. Protásio Alves 943	2.40	1.075	3.21	0.802	4.537	0.045
Av. Protásio Alves 1210	2.80	1.229	3.21	1.051	0.788	0.384
Av. Sertório 6600	3.40	0.699	3.77	0.439	2.412	0.135
R. Siqueira Campos 1300	2.30	1.059	2.14	0.864	0.160	0.693
R. Voluntário da Pátria 650	1.20	0.422	1.21	0.426	0.007	0.936

= significant difference of opinion between male and female

Table IV – ANOVA results (Motor vehicle ownership)

Endereço	Vehicle Owner		Non Vehicle Owner		F	Significance
	Mean	Standard Deviance	Mean	Standard Deviance		
Av. Assis Brasil 2834	2.58	0.900	2.17	0.577	1.821	0.191
Av. Bento Gonçalves 2948	3.17	1.030	3.92	0.793	3.996	0.058
Av. Bento Gonçalves 3031	3.17	1.030	3.25	0.965	0.042	0.840
Av. Borges de Medeiros 1945	3.67	0.985	3.00	0.603	4.000	0.058
Av. Independência 1184	1.50	0.674	1.50	0.674	0.000	1.000
Av. Independência 1206	1.50	0.522	1.83	0.835	1.375	0.253
Av. Ipiranga 5200	2.58	0.900	2.25	0.965	0.765	0.391
Av. João Pessoa 1831	2.50	0.798	2.67	0.888	0.234	0.633
Av. João Pessoa 2050	1.83	0.835	1.33	0.651	2.676	0.116
Av. Júlio de Castilhos 284	1.58	0.669	1.17	0.389	3.481	0.075
Av. Loreiro da Silva 1500	1.25	0.452	1.08	0.289	1.158	0.294
Av. Loreiro da Silva 1520	1.50	0.674	1.50	0.798	0.000	1.000
Av. Loreiro da Silva 2001	1.25	0.452	1.33	0.651	0.133	0.719
Av. Paulo Gama 110	1.17	0.389	1.00	0.000	2.200	0.152
Av. Praia de Belas 408	2.25	0.965	2.33	0.888	0.048	0.828
Av. Praia de Belas 422	4.33	0.492	4.17	0.718	0.440	0.514
Av. Protásio Alves 943	2.50	1.000	3.25	0.866	3.857	0.062
Av. Protásio Alves 1210	3.08	1.084	3.00	1.206	0.032	0.860
Av. Sertório 6600	3.64	0.505	3.58	0.669	0.045	0.833
R. Siqueira Campos 1300	2.58	0.900	1.83	0.835	4.477	0.046
R. Voluntário da Pátria 650	1.25	0.452	1.17	0.389	0.234	0.633

= significant difference between the opinion of vehicle owners and non vehicle owners

MODEL DEVELOPMENT

The main objective of developing a regression model was to create a tool to relate pedestrian safety with the prevailing operational and physical characteristics of midblock crossings. In the proposed model, the crossing ratings were selected as the model outcome. Risk factors were used as determinant variables.

The first step on the model development was to convert the categorical variables in dummy variables: "yes" =1; "no" = 0. The dummy variables related to the presence of traffic signal and marked crosswalks were merged, in order to avoid the perfect multicollinearity.

A correlation matrix was calculated for all possible pair of quantitative variables. Strong correlations ($|\rho| > 0.70$) were observed between road width, vehicle volumes and number of traffic lanes. The percentage of male pedestrians was positively correlated with the distance to the closest marked crosswalk or intersection (ρ= 0.63), while the percentage of elderly pedestrians was negatively correlated to this distance (ρ= -0.55).

Many different models were tested using a multilinear regression model in Stata software. However, it was not possible to develop a statistically significant model without including strongly correlated variables. This raises the issue of multicollinearity.

Multicollinearity leads to inaccurate estimates of the coefficients of highly correlated variables. It is a serious problem if it is necessary to understand how individual determinant variables impact the outcome variable. However, if the objective of the model is to estimate an outcome, multicollinearity should not be a serious concern as long as two conditions are reasonably satisfied: (i) correlated variables as a group are precisely estimated; (ii) correlation pattern prevails in the situation being estimated (Baltes et al., 2002).

This study did not aim to evaluate the effect of individual risk factors on pedestrian safety, so correlated variables could be used. Other studies also used correlated variables in the formulation of pedestrian safety evaluation models (Baltes et al., 2002; Greibe, 2003).

The model was developed including all determinant variables on the prediction. The least statistically significant variables at a confidence level of 95% (p-value ≤ 0.05) were dropped one by one from the analysis. Equation 1 presents the basic formulation of the model. The final model revealed 8 significant variables to explain the pedestrian crash rates at midblock locations (Table V).

$$PS_i = \sum \beta_j x_{ij} \quad (1)$$

where:

- PS_i: perceived safety ranging from 1 (very dangerous) to 5 (very safe).
- x_{ij}: determinant variables
- β_j: model coefficients

Table V – Final Model

Sample size = 21
F(8, 12) = 38,06
Prob > F = 0,0000
R^2 = 0,94

	Coefficient	Standart Error	t	*p-value*
BS [1]	-0.9851003	0.2447617	-4.02	0.002
BTS [1]	-1.0626970	0.2570150	-4.13	0.001
DCBS	-0.0113851	0.0036103	-3.15	0.008
RW	-0.0537945	0.0109635	-4.91	0.000
PP	0.9540397	0.2496829	3.82	0.002
NTD	0.3716855	0.1801003	2.06	0.061
PMCTS [1]	1.9185670	0.1624708	11.81	0.000
Pv [1]	-0.0013057	0.0004841	-2.70	0.019
Constant	3.2084720	0.2976997	10.78	0.000

(1) variables moderately correlated (|ρ| > 0.50)
(2) Significant risk factors list:
BTS: presence of busway transit system (dummy variable: “yes”= 1; “no”=0)
BS: presence of a bus stop (dummy variable: “yes”= 1; “no”=0)
DCBS: distance from the crossing center to the closest bus stop
RW: road width (meters)
PP: parking permission
NTD: number of traffic directions (one or two way road)
PMCTS: presence of marked crosswalk and traffic signal
Pv: hourly pedestrian volume

The goodness-of-fit of the linear regression model was evaluated through the coefficient of determination and the residual plot. In the model of this study, the R^2 was equal to 0.94, meaning that 94% of the variation in the risk perception is explained by the risk factors included in the model. The residual plot, Figure 4, confirms the results of the coefficient of determination; the points are randomly dispersed around the horizontal axis. In this case, the linear model is appropriate for the data.

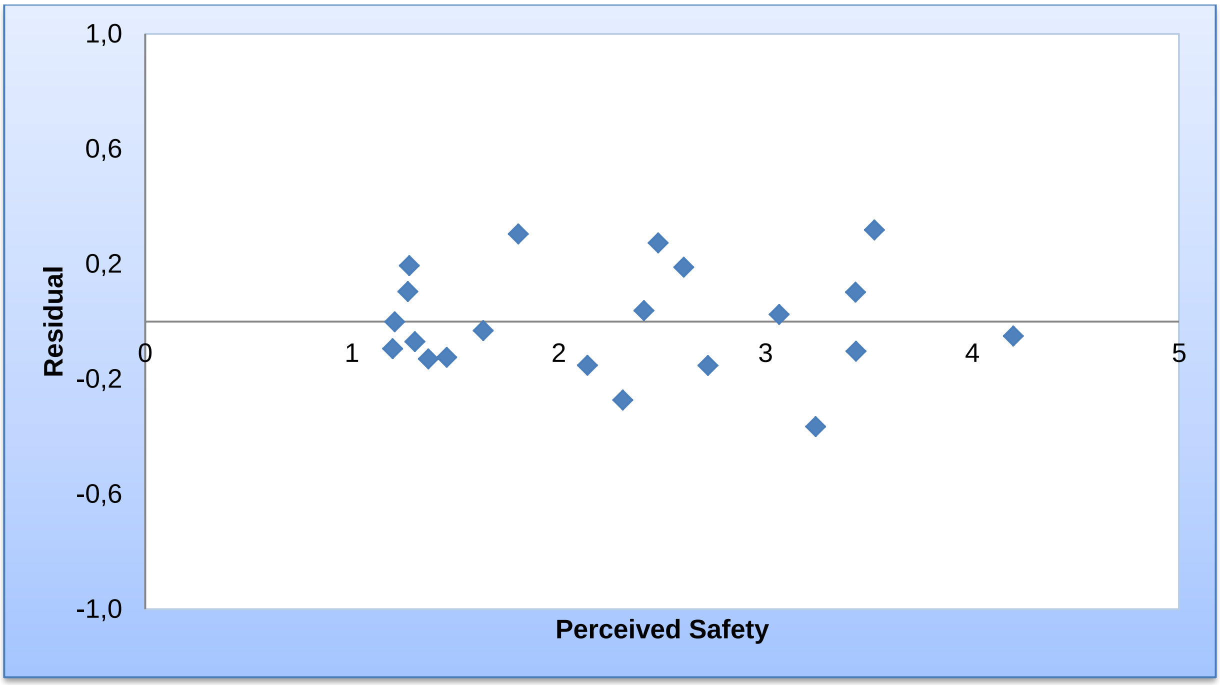


Figure 4 – Residual plot

DISCUSSION

The estimated model shows that several interactive factors can influence pedestrian safety. Although some multicollinearity is present in the data, it is possible to make inferences about weakly correlated variables. The pedestrian perceived risk at midblock crossings seems to increase as the distance from the crossing center to the closest bus stop increases, as the road width increases and in the presence of busway transit systems or bus stops (model output diminishes, lower perceived safety). However, the pedestrian perceived risk decreases in the presence of a marked crosswalk controlled by a traffic signal, in two-way roads, or if parking is permitted (model output increases, higher perceived safety).

The model shows that public transportation characteristics have a strong influence in the perceived safety. For example, the relative position between the crossing and the closest bus stop is an important determinant of the perceived safety. Figure 4 shows the relationship between the distance from the crossing center to the closest bus stop (DCBS) and the perceived safety (PS). An increment of 20 meters in the distance from the crossing to the closest bus stop results in a decrease of 0.20 units in the perceived safety. Thus, the importance of locating pedestrian crossing facilities as close as possible of bus stops.

Furthermore, the interaction between the risk factors is more important in the pedestrian safety evaluation of a crossing than the influence of a single risk factor. For example, two-way roads with large road width usually have a pedestrian facility that increases the safety of the crossing, such as traffic signals or refuge islands. Likewise, pedestrian volume tend to be higher when there is a marked crosswalk controlled by a traffic signal, what increases the perceived safety, and in the presence of a busway transit system, what decreases the perceived safety.

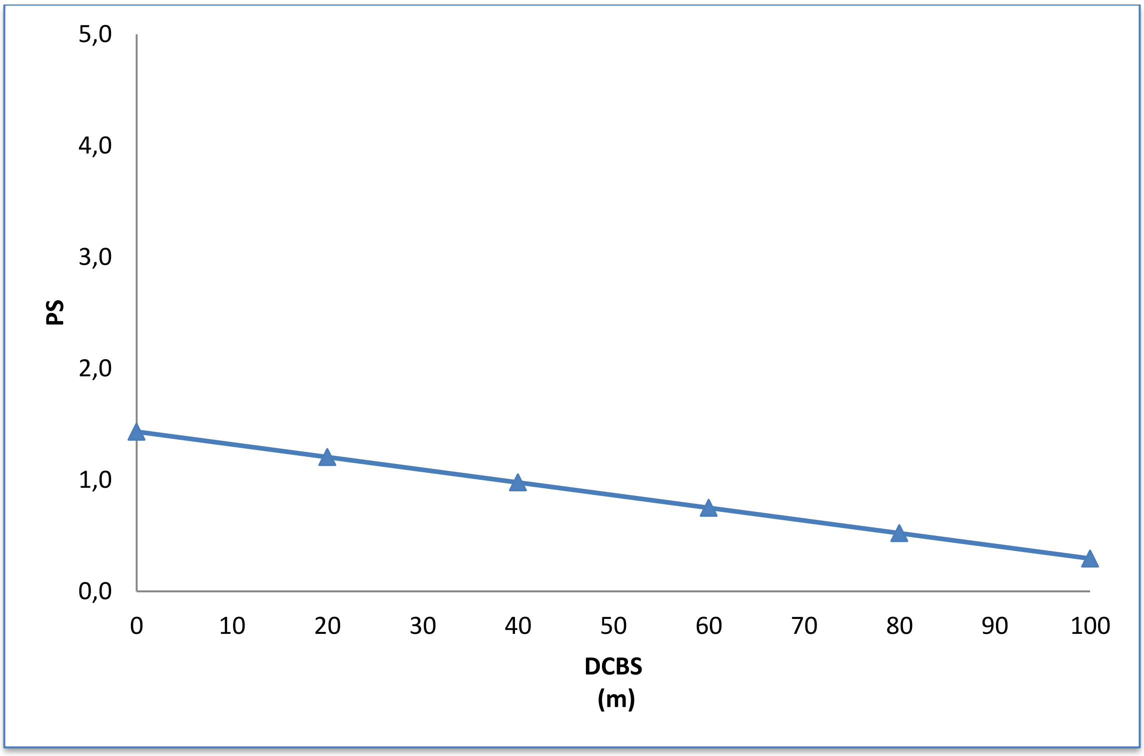


Figure 5 – Relationship between PS and DCBS

CONCLUSIONS

Many interactive risk factors define the level of safety of a midblock crossing. Risk perception techniques can be used as a proactive method to identify pedestrian safety problems and the factors related to pedestrian crash risk.

This paper presents a model for evaluating pedestrian safety at midblock crossings in Brazil based on the perceived safety of pedestrians and experts. The model points out that the safety of a midblock crossing is determined rather by the interaction of the risk factors than by a single factor. For example, a midblock crossing on a one-way road with many traffic lanes can be more dangerous than a midblock crossing on a two-way road, with a refuge island plus a marked crosswalk controlled by a traffic signal.

The model also shows that public transportation influences pedestrian safety. The perceived safety decreases in the presence of a bus stops or a busway facility. Several arterial avenues in Porto Alegre contemplate busway corridors and public transportation accounts for around 50% of all motorized trips in the city. It is also likely that pedestrians behave unsafely on these crossings, such as running to catch a specific bus; in some cases, it is possible that the location of a bus stop is not the most appropriated for the needs of the pedestrians. Thus, it is important to consider the implementation of countermeasures capable of improving pedestrian safety at bus stops, such as increasing enforcement and alerting drivers and pedestrians about the dangers around these areas.

In general, the developed model can enable the detection of pedestrian safety problems in Porto Alegre and support the development of countermeasures for reducing the number of pedestrian crashes. The model is also useful in the identification of midblock crossings that must be prioritized when implementing pedestrian safety treatments.

Further work should focus on gathering the perceived risk on crossings with few or no reported crashes. This could lead to the identification of other risk factors influencing pedestrian safety, and consequently, to modifications on the proposed model.

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