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Analyzing pedestrian behavior when crossing urban roads by combining RP and SP data

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ABSTRACT

Considering the high crash rates involving pedestrians on urban roads, it is highly relevant to understanding pedestrian crossing behavior. This paper is the first to combine stated preference (SP) and revealed preference (RP) data to evaluate the impact that individual attributes, trip characteristics, built environment, strategies to prevent unauthorized crossing, and traffic flows have on pedestrians crossing decisions in an urban context. SP and RP surveys were designed and collected in Barranquilla (Colombia) near pedestrian bridges or signalized intersections where direct crossings and a high concentration of pedestrian fatalities related to traffic accidents exist. A logit model was estimated using the data enrichment paradigm. Results show that pedestrians weigh risks and costs when choosing how to cross the road. The trajectories observed in the RP component suggest that people prefer direct crossings; nevertheless, pedestrian bridges and signalized intersections can be attractive alternatives if their location matches the origin or destination of the crossing, and no detour is needed to use them. Waiting time; safety; the fine imposed for jaywalking; personal security, and previous decisions are also variables that influence pedestrian behavior when crossing urban roads. These results can be helpful to urban planners and decision-makers interested in proposing appropriate pedestrian infrastructure. The data pooling technique and the inclusion of a cost-related variable (i.e., fine) allowed computing the willingness to pay and marginal substitution rates for attributes of the built environment and other characteristics associated with the crossing decision. Also, the inclusion of several crossing alternatives and situations allowed assessing pedestrian crossing preferences under different scenarios.

1. Introduction

Traffic crashes are a global concern due to the alarming statistics related to fatalities and injuries resulting from these events, especially in developing countries. In fact, 93% of the world's road-related fatalities occur in low- and middle-income countries, even though these countries only possess around 60% of the vehicles around the globe (World Health Organization, 2019). Although collisions between vehicles cause most traffic collisions, the events with higher mortality rates often involve vulnerable road users (i.e., pedestrians, cyclists, and motorcyclists). According to the World Health Organization (2019), traffic crashes cause about 1.35 million

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deaths each year, 54% of them related to vulnerable road users.

In the Americas, the situation is not different. Vulnerable road users make up 45% of the region's traffic deaths. Estimations indicate that, just in Latin America and the Caribbean, the lack of road safety caused nearly 125,000 annual deaths, with an average death rate of 17.55 per 100,000 inhabitants (Martinez, Sanchez, & Yañez-Pagans, 2019).

In Colombia, 6,892 people died, and 36,832 were injured in traffic crashes in 2019. 25.3% (1,747) of the fatalities and 20.1% (7,417) of the injuries were related to pedestrians (Instituto Nacional de Medicina Legal y Ciencias Forenses, 2020). They also represented 25,35 % of the deceased and 20,14 % of the injured. In Barranquilla, the location used as a case study for this research and the fourth most populous city in the country, the statistics show the same trend, where 24,5% of 1,073 injured, and 40% of the 95 dead reported in 2019 were pedestrians (Instituto Nacional de Medicina Legal y Ciencias Forenses, 2020). Specifically, 81% |of the deceased and 60% of the injured pedestrians in the city were males. Regarding the age ranges, most of the dead pedestrians in Barranquilla were over 55 years old (55.5%), followed by those between 30 and 55 (38.9%). No pedestrians under 20 years old were killed in traffic accidents. When it comes to the injured, the age group distribution was more even; 46.5% were over 45 years old, and 17% were under 20 years old (Observatorio Nacional de Seguridad vial, 2020).

Researchers have identified a couple of issues that need to be addressed to improve this panorama. First, road-building projects in developing countries usually secure vehicles rather than pedestrian mobility (Obeng-Atuah, Poku-Boansi, & Cobbinah, 2017; Arellana, Alvarez, Oviedo, Guzman, 2021). Also, when trying to mitigate the impact that roads have on pedestrian mobility, the most recurred alternative is the construction or improvement of pedestrian crossing facilities. However, several studies suggest that the provision of crossing facilities such as overpasses (pedestrian bridges) or underpasses (tunnels) does not necessarily facilitate the task of crossing busy roads nor eliminate the barriers faced by pedestrians (Demiroz, Onelcin, & Alver, 2015; Sinclair & Zuidgeest, 2016; Rankavat & Tiwari, 2016).

Pedestrians frequently dislike some facilities, causing more people to cross the road informally away from the crossing alternatives. For example, grade-separated crossing facilities (such as pedestrian bridges and underpasses) are beneficial for pedestrians since they eliminate any risk of collision, but are very disliked because using them requires additional time and effort. Also, some people perceive them as unsafe regarding personal security (Räsänen, Lajunen, Alticafarbay, & Aydin, 2007; Tao, Mehndiratta, & Deakin, 2009; Villaveces et al., 2012; Mfinanga, 2014; Rankavat & Tiwari, 2016). Traffic safety and security are the two most crucial factors related to walkability in the global South (Arellana, Saltarín, Larrañaga, Alvarez, & Henao, 2020).

It is not enough to have available crossing facilities. In many cases, pedestrians do not use them because they are far away, in poor condition, not accessible for individuals with reduced mobility (i.e., handicapped, elderly), disconnected from proper sidewalks, or not clean, among others (Arellana et al., 2020). Unfortunately, these conditions are common in several global South cities.

Considering the high mortality rates in pedestrian-related accidents and that pedestrian bridges and signalized crossings tend to be underused in some contexts, it is important to analyze the factors influencing pedestrian crossing behavior. In Cartagena, Colombia, Cantillo, Márquez, & Díaz (2020) showed that the probability of fatal crashes is higher on streets where pedestrian bridges are available. The highest incidence of these accidents happens when pedestrians cross the road through non-authorized places (Cantillo, Arellana, & Rolong, 2015). Therefore, identifying these influencing factors could allow for the proposal of appropriate public policies and measures to protect the lives of the most vulnerable road users (Victoria & Galvis, 2014).

Several approaches have been used to study pedestrian behavior when crossing urban streets. For example, utility-based models such as gap-acceptance and discrete choice approaches are frequently used when studying crossing time and location. However, although these proposals are popular, the models are commonly estimated using Revealed Preferences (RP) or Stated Preferences (SP) data separately.

RP data is useful when the goal is to study current individual choices, considering alternatives available at the moment. This kind of information guarantees a realistic perception of existing attributes and the consideration of certain restrictions related to the choices, which are challenging to incorporate in SP experiments. Several studies have used RP data to study pedestrian behavior when crossing the road (Papadimitriou, 2012).

On the other hand, SP data is based on hypothetical choice situations. Its advantage lies in the possibility of including alternatives that are not currently available, new public policies, or attributes that are difficult to capture in the RP domain. The limitations of SP data are mainly related to the biases associated with reported choices, as people may not behave as they declared under the hypothetical contexts.

This paper proposes a combined RP and SP modeling approach to analyze pedestrian behavior when choosing a crossing alternative in an urban road context. The estimation of RP/SP models is one of the main novelties of this article since applications using the data enrichment paradigm are unknown in this context. Furthermore, combining different data sources to estimate the model makes it possible to estimate willingness to pay for reductions in the risk of being killed or injured in an accident and other marginal substitution rates between studied attributes. This modeling approach also allows exploiting the advantages of both types of information.

2. Literature review

In developing countries, traffic conditions are usually characterized by low accessibility, poor public transport, congestion, and inadequate facilities for non-motorized transport (Sinclair & Zuidgeest, 2016). As a result, middle- and low-income countries have the highest fatality rates related to traffic crashes, where vulnerable road users are the most affected. The above appears to be a consequence of the traffic composition, where there is an increased proportion of vulnerable road users (Oviedo-Trespalacios & Haworth, 2015).

Many traffic crashes involving pedestrians are caused by the high incidence of informal road crossing behavior, away from proper crossing facilities. The decision regarding where and how to cross the road is affected by different aspects, either social or personal. Although there is a possibility of crossing the street using underpasses, pedestrian bridges or signalized passes, pedestrians often prefer to cross the road directly despite the risk they are exposed to because it is an alternative they perceive as more accessible and faster.

Pedestrian crosswalks are not always placed at correct locations, causing walkers to detour from their shortest routes; consequently, some of them run the risk of jaywalking (Han & Chang, 2021). In addition, pedestrians usually find obstacles and barriers when walking (Larranaga, Arellana, Rizzi, Strambi, & Cybis, 2019). In other words, when crossing a road, pedestrians make a trade-off between the time/effort needed to complete the maneuver and the risk of being involved in a traffic accident.

Pedestrian behavior is closely related to the characteristics of the trip and the context where the journey takes place. It is relevant to consider variables such as the origin/destination of the trip, the travel distance, and the walking distance required to cross the road using different crossing alternatives available in the area (Sisiopiku & Akin, 2003). The pedestrian's perceived quality of service on urban sidewalks also determines their decisions (Vallejo-Borda, Cantillo, & Rodriguez-Valencia, 2020) and influences other perceptions. For instance, individual understanding of microscale and mesoscale built environment variables influences the perception of how walkable a zone is (Arellana et al., 2020), which in turn affects the number of walking trips (Larrañaga, Rizzi, Arellana, Strambi, & Cybis, 2016), the subjective wellbeing (Lucchesi, Larrañaga, Ochoa, Samios, & Cybis, 2020), and the property prices (Lucchesi, Larranaga, Cybis, Abreu e Silva, & Arellana, 2021).

Other external factors may influence crossing choice. Li, Peng, Zhang, & Huang (2009) studied the determinant aspects of unsafe pedestrian behavior in China using the theory of planned behavior. They found that the negative perception of public infrastructure, the location and quantity of pedestrian bridges and signalized crossings available, and the time available for crossing at traffic lights are significant for pedestrian understanding of unsafe behavior. Quistberg, Koepsell, Boyle, Miranda, Johnston, & Ebel (2014) conducted a study in Lima, Peru, to determine if countermeasures like pedestrian signalization helped improve pedestrian safety. They found that pedestrian signalization in the observed context was not associated with pedestrian safety.

Holland and Hill (2007) evaluated the effect of age, gender and possession of driving license on the crossing decisions in high-risk situations, finding that women are less likely to cross when faced with risky situations, just as with older people. Similar conclusions were obtained by Poó, Ledesma, & Trujillo (2018) in Argentina, as men presented higher scores on risky behaviors; however, they observed no differences by age group. On the other hand, studies suggest that car approach speed significantly impacts pedestrian crossing behavior (Bertulis & Dulaski, 2014).

Hensher, Rose, Ortúzar, & Rizzi (2011), using a discrete choice model estimated from SP data, assessed an increase in rent or taxes for improvements in pedestrian infrastructure in the survey to derive managerial measures. As a result, they obtained the willingness to pay to avoid the risk of fatalities or injuries when walking. Cantillo et al. (2015) also used SP data but included latent variables to study pedestrian crossing behavior in Bogotá (Colombia). They found that the respondent characteristics and the travel conditions (e.g., if the person is walking with someone else) affect the crossing behavior. These effects could be captured adequately using SP experiments. Furthermore, they found that latent variables such as the attractiveness and safety of the crossing alternatives may affect the choice behavior reported by pedestrians.

Recent studies on pedestrian preferences towards different crossing facilities have also used SP data (Anciaes & Jones, 2018; Dada, Zuidgeest, & Hess, 2019). These studies concluded that personal characteristics (i.e., gender, age, body type, frequency or driving experience, academic background), trip purpose, vehicular and pedestrian traffic, and built environment attributes explain the crossing site choice. In addition, the location of the pedestrian facilities and the pedestrian trip destinations turned out to be relevant in determining where they cross the road. Variables such as safety, convenience, risk perception, crossing time, accessibility, and personal security also determine individual preferences about crossing facilities.

Oviedo-Trespalacios & Scott-Parker (2017) explored the factors influencing pedestrian choices when crossing a high-traffic highway in Barranquilla. They used a logistic regression explained by the frequency of footbridge usage; the perception of security when using the footbridge; the safety perception regarding traffic accidents; the proximity of the footbridge to the ground crossing, and if the subject had been injured when previously crossing a highway.

Demiroz et al. (2015) conducted an observational survey of illegal road crossings at four overpass locations in Izmir (Turkey) using a video recording technique and a questionnaire to reveal the factors lying behind this behavior. An ANOVA was used to analyze gender, age, carrying items, group size and vehicle speed limit effects on safety margin and crossing times. Results suggested that the time required to use the overpass and the perceived overpass insufficiencies are the most critical factors affecting the use rate. Also, most illegal crossings were completed when the vehicle was beyond 50 m; pedestrians felt safer while crossing when the vehicle speed was low.

Hasan & Napiah (2018) conducted a similar study in Malaysia and concluded that the most influential factor regarding the usage of footbridges is the availability of an escalator. They also found that being in a hurry and the fear of heights are associated with choosing not to use a footbridge. Zebra crossing was chosen as the most favorable crossing facility for pedestrians. The findings were confirmed through further research about the effectiveness of some interventions to change the crossing behavior of footbridge non-users (Hasan, Oviedo-Trespalacios, & Napiah, 2020). Bridge height and effort required to use it were the main drivers of behavior, while the most effective intervention to promote bridge usage ended up being the installation of escalators.

Zhang, Wang, Wang, Feng, & Du, (2016) estimated a binomial logistic model of pedestrian crossing behavior based on SP survey data to evaluate red-light running. The response variable was binary: run and not run a red light. They found that strolling people are more likely to have a safe crossing behavior than those going to work/school. Also, pedestrians who cross the street during the daytime, who are in a hurry or affected by the road facility quality, are more likely to run on a red light.

Uttley & Fotios (2017) studied the impact of darkness on road traffic collisions involving pedestrians by recording the frequency of collisions in a case one hour before and after a daylight-saving clock change. Their findings suggest a significantly greater risk of a pedestrian road collision during an after-dark crossing than during daylight. Results also indicate a higher risk after-dark at a pedestrian crossing than at a location at least 50 m away from a crossing. The previous findings raise the question of whether the lighting at crossings is adequate.

Jha, Tiwari, Mohan, Mukherjee, & Banerjee (2017) used a naturalistic observation technique with a vehicle-mounted camera to study pedestrian choice of walking on the road versus using a footpath in the presence of various road features, such as the number of lanes, presence of medians, and presence of footpaths. Crosswalk location relative to the origin and destination of the pedestrian was the most influential decision factor for pedestrians deciding to cross at a designated location.

In Mumbai, Patra, Perumal, & Rao (2020) analyzed pedestrian behavior when choosing between an at-grade signalized crosswalk and a footbridge using a video survey. This RP data allowed them to estimate a binary logit model. Results showed that the total pedestrian crossing time ratio and the risk taken while crossing both influence choice. Also, women and older pedestrians are influenced primarily by convenience, whereas the choices of pedestrians accompanied by children are driven by the safety benefits of the crossing facility. Zareharofteh et al. (2021) used a similar methodological approach to study unsafe behaviors from pedestrians in Iran.

In China, Zhang, Chen, & Wei (2019) evaluated pedestrian crossing behavior considering crossing mode; waiting time at the roadside; path or speed change while crossing; crossing with others, and safety at mid-block crosswalks with different vehicle lanes. They collected videos and proposed three ordered probit (OP) models for pedestrian-vehicle conflict analysis (PVCA). Behavioral characteristics such as rolling gap crossing mode and crossing with others significantly increased the possibility of pedestrian-vehicle conflict. Furthermore, as the number of vehicle lanes increased, the conflicts between pedestrians and vehicles increased accordingly, also occurring on the roads further across the crossing. Zhu & Sze (2021) also used video observation surveys to study the factors and propensities of the red-light running of pedestrians at two-staged crossings. They developed random parameter logit regression models to evaluate demographics, behavioral characteristics, social influences, geometric design, signal time, and traffic conditions.

Soathong, Chowdhury, Wilson, & Ranjitkar (2021) conducted an on-site survey including questions related to the constructs of the Theory of Planned Behavior, habit, and relationships considering gender. They found that crossing at mid-block is perceived as a necessary risk worth taking, which is mentally linked to convenience gain, including saving travel time and reducing walking distances.

Recently, Bendak, Alnaqbi, Alzarooni, Aljanaahi, & Alsuwaidi (2021) collected data at five signalized crosswalks at road intersections and five midblock signalized crosswalks using direct unobstructed roadside observations. The analysis showed that pedestrians crossing at midblock, alone (or with small groups), and at broader roads tended to walk faster. In addition, an alarming 70% of the observed pedestrians did not look around before crossing the street.

Arellana, Garzón, Estrada, & Cantillo (2020) assessed how the survey format could influence individual responses in SP experiments to evaluate the crossing behavior at an urban street. Specifically, they tested the benefits of using immersive virtual reality to understand complex attributes by surveying a sample of individuals from Barranquilla, Colombia. Modeling results suggest that the assisted use of virtual reality allows respondents to perceive environmental and crowd dynamics better than traditional choice experiments dealing with pedestrians.

As the previous literature review suggests, there is abundant literature dedicated to a better understanding of pedestrian behavior when crossing streets (see Appendix for a summary). Generally, the data used in these studies comes from observational experiments (most of them using video recordings) or surveys/interviews applied to pedestrians in the field, stating their preferences, habits, and motivations. There is no study on pedestrian choice behavior combining different data sources to the best of our knowledge. Even when recent research has studied pedestrian choice behavior and their interactions with drivers through observation protocol and a follow-up questionnaire (Lee et al., 2021), they performed separate analyses of both datasets.

The comparative analysis of observed and stated pedestrian road crossing behavior performed by Papadimitriou, Lassarre, & Yannis (2016) concluded that most pedestrians behave following their declared behavior. However, they found dissonance in a significant share of pedestrians between their observed and declared behavior. These results are expected and highlight the relevance of studying crossing behavior combining both stated and revealed preferences data to take advantage of both types of information and diminish the disadvantages of using either of them separately (Hensher, Louviere, & Swait,1998). The process of combining SP and RP data, also known as the data enrichment paradigm, has been widely used in transportation studies (Pursula & Weurlander, 1999; Lam & Xie, 2002). However, it has not been used in the context of pedestrian crossing behavior on urban roads.

3. Methodology

This research aims to analyze and model pedestrian decisions regarding crossing facility choice and crossing location. To do so, we combined data from different sources: a revealed preference experiment collected through unobstructed observation at various locations and a discrete choice experiment designed to capture pedestrian stated preferences.

3.1. Survey

The surveys were collected face-to-face by trained interviewers following all the ethics protocols from Universidad del Norte. They randomly chose pedestrians crossing the road by any crossing alternative available at the survey locations. The survey started by randomly selecting a person from the other side of the road to register their trajectories from afar, corresponding to the RP component. Note that pedestrians were chosen without letting them know they were being observed. Then, the interviewer approached them to complete the rest of the survey. The data was collected at different times of day during several days of the week. The attributes considered were chosen based on the literature review and the effects that have been proven to influence pedestrian behavior. The

Fig. 1. View of one of the surveyed areas.

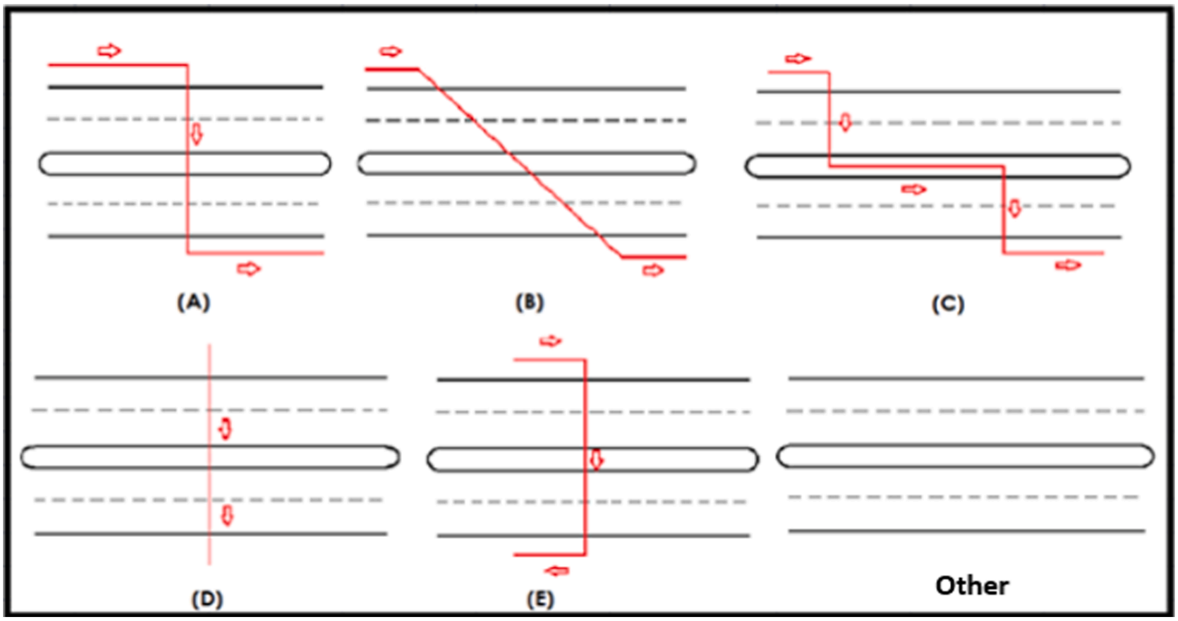

Fig. 2. Pedestrian crossing trajectories.

survey comprised three sections:

a) General information and respondent characteristics: which contained a survey identification number, location, date, time, respondent age, gender, SES (socioeconomic strata, which is a metric ranging from 1 to 6 used in Colombia as a proxy for income classification to determine the utilities and public services fees (Cantillo-García, Guzman, & Arellana, 2019)), education level, occupation, household size, car or motorcycle ownership, and approximate monthly family income.

b) Revealed preference (RP) component: interviewers were placed at an unobstructed location observing randomly selected pedestrians. They gathered observational data such as:

- Crossing origin and destination (a map from the area was used for this purpose, as shown in Fig. 1).
- Facility chosen to cross the road (i.e., direct crossing, pedestrian bridge, or signalized crossing).
- Crossing trajectory (Fig. 2 was used for this purpose). These trajectories helped to estimate the walking distance.

Choice scenario	1
Delay	10 minutes
Baggage	Nothing
Company	Alone
Environment	Night
Traffic flow	Medium

	Pedestrian bridge	**Signalized crossing**	**Direct crossing**
Walking distance (m)	**100**	**100**	----------------------------
Thefts per year	**50**	**10**	**10**
Injured pedestrians per year	----------------------------	**4**	**5**
Pedestrian casualties per year	----------------------------	**2**	**6**
Average waiting time (min)	----------------------------	**0**	**2**
Probability of being fined	----------------------------	----------------------------	**1 out of 500**
Fine cost (COP)	----------------------------	----------------------------	**$200,000.00**

Fig. 3. Example of choice scenario.

Table 1
Experimental design attributes levels and description.

Attribute	Unit	Description	Levels
Delay	Min	How late is the pedestrian going to arrive at their destination when crossing the road	0, 15, 30.
Companion	–	Whether the individual was traveling alone or accompanied	Alone, accompanied.
Baggage	–	Whether the individual was carrying any baggage	Nothing, carrying bags, or luggage.
Environment	–	Environmental conditions	Night, rainy, sunny
Traffic flow	–	Traffic flow on the road to be crossed	Low, medium, high.
Walking distance	m	Additional walking distance required to complete the maneuver using the provided infrastructure instead of crossing directly (only for direct and signalized crossing)	100,150,200
Robberies per year	Incidents per year	Registered robberies in the surroundings of each crossing alternative	10, 30, 50, 100, 150
Injured pedestrians	Incidents per year	Number of pedestrians injured in a traffic accident (only for direct and signalized crossing)	4, 5, 7, 10, 15
Pedestrian casualties	Incidents per year	Number of pedestrian casualties caused by traffic accidents (only referring to direct crossing and signalized crossing)	0, 2, 4, 6
Waiting time	min	Average waiting time to cross the road directly or using the signalized crossing	0, 2, 5
Probability of being fined.	–	Probability of being fined for jaywalking	1 out of 50, 1 out of 500, 1 out of 1000
Fine[1]	Thousands of COP*	Amount to be paid in case of being fined for jaywalking instead of using the pedestrian facilities	100, 150, 200

The exchange rate was 1USD = 2,500 COP when the survey was applied.

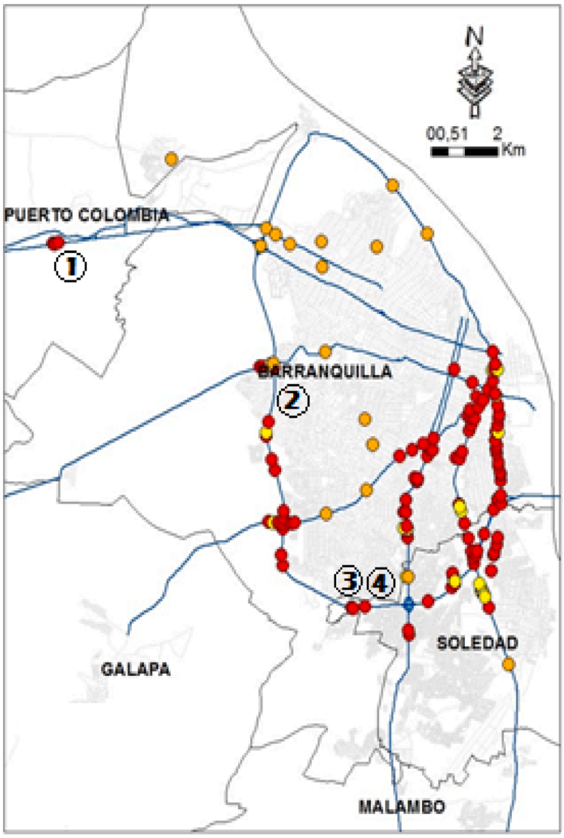

Fig. 4. Map with locations of high traffic accidents incidence and survey locations.

- Time needed to complete the crossing maneuver. Interviewers collected waiting and walking times separately.
- Whether individuals were carrying a bag or package.
- Whether respondents were accompanied by a child, elderly, disabled or other.
- In the case of being a woman, whether she was pregnant.
- The interviewer only asked the respondent for the following information:
- Trip purpose (work, school, home, or errands).
- Primary transportation mode (walking, bus, taxi, jeepney or motorcycle taxi).
- Crossing frequency through that particular road.

The data was complemented with secondary information about traffic, pedestrian flows, and road geometry.

c) Stated preference (SP) component: each individual faced a discrete choice experiment. After holding two focus groups conducting unstructured interviews with pedestrians for assessing the variables, they thought relevant when crossing a road, and collecting two pilot surveys, we obtained the final design. We used an efficient design with 18 rows divided into three blocks, meaning that each respondent answered six different choice situations.

Each choice scenario listed three crossing alternatives: pedestrian bridge, signalized crossing (i.e., at grade crossing with assigned right of way), and direct crossing. We asked respondents to indicate which option they would use to cross the road, considering certain constraints and attributes (see choice situation example in Fig. 3). Table 1 shows the attributes and levels used in the experimental design.

An innovative aspect of the survey is including a cost attribute in the choice experiment. This attribute was considered to estimate the pedestrian willingness to pay for changing other attributes included in the model. The cost variable was related to a fine imposed when crossing the road using unauthorized places (e.g., not using the pedestrian bridge or the signalized crossing). Colombian law registers these fines, which cost about 25,000 COP (10 USD), although they are unknown by most pedestrians and are not usually applied. Nevertheless, the focus groups and the pilot surveys suggested some low sensitivity to the current value of the fine. Therefore, we decided to present higher fines than the current ones in the final design.

During preliminary designs, we tested alternative ways to describe the cost attribute. For instance, we considered increasing rent or taxes to build better infrastructure for pedestrians, as Hensher et al. (2011) proposed. However, we did not consider these alternatives feasible because surveys mainly included people with a low-income who are not used to paying for urban infrastructure, paying specific taxes, or experiencing rent increases.

Table 2
Survey locations.

	**Location 1:** Context of high pedestrian flow since there is a university in the surroundings. There is a median dividing the road with two lanes in each direction (60 km/h speed limit). There is a pedestrian bridge available.
	**Location 2:** Commercial area, with moderate pedestrian flow and high traffic flow, including many heavy vehicles and transit routes. There is a median dividing the road with three lanes in each direction (80 km/h speed limit). There is a pedestrian signalized crossing available.
	**Location 3:** Context of high pedestrian flow since there is a public school with many students in the surroundings. High traffic flow, including heavy vehicles and transit routes. There is a median dividing the road with three lanes in each direction (80 km/h speed limit), and a pedestrian bridge available.
	**Location 4:** Context of high pedestrian flow since there is a large residential complex in the surroundings. High traffic flow, including heavy vehicles and transit routes. There is a median dividing the road with three lanes in each direction (80 km/h speed limit), and a pedestrian bridge available.

It is important to clarify that increasing the penalty is not convenient as it goes against sustainable transport policies and could have equity implications. Previous research supports the idea that using fines or penalties to modify undesirable behavior from individuals is not necessarily effective (Guzman, Arellana, & Camargo, 2021). It is also a victim-blaming policy for road users who are already neglected by transport and built environment authorities in low- and middle-income countries. Including higher rates in the survey is just part of the design process to estimate the cost effect and the willingness to pay for the considered attributes. The focus should be on providing an appropriate environment and infrastructure for pedestrian needs and prioritizing their movements.

3.2. Survey locations

The city of Barranquilla was the location of the case study. Barranquilla is the fourth most populous city in Colombia, with approximately 1.120.000 inhabitants, 52% females. It is also the nucleus of a metropolitan area complemented by four other municipalities (Soledad, Puerto Colombia, Malambo, and Galapa) whereby the population ascends to 2.3420.000 inhabitants (DANE, 2018).

The surveys were collected at four locations. As shown in Fig. 4, these spots present a high frequency of traffic crashes and conflicts between vehicles and pedestrians (elaborated based on the geolocalization of traffic accidents). A curious yet critical characteristic of these places is that pedestrian bridges or signalized crossings are available, suggesting that some pedestrians are not using them. Table 2 shows and describes the survey locations.

4. Sample description

The survey was applied to 204 pedestrians randomly selected after crossing the road using any crossing alternative at the survey location. Almost half of them were men (52%), and most of them were from 18 to 30 years old (67%), followed by the group from 31 to 45 years old (17%).

Individuals also provided their household SES, a metric used in Colombia as a proxy for income classification to determine the

Table 3
Socioeconomic characteristics summary.

Age	N	%	SES	N	%	Education level	n	%
<18	13	6%	1	44	22%	Elementary	20	10%
18–30	136	67%	2	58	28%	Highschool	80	39%
31–45	35	17%	3	42	21%	University/college	103	50%
46–60	16	8%	4	36	18%	Post graduate	1	0%
>60	4	2%	5	20	10%	**Ocuppation**	**n**	**%**
Gender	**N**	**%**	6	4	2%	Employed	52	25%
Female	97	48%	**Owns car**	**N**	**%**	Self-employed	27	13%
Male	107	52%	Yes	28	14%	Student	111	54%
Owns motorcycle	**N**	**%**	No	176	86%	Retired	4	2%
Yes	5	2%	**Avg. Household size**	4.22		Unemployed	10	5%
No	199	98%						

utilities and public services fees ranked from 1 to 6 (Cantillo-García et al., 2019). Since most of the surveyed areas are considered low-income, respondents predominantly belonged to low and low-medium SES strata households. Nearly half of them belonged to low-income SES levels (1–2), and only 12% of them to high-income SES (5–6). The data collected is consistent with the demographics of Barranquilla.

Considering two of the locations selected were near a university or a school, most respondents were students (54%), followed by employees (25%). Only 14% of them owned a car, and only 2% owned a motorcycle. Table 3 presents a summary of the socioeconomic characteristics of the participants.

A low percentage had been hit or run over by a car (11%). Almost one-third knew someone who had been run over, and nearly half of them had witnessed this type of crash (41%). In those locations where only a pedestrian bridge and direct crossing were available (i.e., locations 1, 3 and 4), most pedestrians crossed the road directly (76%). Moreover, in location 2, where only the signalized crossing and direct crossing were available, people clearly preferred using the signalized crossing (87%). The observed choices suggest that people do not like to cross the road using a pedestrian bridge; they prefer grade crossing options as these alternatives do not require extra effort in walking distance or climbing stairs.

Observed crossing trajectories (Fig. 2) suggest that most pedestrians try to cross the road in the most direct possible way (60%). Also, the pedestrian bridges and signalized crossings were mainly used when individuals did not have to detour from their destination to use them (i.e., to walk an extra distance to get to the crossing facility).

Half of them were heading home (50%), followed by a smaller proportion (24%) traveling to do different errands. Most people (61%) crossed the road to catch the bus, while only 30% crossed it as part of their walking journey.

In the stated preference scenarios, respondents chose the crossing alternatives almost evenly, obtaining a 35% preference for the pedestrian bridge, 30% for the signalized crossing, and 35% for direct crossing.

5. Choice model

Considering the availability of both RP and SP data and the presence of more than one common attribute measured in both types of surveys, a logit model that accounts for scale differences between the two types of data was estimated to allow using the data enrichment paradigm.

Let Equations (1) and (2) be the utility functions associated with alternative i considering a random utility model approach for each data source separately (Mcfadden, 1981):

$$U_i^{RP} = ASC_i^{RP} + \beta^{RP}\mathbf{X_i^{RP}} + \gamma\mathbf{Z_i} + \varepsilon_i^{RP} \tag{1}$$

$$U_i^{SP} = ASC_i^{SP} + \beta^{SP}\mathbf{X_i^{SP}} + \alpha\mathbf{W_i} + \varepsilon_i^{SP} \tag{2}$$

where ASC represents the alternative specific constants, $\mathbf{X_i}$ represents the vector of common attributes between both types of data, and $\mathbf{Z_i}$ and $\mathbf{W_i}$ represent the specific attribute vector for PR and SP, respectively. Also, $\boldsymbol{\beta}$ is the vector of parameters associated with the common attributes $\mathbf{X_i}$, while $\boldsymbol{\gamma}$ and $\boldsymbol{\alpha}$ are the set of parameters related to the specific attributes in $\mathbf{Z_i}$ and $\mathbf{W_i}$. The error terms were assumed to follow the Gumbel distribution but with different variances for each data.

Since both surveys (i.e., the RP and SP) were applied to all respondents, it is reasonable to think that taste parameters towards the same attribute for the same person should not change between one type of survey and the other. Therefore, it was assumed that the $\boldsymbol{\beta}$ taste parameters for both formulations (1) and (2) are the same for each attribute, regardless of the data type. Given that the estimated parameters of a choice model are always confounded with the scale factor $\lambda = \frac{\pi}{\sqrt{6}\sigma}$, this assumption can be represented as shown in Equation (3):

$$\lambda^{RP}\beta^{RP} = \lambda^{SP}\beta^{SP} \tag{3}$$

Because both scale factors cannot be estimated, then the scale factor from the RP data (λ^{RP}) was normalized to one. Due to the assumption of parameters being equal for common attributes, it is possible to estimate the scale factor for SP data (λ^{SP}) in relation to parameter λ^{RP}.

Table 4
Attributes and parameters considered in the model.

Attribute	Attribute name	Parameter	Description
Common			
Waiting time	*Wait*	B_{Wait}	Time (minutes) spent waiting for an acceptable gap to cross the road directly or to obtain the right of way at a signalized crossing.
Walking distance	*Dist*	β_{Dist}	Additional distance (meters) the pedestrian must walk to cross using the provided alternatives instead of crossing directly.
Panel effect	$\eta\mu$	–	A random term distributing normal with mean 0 and standard deviation σ_η. This term captures the correlation associated with multiple responses from the same individual.
λ^{RP} and λ^{SP} ratio		-	Represents the relationship between the scale factors λ^{RP} and λ^{SP}, assuming that λ^{SP} was normalized to one
Specific for RP			
Specific constant for bridge	$ASC_{BridgeRP}$	–	Alternative specific constant for the bridge in the RP experiment.
Specific constant for signalized crossing	ASC_{SignRP}	–	Alternative specific constant for to the signalized crossing alternative in the RP experiment.
Alternative destination	*Dest*	β_{Dest}	Dummy variable that is equal to one when the crossing alternative is located conveniently and matches the pedestrian destination (no detour needed)
Specific for SP			
Specific constant for bridge	$ASC_{BridgeSP}$	–	Alternative specific constant for the pedestrian bridge in the SP experiment.
Specific constant for signalized crossing	ASC_{SignSP}	–	Alternative specific constant for the signalized crossing in the SP experiment.
Cost of the fine	*Cost*	β_{Cost}	Cost in thousands of Colombian pesos that the pedestrian would have to pay if they were caught crossing directly where it is prohibited.
Baggage	*Baggage*	$\beta_{Baggage}$	Dummy variable indicating whether the pedestrian is carrying any bag or baggage when crossing.
Habit	*Habit*	B_{Habit}	Dummy variable referring to the individual tendency to take the same decisions taken in the past. It takes the value of 1 if the SP and the RP responses are the same.
Dead and injured	*Crashes*	$\beta_{Crashes}$	Number of dead and injured pedestrians resulting from using certain alternative per year.
Number of robberies	*Robberies*	$B_{Robberies}$	Number of robberies reported by pedestrians using a specific alternative per year.
Socioeconomic attributes			
Low income	*Low_Inc*	B_{LowInc}	Dummy variable that takes the value of 1 if the person belongs to SES level 1 or 2. It is modeled in interaction with the cost of the fine.

The vector of common attributes X in the proposed model is constituted by the average waiting time and the walking distance. Several model formulations were tested; only the specification with the best model fit and attributes significance is shown. Table 4 shows the attributes and parameters included in the model. The remaining attributes collected in the survey that are not included in the model suggest that they are not significant in understanding the crossing decision. It is important to note that the number of lanes was not included in the analysis since there is not enough variability regarding this characteristic between the surveyed locations.

The alternatives considered in both RP and SP domains were direct crossing, pedestrian bridge, and signalized crossing. Bear in mind that only two crossing options were available simultaneously at the same location for the RP component. A mixed logit model considering the panel effect to capture correlation associated with multiple responses from the same individual was proposed (Arellana, Daly, Hess, Ortúzar, & Rizzi, 2012; Cantillo, Ortúzar & Williams, 2007). The utility function for each alternative was formulated as follows:

$$U^{RP}_{Direct} = \beta_{Wait}{}^*Wait^{RP}_{Direct} + \beta_{Dest}{}^*Dest^{RP}_{Direct} + \varepsilon^{RP}_{Direct} + \eta \tag{4}$$

$$U^{RP}_{Signalized} = ASC^{RP}_{Sign} + \beta_{Dist}{}^*Dist^{RP}_{Sign} + \beta_{Wait}{}^*Wait^{RP}_{Sign} + \varepsilon^{RP}_{Sign} + \eta \tag{5}$$

$$U^{RP}_{Bridge} = ASC^{RP}_{Bridge} + \beta_{Dist}{}^*Dist^{RP}_{Bridge} + \varepsilon^{RP}_{Bridge} + \eta \tag{6}$$

$$U^{SP}_{Direct} = \mu^*(\beta_{Wait}{}^*Wait^{SP}_{Direct} + \beta_{Crashes}{}^*Crashes^{SP}_{Direct} + (\beta_{Cost} + \beta_{LowInc}{}^*LowInc)^*Cost^{SP}_{Direct} + \beta_{Robberies}{}^*\left(Robberies^{SP}_{Signalized} + Robberies^{SP}_{Bridge}\right) + \beta_{Habit}{}^*Habit^{SP}_{Direct} + \varepsilon^{SP}_{Direct} + \eta \tag{7}$$

$$U^{SP}_{Signalized} = \mu^*(ASC^{SP}_{Sign} + \beta_{Wait}{}^*Wait^{SP}_{Sign} + \beta_{Habit}{}^*Habit^{SP}_{Sign} + \beta_{Baggage}{}^*Baggage + \varepsilon^{SP}_{Sign} + \eta) \tag{8}$$

Table 5
Model estimation results.

Parameter	RP-Model		SP-Model		RP-SP Model	
	Estimate	Robust *t*-test (0)	Estimate	Robust *t*-test (0)	Estimate	Robust *t*-test (0)
ASC_{SignSP}	–	–	−0.6147	−1.18	−0.1447	−0.3
$ASC_{BridgeSP}$	–	–	−0.6085	−1.26	−0.6085	−1.26
ASC_{SignRP}	1.157	0.94	–	–	−0.0003	0
$ASC_{BridgeRP}$	0.1995	0.18	–	–	−1.983	−1.15
β_{Cost}	–	–	−0.003	−1.41	−0.0028	−1.34
β_{Dest}	−2.1384	−4.63	–	–	−2.8239	−1.44
β_{Dist}	−0.0182	−1.9	−0.0015	−0.53	−0.0058	−3.08*
$\beta_{Baggage}$	–	–	0.1343	0.83	0.1322	0.81
β_{Wait}	−0.0059	−1.43	−0.0958	−3.28	−0.0906	−3.05*
β_{Habit}	–	–	0.3549	2.83	0.3564	2.82*
β_{Crash}	–	–	−0.0511	−2.02	−0.0481	−1.97*
$B_{Robberies}$	–	–	0.0042	2.57	0.0037	2.24*
β_{LowInc}	–	–	−0.0026	−1.68	−0.0027	−1.76
Scale factor μ	–	–	–	–	1.4907	1.13*
σ_η	–	–	1.0953	12.2	1.0849	12.09
Draws	–		1000		1000	
Responses (6SP + 1RP responses per individual)	204		1224		1428	
Log-likelihood	−68.84		−1205.7		−1277.9	
Rho-squared adjusted	0.4608		0.095		0.136	

*Significant at 95% confidence level. **Robust test-t (1).

$$U^{SP}_{Bridge} = \mu^*(ASC^{SP}_{Bridge} + \beta_{Dist}{}^*Dist^{SP}_{Bridge} + \beta_{Habit}{}^*Habit^{SP}_{Bridge} + \varepsilon^{SP}_{Bridge} + \eta) \tag{9}$$

6. Results and discussion

Table 5 shows the estimation results. The results from the RP and SP models estimated separately are included for reference. Regarding the combined model, all parameters have the expected signs and are in line with theoretical expectations from the literature. Since the alternative specific constant associated with the direct crossing option was set to zero, the negative sign of the specific constants related to the signalized crossing and pedestrian bridge indicate that *ceteris paribus*, respondents prefer to cross the road directly. The magnitude of the estimated constants also suggests that respondents prefer signalized crossings over pedestrian bridges.

These results add to the impression that forcing pedestrians to use alternatives that they do not find as convenient to benefit motorized mobility is not equitable. When proposing infrastructure such as pedestrian bridges, the pedestrians must assume all the effort to avoid the conflict. Previous research has shown that providing an escalator would make this alternative more attractive (Hasan et al., 2020). On the other hand, signalized crossing alternatives save pedestrians the extra effort of climbing the bridge (which is not even possible if the individual has any mobility limitations) by making drivers wait for individuals to cross the road. In that sense, for pedestrians, a signalized crossing is more convenient than a footbridge.

The cost parameter showed to be significant and negative. The existence of a monetary fine for crossing the road using unauthorized places decreases the possibility of people making direct crossings. The pedestrian bridge and the signalized crossing are more attractive than the direct crossing when their location matches the pedestrian crossing destination, and no detour is required to use them.

The walking distance parameter is negative and significantly different from zero. The above indicates that, as expected, the preference of each alternative decreases with the increase of the walking distance needed to cross the road using it.

Although the time required to cross the road directly is perceived to be the shortest, the negative sign of the waiting parameter suggests that the waiting time needed to find a gap when crossing directly makes the alternative less attractive. The same happens with the signalized crossing alternative where pedestrians must wait for their right of way. Some pedestrians might choose to cross the road directly but accept smaller gaps or run instead of walking, given individual impatience.

The magnitude and positive sign for the habit parameter suggest that previously made decisions strongly condition pedestrian behavior. Studying how habit affects the choices of pedestrians is an issue that should be further explored. The use of latent variables can help this purpose.

The crash parameter is negative and significant, indicating that a higher number of pedestrians killed or injured by traffic accidents in the area decreases the probability of using the direct crossing alternative. The opposite happens when it comes to robberies. The positive and significant parameter indicates that, as the number of robberies registered at the pedestrian bridge and signalized crossing increase, individual preference for the direct crossing also increases.

The parameter of the baggage variable is negative and not significant. This parameter is maintained in the model because it is not a policy variable, but it could help understand behavior. It suggests that if people carry some baggage, they will prefer the signalized crossing. The previous could imply that respondents do not feel safe making direct crossing maneuvers while carrying items because it limits their mobility. Also, they would avoid the extra effort of climbing the pedestrian bridge in that condition.

Regarding the separate models, the RP results show that, given the nature of the data, the list of variables that can be estimated is

Table 6
Model log-likelihood.

	SP-RP Combined model	RP Model	SP Model
Log-Likelihood	−1277.9	−68.84	−1205.7

limited; also, only the destination parameter was significant. The $ASC_{BridgeRP}$ constant represents something opposite to the expected considering the previous literature. According to this, *ceteris paribus,* pedestrians would prefer to cross the road using the pedestrian bridge instead of crossing directly. More variables could be estimated for the SP model, and better results were obtained. However, a critical decision variable such as the walking distance has a very low significance.

Comparing the results of our combined RP-SP model with previous findings from the state-of-the-art, we can conclude that pedestrian behavior has common patterns among different contexts, especially between the global South. They generally try to use the alternatives that let them save time and effort but remain concerned about their safety and personal security. Results also confirm that, as expected given previous findings, the pedestrian bridge was the least preferred alternative as it may promote equity and accessibility issues.

The combined model's main results provide more information than any of the separate ones. It indicates that attributes with the most influence in respondent crossing choices were the walking distance, the waiting time needed to find a gap, their previous choices when crossing the road, and their safety in terms of robberies. Other influential factors were safety regarding the chances of being involved in a traffic accident, the facility location in terms of the crossing destination, and the cost of a possible fine for crossing outside designated facilities. As suggested by the literature, a likelihood ratio test was performed to test whether attributes **X** can be considered as common to both data sets. Let $l^*\left(\beta^{RP}\right)$ be the log-likelihood for the model with RP data only, $l^*\left(\beta^{SP}\right)$ the log-likelihood for the model with SP data only, and $l^*\left(\beta^{SP},\beta^{RP},\mu\right)$ the log-likelihood of the joint RP-SP model. If the k common parameters are equal, then:

$$\boldsymbol{LR} = \left| -2\left\{l^*\left(\beta^{SP},\beta^{RP},\mu\right) - l^*\left(\beta^{SP}\right) - l^*\left(\beta^{RP}\right)\right\}\right|$$

distributes x^2 with k degrees of freedom (Louviere et al., 2000). Table 6 presents the log-likelihood values obtained for the combined RP-SP model and the RP and SP models specified separately.

The LR value is equal to 6.72. Considering $k = 2$, given that common parameters are the walking distance and waiting time, the critical x_k^2 value at the 99% confidence level is 9.21. Since the LR value is less than the critical value, the set of common attributes is well specified.

7. Implications

One of the main advantages of including the SP component in the data pooling technique is that it allows for the inclusion of attributes of interest that are not easy to measure, do not vary enough, or are currently not in the RP domain.

It is not usual for pedestrians to consider a monetary cost attribute when studying crossing behavior. In that sense, including a cost attribute in the form of a fine for jaywalking allowed for estimating individual willingness to pay for the built environment and other characteristics associated with the area where the crossing occurs. Also, the model formulation allowed estimating marginal substitution rates to understand how individuals are willing to trade one attribute for another while maintaining the same utility. Individual willingness to pay and marginal substitution rates are valuable tools for urban planners and decision-makers. These measures let them better understand individual expected behavior when implementing different policies or development projects.

The estimated measures show that if the pedestrian must walk more than 100 m to use the pedestrian bridge, it will not be an attractive crossing alternative even if it matches their destination. The model also indicates that if the destination matches the location of the signalized crossing, the pedestrian would be willing to walk almost 190 m to use this crossing alternative.

If the pedestrian must wait on average more than 2.7 min to make their crossing maneuver directly, *ceteris paribus,* the person would prefer other crossing alternatives. However, it is unlikely that individuals would wait over 2.7 min until they found an acceptable gap to cross the road directly.

Even though pedestrians carrying baggage showed to prefer the signalized crossing, if they have to walk more than 115 m to get to this crossing alternative, they would prefer to cross the road directly. Regarding their risk-taking, only frequent traffic crashes involving pedestrians would make respondents prefer to cross the road using the facilities available. More than 30 accidents per year would make them use the signalized crossing, while 98 events per year would make them choose the pedestrian bridge.

Personal security is another crucial aspect when choosing where to cross the road. As noted in the results section, as the frequency of robberies at crossing facilities increases, the preference for direct crossing also increases. The marginal substitution rate indicates that if the frequency of robberies at these facilities could be less than 47 per year, people would consider crossing the pedestrian bridge or the signalized crossing instead of doing it directly.

The habit variable showed that people tend to cross the road using the previously chosen alternative. However, as expected, changes in the alternative attributes could break the habit. For example, the model suggests that if the average frequency of robberies at crossing facilities is tripled, they would stop using them and prefer direct crossings. In addition, the above suggests that pedestrian bridges or signalized crossings located in insecure areas would be wasted resources without appropriate strategies to guarantee pedestrian security.

Regarding willingness to pay measures, they depend on the SES level. As expected, wealthier pedestrians are willing to pay more to avoid robbery or being injured than individuals with a low-income. Respondents with Medium- and high-incomes would pay COP $1,321/pedestrian/trip to prevent theft in the area, while individuals with a low-income would pay COP $673 /pedestrian/trip. Also, individuals with medium- and high-incomes are willing to pay COP $17,179 /pedestrian/trip to avoid dying or being injured when crossing the road, while respondents with a low-income would pay COP $8,745 /pedestrian/trip.

Pedestrians would consider crossing using the pedestrian bridge only if the penalty for crossing directly is higher than 220.000 COP. However, people with a low-income would only consider crossing using a pedestrian bridge if the penalty for crossing directly is higher than 180.000 COP. The above values are very high compared to the current jaywalking fines. However, using fines as a strategy to enforce safe crossings can discourage walking. Other strategies such as providing appropriate signals; keeping at level crosswalks by raising or depressing vehicle flows; using tactical urbanism to channel pedestrian movements, and conducting pedestrian orientation programs are more suitable.

8. Limitations

This research faced some limitations that could be addressed in future research. Even though variables such as traffic flow, number of dead and injured by traffic accidents, and number of robberies were considered in the SP scenarios, the levels used in the design were approximations from secondary information. Further studies should consider traffic flows, accidents, and robbery rates from specific locations.

On the other hand, there was not enough variability between locations regarding the number of lanes to analyze the effect of this variable. Also, the surveys were conducted during the day, not allowing us to estimate the impact of differences in time of the day and illumination. Another intriguing effect that was not addressed was the behavior of individuals with disabilities or limited mobility since the individuals surveyed were selected randomly. No respondents with these characteristics were spotted at the locations.

9. Conclusions

The need for suitable pedestrian crossings is a priority for urban developers and planners, given the high rate of traffic crashes involving injured or killed pedestrians. However, traffic conditions, especially in developing countries, are usually characterized by low accessibility, poor public transport, congestion, and inadequate facilities for non-motorized transportation. Road development projects tend to focus on securing mobility for vehicles rather than pedestrians in these contexts. There is little guidance on how different pedestrian crossing facility designs contribute to the attractiveness and safety of the walking environment. Policies and guidelines proposed to improve pedestrian safety should be based on knowledge of pedestrian perceptions and behavior. This is the only way for investments and efforts to serve their purpose.

This paper provides more insight on this subject by modeling pedestrian behavior when crossing urban streets using a new approach for this context. The data was collected in Barranquilla (Colombia) and used to estimate a mixed logit model considering panel effects and allowing scale differences from RP and SP data sources. The data pooling technique allowed for studying the actual choice of individuals considering conditions and limitations present at the moment without bias. Also, the pooling technique allowed for considering alternatives that were not currently available and assessing new public policies, such as implementing higher monetary fines. As a result of the data combination and the inclusion of a cost attribute, individual willingness to pay measures and marginal substitution rates were estimated. Estimating these measures helped derive policy implications from the model results.

Model results suggest that pedestrian behavior is complex and that many attributes affect their crossing decisions. They effectively weigh risks and costs when choosing where to cross a road. Furthermore, pedestrians dislike using pedestrian bridges, although they consider them the safest crossing alternative. Generally, pedestrians prefer at grade crossings. Remarkably, they prefer the direct crossing following the shortest trajectory to their destination. Therefore, crossing options that allow direct access to the destination without detours are more appreciated.

Waiting time; walking distance; safety (number of pedestrians killed or injured); location of the crossing facility in relation to the pedestrian destination; cost (i.e., monetary fine for crossing directly through unauthorized places); number of robberies in the area, and previous decisions are variables that influence pedestrian behavior when crossing urban roads.

When estimating the marginal substitution rates, the main findings suggest that if the pedestrian must wait, on average, more than 2.7 min to cross directly, *ceteris paribus*, the person would prefer other alternatives. Also, if the pedestrian must walk more than 100 m to use the pedestrian bridge, even if the pedestrian bridge matches their destination, it will not be an attractive crossing alternative. A substantial increase in robberies would break the individual habit of using pedestrian bridges and signalized crossings regarding personal security.

Finally, although the approach presented is attractive to estimate willingness to pay values, we suggest considering intentions and crossing habits to enhance the understanding of pedestrian behavior. Hybrid choice models and latent variables should allow this analysis. Notably, the theory of planned behavior and the health belief model can theoretically guide which latent constructs to include in the analysis. Future studies may also include variables related to roadway configuration (number of lanes), traffic speed and pedestrian disabilities.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

None

1. APPENDIX A

Table A1.

Table A1
Literature review summary.

Attributes considered	Data source	Modeling technique	(Authors) Location
Pedestrian profile, crossing patterns, crossing controls, pedestrian's priorities, perceptions on right of way and safety, crossing choice reasoning, crossing compliance.	Via e-mail survey to pedestrians and video recordings	Statistical analysis and compliance rate calculation	(Sisiopiku & Akin, 2003) Delhi, India
Age, gender and driver status (driver-not driver).	Questionary applied to pedestrians	Theory of planned behavior. Principal component analysis	(Holland & Hill, 2007) Birmingham, England
Evaluations about public facilities, amount or location of pedestrian overpasses, pedestrian crossing, subway to cross the road and traffic light latency time	Questionary applied to pedestrians	Theory of planned behavior. Structural equation model	(Li et al., 2009) Chongqing, China
History of fatalities and injuries, number of lanes to cross, speed limit, crossing type, walking time and Council rate/housing rent increases.	Stated preferences survey	Mixed logit model	(Hensher et al., 2011) New South Wales, Australia
Pedestrian, trip, road link and crossings' characteristics, traffic conditions, number and location of crossings, walking speed, travel distance, number of lanes, traffic gap, etc.	Pedestrians' trip video recording	Parametrization of topological road network to identify crossing alternatives. Then discrete choice model (MNL, Nested, cross-Nested)	(Papadimitriou, 2012) Athens, Greece
Vehicle speed, Stopping Sight Distance (SSD), yield rate.	Observer measuring vehicle speed with radar gun and recording yielding behavior	Linear regression analysis	(Bertulis & Dulaski, 2014) Boston, USA
Collision's information, pedestrian and vehicle flows, vehicle speed, crosswalk markings and condition, crossing distance (meters), number of radiating roads, the number of crossing segments, information from the intersection, presence of traffic control signals or pedestrian signals.	Reports of pedestrian- vehicle collisions from Police department and on-site measurements.	Conditional logistic regression	(Quistberg et al., 2014) Lima, Peru
Pedestrian information, trip information, schedule delay, traffic flow, walking distance and companionship from a minor.	Stated preference survey and latent variable questionnaire	Hybrid choice models	(Cantillo et al., 2015) Bogota, Colombia
Gender, age, items carried, group size, vehicle speed limit and distance, safety margin and crossing time.	Video recordings of illegal crossings and questionnaire	ANOVA analysis	(Demiroz et al., 2015) Izmir, Turkey
Road and crossing type, traffic conditions, demographics, mobility and travel motivations, attitudes, perceptions and preferences, self-assessment and identity, behavior, compliance and risk taking, opinion on drivers.	Questionnaire and field trip observation	Statistical analysis	(Papadimitriou et al., 2016) Athens, Greece
Age, gender, length of tenure in the city, previous crossing choices, crossing frequency, safety, risk perception, prior exposure to pedestrian crashes, general crossing motivators to understand crossing behavior.	Qualitative survey applied to crossing pedestrians	Statistical analysis	(Sinclair & Zuidgeest, 2016) Cape Town, South Africa
Pedestrian characteristics and attitudes, trip purpose, time requirement, intersection familiarity, tolerable waiting time and time segment.	Stated preferences survey	Binomial logistic model	(Zhang et al., 2016) Hefei, China.
Position of the pedestrian (by GPS and if on the road or walkway), crossing location, speed of the recording vehicle, pedestrians age, gender, movement, road type and features.	Recordings from vehicle mounted cameras	Binary logistic model	(Jha et al., 2017) Delhi, India
Footbridge crossing frequency, safety, security in terms of crime, traffic conflicts, previous injuries, and footbridge proximity	On-site survey	Logistic regression	(Oscar Oviedo-Trespalacios & Scott-Parker, 2017) Barranquilla, Colombia
Ambient light conditions, accidents severity, drivers age and gender, pedestrians age and gender,	Recorded frequency of road traffic collisions	Odds ratios and regression discontinuity analysis	(Uttley & Fotios, 2017) United Kingdom

(continued on next page)

Table A1 (*continued*)

Attributes considered	Data source	Modeling technique	(Authors) Location
road speed limit, weather, and presence of pedestrian crossing.			
Pedestrians count and characteristics, footbridge use rate, vehicles count and speed, posted speed limit, road width, directional flow, number of lanes, fence installation, existence of a median, existence of a traffic light, number of stairways, bridge cover, lighting provision, and bridge surface	Field observation and questionnaire	Multiple linear regression models and chi-square tests	(Hasan & Napiah, 2018) Malaysia
Gender, age, crossing mode, waiting time at roadside, path or speed change while crossing, crossing with others, traffic volume, bicycle interference, pedestrian refuge, median guardrail, and vehicle speed.	Video recording of crossings	Ordered probit models for pedestrian-vehicle conflicts analysis (PVCA)	(Zhang et al., 2018) Wuhan, China
Characteristics of participants, walking trip purpose, perceived health and wellbeing, disabilities affecting mobility, and perceptions about traffic conditions, neighborhood and crossing facilities.	Qualitative interviews and Stated preferences survey	Mixed logit model	(Anciaes & Jones, 2018) England
Pedestrian characteristics, waiting time, crossing time, crossing strategy, traffic volume, vehicle gaps and post-encroachment time.	Videos from cameras near crosswalks	Pedestrian dynamic gap acceptance	(Poó et al., 2018) Wuhan, China
Traffic density, police presence, median barrier or fence, footbridge attributes (crowd, travel time, effort, footbridge security.	Stated choice survey and risk ladder component	Mixed logit and hybrid choice models	(Dada et al., 2019) Cape town, South Africa
Distance to pedestrian facility, # of pedestrians, traffic flow level, number of lanes, time of the day and type of survey.	Stated preference surveys were also collected using virtual reality	Multinomial and mixed logit models	(Arellana et al., 2020) Barranquilla, Colombia
Socioeconomic characteristics, trip purpose, frequency of crossing and using the bridge, past accidents, easiness, safety, hurry, tiredness, height and attractiveness of the footbridge, maps usage, perceived law enforcement in the safety field and on footbridge usage, safety training.	Intercept study	Decision tree analysis and Chi-square tests	(Hasan et al., 2020)
Waiting time, at grade walking time, foot over bridge crossing time, pedestrian's characteristics.	Video observation survey	Binary logit model	(Patra et al., 2020) Mumbai, India
Perceptions and attributes of the infrastructure, interaction with other modes, safety, and the emotions produced by sidewalks quality of service	On-site surveys	Structural equation modeling and latent variables	(Vallejo-Borda et al., 2020) Bogota, Colombia
Pedestrian's gender and age, day of week, number of people waiting, type of pedestrian lights, green duration, number of lanes, temperature, walking with children, among others.	Direct unobstructed roadside observations	Hypothesis tests (Chi-square and normality tests)	(Bendak et al., 2021) Sharjah, UAE
Total travel cost and network connectivity to find appropriate crosswalk locations.	Travel time for pedestrians walking network	Shortest cost path algorithm and Modified Dial algorithm	(Han & Chang, 2021) Seoul, Korea
Information about movement, looking behavior, hand gestures, and signals used, time of day and weather conditions, and some demographic data.	Observation protocol and questionnaire	Statistical analysis	(Lee et al., 2021) Leeds, Munich, and Athens
Individuals socioeconomic characteristics, age and gender, attitude, habit, mid-crossing goals, social norms, perceived behavioral control, and behavioral intention.	On-site survey	Theory of planned behavior, factor analysis and structural equation modelling	(Soathonge et al., 2021) Auckland, New Zealand
Risky behavior categories such as: usage of pedestrian bridges or crosswalks, usage of cellphone while crossing, looking when crossing, unsafe crossing patterns.	Recorded videos	Binary logistic regression	(Zareharofteh et al., 2021) Iran
Pedestrian's age and gender, presence of a companion, number of pedestrians waiting, presence of a non-complier, geometric design, signal red time and maximum waiting time, two staged crossing, traffic volume, percentage of heavy vehicle and number of traffic lanes.	Video observation survey	Random parameter logit regression models	(Zhu & Sze, 2021) Hong Kong, China

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