PEDESTRIAN PREFERENCES WITH RESPECT TO ROUNDABOUTS – A VIDEO-BASED STATED PREFERENCE SURVEY

Mario Perdomo
Transport Research for Integrated Planning (TRIP) Lab
Department of Geography, Planning and Environment, Concordia University
1455 de Maisonneuve W. H 1255-15 (Hall Building)
Montréal (QC), Canada H3G 1M8
Tel.: (514) 848-2424 ext. 3310
E-mail: icimcp@gmail.com

Ali Rezaei
Transport Research for Integrated Planning (TRIP) Lab
Department of Geography, Planning and Environment, Concordia University
1455 de Maisonneuve W. H 1255-15 (Hall Building)
Montréal (QC), Canada H3G 1M8
Tel.: (514) 848-2424 ext. 3310
E-mail: a.rezaaei@gmail.com

Zachary Patterson (corresponding author)
Transport Research for Integrated Planning (TRIP) Lab
Department of Geography, Planning and Environment, Concordia University
1455 de Maisonneuve W., H 1255-15 (Hall Building)
Montreal (QC), Canada H3G 1M8
Tel: (514) 848-2424 ext. 3492
E-mail: zachary.patterson@concordia.ca

Nicolas Saunier
Polytechnique Montréal
C.P. 6079, succ. Centre-ville
Montréal (QC), Canada H3C 3A7
Tél. (514) 340-4711 poste 4962
Email: nicolas.saunier@polymtl.ca

Luis F. Miranda-Moreno
Department of Civil Engineering and Applied Mechanics, McGill University
Room 268, Macdonald Engineering Building, 817 Sherbrooke Street West
Montreal (QC), Canada H3A 2K6
Tel: (514) 398-6589 Fax: (514) 398-7361
E-mail: luis.miranda-moreno@mcgill.ca

7,182 words + 1 Figure + 3 tables

ABSTRACT

Research on user behavior and preferences has been a helpful tool in improving road safety and accident prevention in recent years. At the same time, there remain some important areas of road safety and accident prevention for which user preferences, despite their importance, have not been explored. Most road safety research has not explicitly addressed vulnerable user (pedestrians and cyclists) preferences with respect to roundabouts, despite their increasing construction around the world. The present research stems from the fact that studies related to roundabout safety have generally focused on drivers, while overlooking the importance of safety as it relates to vulnerable users, especially pedestrians. Moreover, it handles this particular issue through an approach that has not been used so far in this context; the Stated Preference (SP) survey. As such, there are two main goals (and contributions) of this work. First, to show how SP surveys can be used to investigate the importance of different design and operational features to pedestrian perceptions of safety in roundabouts. This allows us, for example, to quantify how some features of roundabouts (e.g. high traffic volume) can be compensated for by design features such as pedestrian islands. This is useful in helping to design roundabouts that pedestrians prefer and will hopefully use, to help encourage active transport. Second, to demonstrate how traffic simulation software can be successfully used to include difficult-to-communicate attributes in SP surveys.

Keywords: *Roundabouts, pedestrians, stated preference methods, vulnerable user safety*

1. INTRODUCTION

Developed initially in the UK in the 1960s, roundabouts have become increasingly popular in the last two decades in North America. Roundabouts are circular intersections where traffic flows counter-clockwise around a central island, preventing vehicles from crossing in a straight, and therefore faster, path. These intersections work based on the principle that vehicles entering the roundabout must yield to those already traveling within the central circle (Rodegerdts *et al.* (2010), pp. 3-5).

There are several commonly identified benefits of roundabouts compared to regular intersections that have been documented in the significant body of research on the topic. These benefits can be divided into different categories including environmental (e.g. reduced emissions because of increased fluidity of traffic flow, in particular fewer stops), mobility (increased fluidity of traffic flow compared with regular intersections), and safety (fewer accidents) improvements - the former of which can be further classified between driver and vulnerable user safety benefits.

How roundabouts improve driver safety is an issue addressed in the majority of the studies on the topic, although in some cases vulnerable road users (cyclists and pedestrians) are also considered. In the literature focusing mainly on motorists it has been shown that for these users, roundabouts are safer than other types of intersections, both in terms of frequency of accidents and their severity (Bared *et al.* 1997, Bie *et al.* 2008, Chen *et al.* 2013, Gross *et al.* 2013). On the other hand, Daniels *et al.* (2010a), (2010b) found that vulnerable road users have a higher probability of being injured in roundabouts than expected based on their share of occupancy in traffic. Daniels *et al.* (2010a) also found that some geometric elements such as the presence of bicycle lanes inside roundabouts are a significant risk factor. At the same time there is a bit of literature that has touched on the question of vulnerable road users in roundabouts, according to Wall *et al.* (2005) there are simply not enough studies related to the safety of this type of roundabout user, despite the importance of the subject.

While there has not been much research on the safety of vulnerable road users in roundabouts, pedestrian safety has attracted increased attention recently. Different approaches have been proposed to map injury risk and/or identify factors associated to injury frequency or severity of pedestrians using traditional methods based on historical crash data, but many of these have been focused on intersections or crosswalks (Harwood *et al.* 2008, Clifton *et al.* 2009, Miranda-Moreno *et al.* 2011). To address some of the issues of traditional crash-based methods, surrogate safety methods have also been proposed to investigate pedestrian safety using field observations such as video data (Ismail *et al.* 2009). While there is an important body of literature on objective safety using crash-risk or surrogate measures, the literature on safety perception is limited, in particular at roundabouts (Li 2006, Ren *et al.* 2011, Brosseau *et al.* 2013, Lipovac *et al.* 2013). Papadimitriou *et al.* (2013) focuses on pedestrian perceptions of intersection safety with respect to traffic characteristics such as vehicle volume and vehicle speeds. De Brabander and Vereeck (2007), Xi and Son (2012) on the other hand concentrate on statistical analyses of pedestrian accidents and injuries, but do not consider pedestrian preferences or behavior explicitly. Finally, Meneguzzer and Rossia (2011) examine the empirical relationships between pedestrian occupancy of crosswalks and impedance to vehicle flow in roundabouts. Despite there being a literature on roundabouts, and there being a literature on pedestrian safety, there is little research that focuses exclusively on pedestrian safety in roundabouts, especially when compared with how much literature there is for drivers. Perhaps the most comprehensive research focused on pedestrian safety in roundabouts is Report 674 of the National Cooperative Highway

Research Program (see Schroeder *et al.* (2011), pp. 34-61), which gathers various studies of the National Research Council of America on roundabouts. In the report, different roundabout attributes are studied in order to provide specific recommendations for their construction. While some of the research surveyed in the report looks at pedestrian preferences with respect to roundabouts, none of that research broached the question by means of an Stated Preference (SP) survey.

SP surveys have been used in a limited number of situations to understand vulnerable road user preferences and behavior. The method has been used for example to better understand cyclist preferences, although never in the context of roundabouts (see e.g. Krizek (2006)). Furthermore, pedestrian preferences and behavioral analyses have been confined to: route choice and behavior at intersections (Papadimitriou *et al.* 2009); the influence of perceived level of safety at an intersection and where pedestrians cross (Li 2006); preferences with respect to pedestrian crossing facilities (Sisiopiku and Akin 2003) and pedestrian-motorist interactions at intersections (Kaparias *et al.* 2012).

Another field related to this research is that on the use of visual aids in transportation SP surveys. Studies by Taylor and Mahmassani (1996), Krizek (2006) and Arentze *et al.* (2003) can be observed as evidence of the good results that visual aids can produce in SP surveys. Particularly interesting is the work of Krizek (2006), where the use of visual aids (10-second video clips of bicycle paths) was reported to improve survey performance markedly.

In summary, the existing literature on roundabouts has focused on motorists and has mostly ignored vulnerable road users, despite an explosion in research and interest of this subject recently. Moreover, despite being used to successfully understand user preferences in other branches of transportation research, there has been no research to have explored the use of SP surveys to understand pedestrian preferences with respect to safety in roundabouts.

Understanding pedestrian preferences and behavior is an important goal in order to help encourage the use of active modes of transportation (see e.g. NCHRP report 674 (Schroeder *et al.* 2011)). Also, the use of visual aids in SP surveys to understand preferences, especially those that are difficult to communicate in words – and particularly in the context of vulnerable road users – is in its infancy.

As such, this research contributes to existing literature along these dimensions through the use of a video-based stated preference survey of pedestrian preferences in terms of safety with respect to roundabouts. There are two main goals of this work. First, to show how SP surveys can be used to quantify the importance of different design and operational features to pedestrian perceptions of safety in roundabouts. This allows us to quantify how some factors such as high traffic volume can be compensated for, by design features such as pedestrian islands. Second, to demonstrate how traffic simulation software can be successfully used to include difficult-to-communicate attributes in SP surveys.

The paper continues with a description of the development and administration of the survey. This is followed by a description of the statistical model used to analyze the data, model results and interpretation. The paper is finished with a discussion and conclusion of the results as well as a few notes on future work.

2. METHODOLOGY

An SP study typically involves a long process that includes: the design, administration and analysis of collected data (Louviere *et al.* 2000, Arentze *et al.* 2003, Chu *et al.* 2004, Papadimitriou *et al.* 2009, Kelly *et al.* 2011, Kaparias *et al.* 2012). In the present research, the purpose of the survey was to understand what factors (and to what degree those factors) influence vulnerable user preferences with respect to roundabouts in terms of safety. The first step in the development of an SP survey is an examination of the existing literature to understand what characteristics and attributes have been considered important in previous relevant studies. TABLE 1 provides a summary of relevant work for pedestrian safety where vulnerable road user safety has been considered, focusing on the attributes (geometrical and operational) and their levels that have been used and evaluated in them. The literature is categorized by the type of intersection considered (traditional or roundabout) and the methodological approach adopted (SP or Other). This organization of the existing research allowed us to know which attributes (and their levels) have been found to be important in previous vulnerable user safety studies.

TABLE 1 Attributes and Levels Used in Existing Literature for analyzing Vulnerable Road User Safety of Regular Infrastructure and Roundabouts

Attribute	Levels	Vulnerable Road User safety analysis for traditional infrastructure		Vulnerable Road User safety analysis in roundabouts	
		By other methods	Using Stated Preference	By other methods	Using Stated Preference
Traffic volume	Low, Medium, High.	(Sisiopiku and Akin 2003, Guo *et al.* 2012, Papadimitriou *et al.* 2013)	(Chu *et al.* 2004, Papadimitriou *et al.* 2009, Kelly *et al.* 2011, Kaparias *et al.* 2012)	(Hels and Orozova-Bekkevold 2007, Moller and Hels 2008, Daniels *et al.* 2010a, b, Macioszek *et al.* 2011, Schroeder *et al.* 2011)	-
Traffic speed	Low, Medium, High.	(Sisiopiku and Akin 2003, Guo *et al.* 2012, Papadimitriou *et al.* 2013)	(Chu *et al.* 2004, Papadimitriou *et al.* 2009, Kelly *et al.* 2011, Kaparias *et al.* 2012)	(Hels and Orozova-Bekkevold 2007, Moller and Hels 2008, Daniels *et al.* 2010a, b, Macioszek *et al.* 2011, Schroeder *et al.* 2011)	-
Pedestrian volume	Low, Medium, High.	(Sisiopiku and Akin 2003, Asano *et al.* 2010, Guo *et al.* 2012)	(Papadimitriou *et al.* 2009, Kaparias *et al.* 2012)	-	-
Signalization	No signalization, Yield, Speed limit, Pedestrian crossing.	(Sisiopiku and Akin 2003, Chaurand and Delhomme 2013)	(Chu *et al.* 2004, Papadimitriou *et al.* 2009, Kelly *et al.* 2011)	(De Brabander and Vereeck 2007, Moller and Hels 2008, Schroeder *et al.* 2011)	-
Pedestrian crossing location	In the entrance of intersection, Near the entrance, Far from the entrance	(Sisiopiku and Akin 2003)	(Chu *et al.* 2004, Papadimitriou *et al.* 2009, Kelly *et al.* 2011)	(Meneguzzer and Rossia 2011, Schroeder *et al.* 2011)	-
Physical barriers	Vegetation, Median, Non barriers	(Sisiopiku and Akin 2003, Papadimitriou *et al.* 2013)	(Chu *et al.* 2004)	-	-
(-) Nonexistent related work					

As can be seen, most of the research has considered the following attributes: traffic volume, traffic speed, pedestrian volume, signalization, pedestrian crossing location and the presence of physical barriers (e.g. pedestrian islands).

While the first step provides an idea of the attributes that are likely to be included in the survey instrument, further complementary studies, such as focus groups and pilot tests are necessary to establish which attributes should be included in the final survey instrument. This constitutes a second step in survey development. A focus group is an exploratory research tool where a group of potential respondents are asked to identify which attributes they consider to be important in the question (choice) of interest. While being asked what attributes are important, respondents are also asked what appropriate ranges and/or levels of those attributes are (see Louviere *et al.* (2000), pp. 257-258). In this study, a focus group of eight individuals was convened. The focus group participants were contacted by a survey company specializing in the recruiting and administering of surveys. They were contacted if they lived within 1km of roundabouts in the region of Montreal and were asked to participate if they had accessed a roundabout by foot in the past three months. Gender and age diversity were sought in the formation of the focus group. Participants were asked at the beginning to simply share what they thought about roundabouts. Afterwards, they were asked to share their perceptions in terms of particular roundabout attributes and their relation with safety perception. While previous literature served as a backdrop of what to expect, the particular attributes to be addressed were left open to the focus group participants to discuss.

Based on these discussions, five attributes from the literature review were confirmed to be important for potential respondents: Signs; Pedestrian crossing position – i.e. distance from the intersection (although a particular preference for this attribute was not predominant); Traffic volume (less traffic preferred); Traffic speed (slower traffic preferred) and Pedestrian volume (more volume preferred). These preferences with respect to roundabout characteristics were consistent with what has been found in previous literature (see e.g. Hels and Orozova-Bekkevold (2007), Daniels *et al.* (2010a)). In addition, participants brought up two new attributes: Number of lanes (fewer lanes preferred), and the presence of a pedestrian island (presence of a pedestrian island preferred). They also suggested a new level for the Signs attribute: “Flashing signs” (presence of signs preferred over no signs). Thus, the very first version of the survey to be tested – the Pilot Survey – included all of these seven attributes.

2.1. Pilot Survey

A pilot survey is a tool that aids in identifying the strengths and weaknesses of the survey instrument. In this case, it was conducted online in order to test not only the instrument itself, but also to test the administration and data collection procedures to be implemented in the final survey. The pilot version had essentially the same structure as the final version of the survey.

Six Choice Tasks with two alternative roundabouts for each were shown to 48 participants in the pilot survey. As a result of the pilot survey, Traffic Speed and Traffic Volume were redefined so that differences between low and high values of these attributes were easily discernible without being unrealistic. These values were tested once again through a simpler online survey. In addition, this test showed Pedestrian volume did not seem to affect respondent choices with respect to preferred roundabouts.

2.2. Final Survey Administration

The definitive version of the survey instrument was divided into the same four sections as the pilot version of the survey. As such, it was structured as follows:

- First section (six questions). Respondent and household general information.
- Second section (two questions). Transportation mode going through a roundabout and frequency with which they accessed roundabouts by each mode (driving, by car but not driving, by transit, cycling and walking) in the past three months.
- Third section (three questions). Safety perception and knowledge of roundabout functionality.
- Fourth section (six Choice Tasks).

Based on what focus group and pilot test analyses revealed, the final survey included the following attributes and their respective levels:

- Signs: Absence of signalization, presence of standard pedestrian and cyclist crossing signs, and flashing pedestrian and cyclist crossing signs. According to previous literature and the focus group, it was expected that pedestrians would prefer the presence of signs, and flashing signs in particular.
- Number of lanes: One or two lanes per direction. In this case it was expected that pedestrians would prefer a shorter crossing distance (one lane).
- Presence of a pedestrian island: With and without an island. It was expected that pedestrians would prefer the presence of an island.
- Distance of pedestrian crossing from the entrance of the roundabout: Absence of pedestrian crossing, crossing at the entrance of the roundabout, and crossing 5 meters from the entrance. In this case there was not a clear preference in focus groups, although existing literature and the pilot survey point to a preference for a crossing far from the entrance over other options.
- Traffic volume: Low and high volume (100 and 500 vehicles/h). These values were proposed after the results observed in the pilot survey. The main objective was to make the difference easy to perceive for respondents while at the same time ensuring realistic volumes. It was expected that pedestrians would prefer lower traffic volumes.
- Traffic speed: Low and high speed (22 and 65 km/h on average). As in the case of traffic volume, the intention in the simulations was to establish a clear difference between high and low speed levels, while at the same time ensuring realistic speeds. It was expected that pedestrians would prefer lower traffic speeds.

The alternatives of the individual Choice Task videos were created with VISSIM, a microscopic simulation tool developed by PTV Group for modeling multimodal traffic flows. The attributes of each of the alternatives of the Choice Tasks were pre-determined by experimental design (explained further below) and programmed in VISSIM so that each Choice Task was unique. A constant pedestrian volume was used in all simulations, based on findings from the pilot survey (i.e. respondents could not distinguish different realistic levels of pedestrian volume). FIGURE 1 shows a screen shot of one of the Choice Tasks that were viewed as embedded YouTube videos with the VISSIM simulations.

FIGURE 1 Example of a Choice Task in the on-line survey (1.5-column fitting image, color).

The first option shows a roundabout with one-lane roads, no island, regular signs, and a pedestrian crossing at the entrance of the roundabout. The second shows a roundabout with two-lane roads, pedestrian flashing signs, a pedestrian island and a pedestrian crossing far from the entrance of the roundabouts. While it is possible to distinguish the low (left Choice Task) and high (right Choice Task) traffic levels in this static photo, it is not possible to distinguish traffic speed, without watching the videos.

In Stated Preference surveys, the choice of levels of attributes characterizing choice alternatives must be done with great care. The determination of what attribute levels will characterize the alternatives in the choice tasks in a SP survey is referred to as the "experimental design" (see Louviere *et al.* (2000), pp. 83-131). For the final version of the survey our aim was to recruit 500 respondents. As such, we used an experimental design of 500 different versions of the survey. Each version was composed of six choice tasks involving two alternative hypothetical roundabouts (see Figure 1 for an example of one of the choice tasks). The versions themselves were obtained from Sawtooth Software, a software specialized in the development of SP surveys. Sawtooth offers different approaches (or strategies) to select experimental designs from the set of all possible choice task combinations, known as the full factorial design.

In this research we used the "balanced-overlap strategy". This strategy represents a trade-off between the random strategy and the complete enumeration strategy. The random strategy employs random sampling with replacement for characterizing concepts (or alternatives within the Choice Task), allowing an attribute to have identical levels across concepts, but not identical concepts in all attributes within the same task. With the complete enumeration strategy, all possible concepts are considered, while ensuring the most nearly orthogonal design for each respondent in terms of main effects. The balanced overlap strategy allows roughly half as much overlap within the same task as the random method. With respect to design efficiency (the minimization of the standard error of coefficient estimates), the balanced overlap strategy is less efficient than designs with minimal overlap, however it can result in more thoughtful responses by encouraging respondents to trade-off between more alternatives (Sawtooth Software 2013). The design in this study was 24 % less efficient than the most efficient design, but it allowed us to capture all attribute interactions.

For the final survey, a company specialized in web-based surveys and the administration of online research tools (Groupe Altus) was hired in order to recruit the 500 respondents qualifying for the survey. In order to qualify, respondents needed to: be 18 years old or older; live within a buffer of 1 km from a roundabout (as was done in the work by Goudie (2002), Kelly *et al.* (2011) and Krizek (2006) where only respondents located within a specific buffer were considered for the survey); and have walked through a roundabout in the past three months. In order to select possible respondents within a 1 km buffer, the company administering the survey was provided with coordinates of all roundabouts in Quebec.

The survey was conducted during the first week of July, 2013, finishing with 501 completed online surveys. Before proceeding to the estimation of the final models presented below, some data cleaning was done. Data cleaning is considered to be a critical and necessary step of stated choice analysis. Guidance and examples of data cleaning by leaders in stated preference analysis can be found in Hensher et al. (2005) , as well as in Hess *et al.* (2010). The approach we used was similar to Hess *et al.* (2010). In particular, all of the choice tasks were examined and respondents who chose choice tasks that were dominated (i.e. the alternative had at least one better attribute and no worse attributes – based on preferences found in the literature and confirmed in focus groups, see last paragraph of section 2) were removed from the analysis. Altogether this represented 14 % of the respondents.

2.3. The Multinomial Logit Model and the Mixed Logit Model

The last stage of a Stated Preference survey is the statistical analysis of respondent choices. This is most typically done through the use of discrete choice statistics. This section describes the statistical model used.

This description of the multinomal logit (MNL) and mixed multinomial logit models draws primarily on Kenneth Train's book *Discrete Choice Methods with Simulation* (Train 2009). It is kept brief since comprehensive explanations can be found in many other references.

The logit model is used when trying to explain discrete choices; choices among several mutually exclusive alternatives.

According to random utility theory, a decision maker (n) will choose the alternative (i) that provides them the highest utility. It is important, nonetheless, to understand that: only the decision-maker knows (intuitively) the utility of each alternative; whereas the researcher can only observe the choices made by, and some of the characteristics of, the decision maker. By analyzing the decision maker's choices, the researcher can estimate a representative utility function (the deterministic portion of the utility). This is typically represented as in equation *(1)*.

$$U_{ni} = V_{ni} + \varepsilon_{ni} \qquad \forall i \qquad (1)$$

Here, U_{ni} is the utility individual n obtains from alternative i. V_{ni} is the systematic portion of utility and ε_{ni} is the random error. V_{ni} can be re-expressed as in equation *(2)* where it is a linear combination of the model coefficients and alternative and decision-maker characteristics.

$$V_{ni} = \alpha_{ni} + \beta x_{ni} \qquad \forall i = 1, \dots, n \tag{2}$$

The error is unobserved and unknown and in fact, it is the assumption about its distribution that determines the model used to estimate the utility function. If the error is assumed to be independently and identically extreme value distributed, then the probability that the individual n chooses alternative i will be defined by the closed-form expression of the MNL:

$$P_{ni} = \frac{e^{V_{ni}}}{\sum_{j=1}^{J} e^{V_{nj}}} \tag{3}$$

Although this form of the MNL model makes it straightforward to estimate, interpret and use, the assumptions related to the error in this model are questionable in many choice contexts, such as when observations involve more than one response from the same person. The relaxation of such assumptions can be allowed by the use of models that require numerical integration, such as the Mixed Logit Model.

In the MNL model the coefficients for β are fixed across users. In contrast, the Mixed Multinomial Logit Model (MMNL) allows having a vector of random coefficients. Assuming the utility as varying over people, but being constant over choice situations for each person, the utility for alternative j in choice situation t by respondent n is $U_{njt} = \beta_n x_{njt} + \varepsilon_{njt}$, with ε_{njt} being independently and identically distributed (iid) extreme values over time, people and alternatives. Considering a sequence of alternatives for each time period $i = \{i_1, \dots, i_T\}$, the probability that a respondent makes this sequence of choice is defined as the product of logit formulas (see equation 4), since the ε_{njt}'s are independent over time.

$$L_{ni}(\beta) = \prod_{i=1}^{T} \left[\frac{e^{\beta'_n x_{nit}}}{\sum_{j=1}^{J} e^{\beta'_n x_{nit}}} \right] \tag{4}$$

The integral of this product over all values of β, is the unconditional probability:

$$P_{ni} = \int L_{ni}(\beta) f(\beta) d\beta \tag{5}$$

By integrating the product of logit formulas over all values of β, the correlation of errors across the choices of a given individual are captured. As with the MNL, the MMNL is also capable of identifying random sources of heterogeneity, making these choice models less restrictive than models that assume fixed βs.

3. RESULTS

TABLE 2 shows the results for the MMNL model estimated with the survey data. Since we used stated choice data with multiple responses from each respondent, we estimated a panel MMNL to account for correlation across respondents. The model has right-signed coefficients (signs of the coefficients are consistent with our expectations based on the existing literature and focus group), that are all significant at the 90% confidence level. The presence of a pedestrian crossing far from the entrance of the roundabout was found to be the attribute that would increase the odds of an alternative roundabout being chosen the most. The segmentations shown in this model suggest that those users not living in Greater Montreal are less sensitive to the number of lanes than those living in Montreal. This is likely explained by the fact that those living in Montreal are more accustomed to roundabouts with more lanes, and as result are less sensitive to this design feature. Those who live outside of Montreal but frequently access roundabouts by foot are more sensitive to speed than the rest of respondents. This is likely explained by the fact that higher speeds are more expected in suburban and rural areas. The model also shows that four variables (pedestrian crossing at the entrance of the roundabouts, pedestrian crossing 5 m from the entrance, number of lanes and presence of island) are specified to have normally distributed random coefficients.

TABLE 2 Multinomial Mixed Logit Model Results for Pedestrian Preferences with Respect to Roundabouts in Quebec

Attributes	Segmented MMNL		
	Coefficient	*t*-Statistic	exp (β)
Presence of regular signs	0.422*	1.67	1.526
Presence of flashing signs	1.117***	4.29	3.055
Number of Lanes	-0.997***	-6.25	0.369
Interacted with not in Great Montreal area dummy variable	0.370*	1.88	1.448
Presence of island	0.737***	6.78	2.091
Pedestrian crossing at the entrance	2.689***	8.45	14.710
Pedestrian crossing 5 m from entrance	4.273***	10.67	71.736
Traffic volume (veh/h)	-0.163***	-6.64	0.849
Traffic speed (10 km/h)	-0.648***	-2.72	0.523
Interacted with pedestrain who mainly walk through a roundabout not in Great Montreal area dummy variable	-1.190**	-2.00	0.304
Number of random coefficients	4		
Number of lanes Standard Deviation	0.686***	2.96	-
Presence of Island Standard Deviation	0.716***	3.50	-
Pedestrian crossing at the entrance Standard Deviation	1.373***	5.38	-
Pedestrian crossing 5 m from entrance Standard Deviation	2.129***	6.91	-
Final Log Likelihood	-961.57		
Pseudo R^2	0.4623		
Number of parameters	14		
Degree of freedom (above base MNL model)	6		
$\chi^2_{(observed)} = -2[LL_{(base\ model)} - LL_{(new\ model)}]$	106.56		

* = Significant at 90% Confidence Interval (C.I.),

** = Significant at 95% C.I.

*** = Significant at 99% C.I.

The model suggests that there is taste variation across respondents with respect to these four attributes, especially with respect to the coefficient for having a pedestrian crossing 5 m from the entrance. For this attribute, such variation was also observed in focus groups – while some pedestrians appear to prefer the safer feeling of being further from the intersection, others prefer a more direct route. It is also interesting to observe that taste variations across respondents are only identified in infrastructure attributes and not in operational characteristics, showing that the perception of speed and volume (operational attributes) is more uniform across respondents. In addition, the log likelihood ratio test (Train 2009) in the MMNL model indicates that this model also offers better explanatory power than the base model at the 99% confidence level.

While these models are instructive, to better understand the results, it is helpful to get a sense of just how important each of the design and operational characteristics are with respect to each other. In order to do so, a substitution rates analysis was done. A substitution rate is an economic concept defined as "the amount of a particular item that must be given to an agent in order to exactly compensate that agent for the loss of one unit of another item" (Hensher *et al.* 2005). In the case of logit models, substitution rates can be obtained by dividing the coefficient of one variable with that of another. The most common substitution rate to be derived from Logit models is the money substitution rate, or the willingness to pay (WTP). This is obtained by dividing the coefficient for a given variable by the coefficient for price (see e.g. Train (2009), pp. 39). If the survey were about vehicle choice, for example, it would be possible to estimate WTP for vehicle fuel efficiency by dividing the coefficient of fuel efficiency by price. Although there is no price attribute in our case, we have estimated other non-monetary substitution rates, as shown in Table 3.

TABLE 3 Substitution rates for segmented MMNL model

	Number of lanes	Number of lanes Outside Greater Montreal	Traffic Volume (veh/h)	Traffic Speed (10 km/h)	Traffic Speed - Frequent Pedestrians Outside Greater Montreal
Presence of regular signs	0.42	0.67	2.59	0.65	0.23
Presence of flashing signs	1.12	1.78	6.85	1.72	0.61
Presence of Island	0.74	1.18	4.52	1.14	0.40
Crossing at the entrance	2.70	4.30	16.50	4.15	1.46
5 m crossing	4.29	6.82	26.21	6.59	2.32

TABLE 3 shows, for instance, that the negative effect of going from one lane to two lanes in a roundabout can be compensated by the presence of flashing signs (coefficient of flashing signs divided by coefficient of number of lanes = 1.12 – the substitution rate between these attributes). Substitution rates can also be calculated for changes in operational attributes. For example the presence of a pedestrian crossing at the entrance has the same effect on pedestrian preferences as decreasing traffic speed by ~41 km/h (substitution rate in Table 3 of 4.15, with the speed variable unit being multiples of 10 km/hr).

Such substitution rates can be helpful by suggesting how different elements could be traded off in the design of a particular roundabout in order to maintain the same degree of satisfaction that pedestrians feel towards them. It is useful to observe that, in general, the impact of those attributes that are difficult to control in practice (such as traffic speed and volume) in pedestrian safety perception, can be compensated through geometrical attributes easy to implement (e.g. by providing a pedestrian crossing).

Although the results confirm what we might expect by intuition (apart possibly from the location of crossings), the interest in using an SP analysis and estimating a discrete choice model lies in the ability to quantify the effect of each of the attributes, while controlling for the effects of all the other attributes.

4. DISCUSSION AND CONCLUSIONS

Both the administration of the SP survey and the analysis of its results provide a rich field for discussion. First, this research shows how Stated Preference methods are relevant (and as yet unused) in trying to better understand pedestrian preferences with respect to safety in roundabouts. As mentioned in the literature review, while SP methods have been used to understand pedestrian preferences at traditional intersections (Kelly *et al.* 2011, Kaparias *et al.* 2012) they have not been in roundabouts. Second, the modeling results and marginal substitution rates derived from them can be interpreted as recommendations of how to improve roundabout design in the eyes of vulnerable users in terms of safety, an application of these models that has not been explored before. Third, it is necessary to highlight the methods used for presenting Choice Tasks to respondents. As explained in the literature review, there is little research where videos (simulated or recorded) are used in Stated Preference surveys, apart from a few studies in other branches of transportation research (e.g. Taylor and Mahmassani (1996), Arentze *et al.* (2003), Krizek (2006)). These studies demonstrated the advantages of using recorded videos to communicate variables difficult to describe by text. Our study contributes to this by providing evidence for the advantages of using traffic micro-simulation videos to communicate operational features of roundabouts, i.e..traffic speed and volume.

A variety of pedestrian crossing positions can be found in roundabouts across Quebec, regardless of land use, levels of service of the road or neighborhood type where they are located. Our research shows that vulnerable users are more likely to prefer roundabouts in terms of safety perception if they have pedestrian crossings, confirming what other authors found for regular intersections (e.g. Sisiopiku and Akin (2003), Chu *et al.* (2004), Kelly *et al.* (2011)). Although many operational attributes are difficult to control in the field, respondents have demonstrated through the survey that they feel safer when traffic volume and speed are low. This is also consistent with previous research that has come to similar conclusions using other methods (see e.g. Hels and Orozova-Bekkevold (2007), Moller and Hels (2008), Daniels *et al.* (2010a), b)). Moreover, our research has found that vulnerable users consider flashing pedestrian crossing signs to be preferable than other (or no) signs – a resul not found in the existing literature.

Evidently, it is difficult to imagine that all roundabouts could be designed according to pedestrian preferences: pedestrian crossing flashing signs, one-lane intersections, presence of an island, pedestrian crossings far from the entrance and low traffic speed and volume; but it is well worth taking them into account when implementing this type of intersection in the region, encouraging, at the same time, the use of active modes of transportation. Moreover, through the substitution rate analysis it is possible to understand how to compensate vulnerable user safety perceptions for negative operational attributes that are difficult to control. In particular, the results show that negative attributes (such as an increase in speed, volume or number of lanes) can be compensated with different roundabout design features. It's particularly interesting to observe how safety perception from vulnerable users in roundabouts can be increased by relatively small changes, such as moving pedestrian crossings. Thus, the substitution rates obtained in this research can be a useful tool in the decision and policy making process related to roundabouts by providing guidance on how to trade-off different design and operational characteristics of roundabouts. The approach, for example, could be used to evaluate the effect on pedestrian perceptions of safety of roundabouts design guidelines such as those in TRB Report NCHRP Report 674: Crossing solutions at roundabouts and channelized turn lanes for pedestrians with vision disabilities (see e.g. Schroeder *et al.* (2011)).

5. FUTURE WORK

The innovative aspects of this current research suggest that there is plenty of room for testing findings and improving procedures. First, it would be interesting to compare the method presented here to a traditional text-based survey to evaluate which type of instrument would be better to use in this context.

More important, however, is the validation of these findings through the comparison between safety perception and actual safety and user behavior (such as the research based on direct behavior observation data funded by the FRQNT in the same larger project as this study). Although perceived safety is important for the acceptability of the design, the direct observation of user behavior and accident analysis relating to roundabouts and pedestrians (or vulnerable road users) would allow future research to propose well-defined recommendations in terms of safety regarding this type of intersection for these users.

6. ACKNOWLEDGEMENTS

This study is part of a larger project on the evaluation of roundabout safety in Québec, funded by the *Fonds de Recherche du Québec sur la Nature et les Technologies* (FRQNT), Transports Québec and *Fonds de la recherche en santé du Québec* (FRQS). We would like to acknowledge the support for this work from the Canada Research Chairs program, the Canadian Social Sciences and Humanities Research Council (SSHRC), as well as the Canadian Foundation for Innovation (CFI). The authors would also like to thank Paul St-Aubin for his help with the focus group, and Sandra Paola Montes for her valuable help in the development of VISSIM video simulations.

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