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Pedestrian Preferences with Respect to Roundabouts – A Video-Based Stated Preference Survey

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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 have not been explored. For instance, so far, most road safety research has not explicitly addressed pedestrian and vulnerable user preferences with respect to roundabouts, despite the increasing construction of these intersections around the world. The present research stems from the fact that studies related to roundabout safety have typically put drivers in a privileged position, while generally 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: the Stated Preference (SP) survey. As such, this paper describes the justification for, the methodology, the analysis and conclusions of an SP survey designed to obtain pedestrian and vulnerable user preferences with respect to roundabout facilities in Quebec. In addition to the fact that an SP survey has not been used in this context before, another innovative facet of the work lies in the use of traffic micro-simulation software to create videos that serve as alternatives in Choice Tasks in the SP survey. The study finds that pedestrian preferences for roundabouts are affected by: the presence of pedestrian crossings (and their location relative to the roundabout), signage, pedestrian islands, and the number of lanes of traffic that must be crossed. In addition to these design features, pedestrian preferences for roundabouts are also affected by the speed and volume of traffic – something we were able to evaluate thanks to the use of traffic simulation videos.

Keywords. Roundabouts, pedestrians, stated preference methods, vulnerable user safety.

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1. INTRODUCTION

For years, road safety research has focused on explaining and improving driver experience of roads and intersections. However, the increasing use of alternative transportation modes has raised attention to vulnerable users such as pedestrians and cyclists.

Whether they consider all kinds of users or only one, transportation researchers have used many different approaches to studying and improving safety. Perhaps one of the more complicated approaches is to attempt to model human behaviour and decision making processes. Commonly used approaches used to understand individual choices and preferences involve Stated Preference (SP) and Revealed Preference (RP) methodologies.

RP methods seek to understand peoples' preferences by asking about, and analyzing, decisions people have actually made. Since revealed data are not always available, SP methods are often used instead. These seek to understand people's preferences by asking them what decisions they *would* make in carefully constructed, hypothetical choice situations (Choice Tasks). The goal of SP surveys is to identify and quantify the effects of different attributes on respondent preferences for the choice being analyzed.

Understanding user preferences is important for many types of transportation infrastructure, but it is particularly important for roundabouts in Quebec because more and more are being built, even though roundabout user preferences for them are not well understood.

Adopted initially in the UK in the 1960s, roundabouts have become increasingly popular in the last two decades in North America. Roundabouts are characterized by a circular intersection where traffic flows counter-clockwise around a central island, preventing vehicles from crossing in a linear, 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. Although several statistical studies have shown their high levels of safety, there is still a lack of research where safety, behavior and preferences are analyzed in an integrated manner with respect to these intersections.

The Quebec provincial government, having built the first intersection of this kind in Canada in 1996, has shown interest in research relating to roundabouts. As such, the *Fonds de Recherche du Québec sur la Nature et les Technologies* (FRQNT), the Quebec Ministry of Transportation and the *Fonds de Recherche du Québec sur la Santé* are currently funding a project on the safety of roundabouts in Quebec, through three approaches: the statistical analysis of crash data, the direct observation of road user behaviour; the use of video surveillance data and a study of behavior and risk perception of vulnerable users.

Although roundabouts are seen as more efficient intersections in terms of capacity and Level of Service (LOS), existing literature shows that for these types of intersections, most of the safety research has been aimed at how drivers perceive them, while very little attention has been paid to vulnerable users and their preferences.

The research described here targets the lack of knowledge about vulnerable user preferences towards roundabouts. These preferences were analyzed through the use of an SP survey – the first of its kind. Specifically, this research sets out to achieve two goals: a) to understand and quantify the geometric and operational attributes that influence vulnerable user preferences for roundabouts in Quebec; and b) to evaluate the safety perceptions of vulnerable users (mainly pedestrians) with respect to roundabouts. It is worth mentioning that neither pedestrian preferences for, nor safety perceptions of, these types of intersections have been analyzed using an SP survey (for drivers or any other users). As such, the novelty of the exercise goes beyond safety research in the region. Moreover, as will be shown, the research used an innovative approach to SP task delivery: the use of software specialized in traffic micro-simulation to create videos of roundabouts according to an SP survey design.

Results of this analysis make it possible to identify and quantify the effect that different attributes have on pedestrian preferences with respect to roundabouts. It also allows for a comparison of the importance of attributes relative to each other. Finally it helps to provide specific recommendations to allow decision makers to propose safer and more comfortable roundabouts for pedestrians.

In order to do this, the paper first explores through a literature review, the relationship between safety, preferences, vulnerable users and roundabouts that have previously been studied. Then, the methodology used in the research (including the development and administration of the survey, as well as the analysis of the survey results) is described. This is followed by specific conclusions and recommendations relating to the relationship between roundabout facilities and vulnerable user preferences.

2. LITERATURE REVIEW

There are several commonly identified benefits of roundabouts that have been documented in the significant body of research on the topic. These benefits can be divided into different categories that include those relating to the environment, and mobility and safety - 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 users 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 outcomes (Bared *et al.* 1997, Bie *et al.* 2008, Chen *et al.* 2013, Gross *et al.* 2013). On the other hand,Daniels *et al.* (2010a), b) who did not distinguish between cyclists and pedestrians, found that vulnerable users have a higher probability of being injured in roundabouts than expected based on their share of occupancy in traffic. Also, Daniels et al. (2010a) find that some geometric elements such as bicycle lanes inside roundabouts are a significant risk factor. While there is a bit of literature that has touched on the question of vulnerable 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.

While there has not been much research on the safety of vulnerable users in roundabouts, pedestrian safety has attracted increased attention recently. Papadimitriou *et al.* (2013) focus 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 (Meneguzzer and Rossia 2011). Despite there being a literature roundabouts, and their being a literature on pedestrian safety, there is little research that focuses exclusively on pedestrian safety in roundabouts, 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 (Council 2011), which gathers together 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 SP survey.

SP surveys have been used in a limited number of situations to understand vulnerable user preferences and behavior. The method has been used for example to better understand cyclist preferences, although never in the context of roundabouts. Furthermore, pedestrian preferences and behavior 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 literature 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.

As can be seen from this literature review, an SP survey solely targeting pedestrians in roundabouts is an unexplored area of research. Moreover, 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 users – is in its infancy. As such, this research contributes to existing literature along these two dimensions.

3. METHODOLOGY

An SP study typically involves a long process that includes: the design, administration and analysis of the survey tool and 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. 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 shows a summary of the attributes that have been used and evaluated in the most relevant works where vulnerable user safety has been considered. The literature is categorized by the methodological approach used (SP or Other) and the type of intersection considered (traditional or roundabout).

TABLE 1 Attributes and Levels Used in Existing Literature for Evaluating the Pedestrians Safety of Regular Infrastructure and Roundabouts

Attribute	Possible levels	Evaluation of safety by other methods	Evaluation of safety using Stated Preference	Evaluation of safety in roundabouts by other methods	Evaluation of safety in roundabouts 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, Council 2011, Macioszek *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, Council 2011, Macioszek *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, Council 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)	(Council 2011, Meneguzzer and Rossia 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 are appropriate ranges and/or levels of those attributes. In this study, a focus group of six individuals was convened. 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. 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 was not predominant); Traffic Volume; Traffic Speed and Pedestrian Volume. In addition, participants brought up two new attributes: the Number of Lanes, and the Presence of a Pedestrian Island. They also suggested a new level for the Signs attribute: “Flashing signs.” Thus, the very first version of the survey to be tested – the Pilot Survey – included all of these seven attributes.

3.1. 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 and as such, 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 mode in the past three months.
- Third section (three questions). Safety perception and knowledge of roundabout functionality.
- Fourth section (6 Choice Tasks).

Six Choice Tasks with two alternative roundabouts for each were shown to 48 participants in the pilot survey. 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.

After analyzing data from the pilot survey, it was found that Traffic Volume, Traffic Speed and Pedestrian Volume didn't seem to affect respondent choices with respect to preferred roundabouts, contrary to what was reported in the literature and expressed in the focus group. After closer inspection and discussion with some of the pilot study respondents, we decided to remove Pedestrian Volume as an attribute for Choice Tasks, since roundabouts in Quebec are not subject to high or very different levels of pedestrian traffic in reality. With respect to Traffic Volume and Traffic Speed, it was found that respondents had difficulty distinguishing between the levels (high volume vs. low volume and high speed vs. low speed), thus explaining the apparent indifference towards these attributes.

As a result, these attributes were redefined so that differences between low and high values of Traffic Volume and Traffic Speed were easily discernible without being unrealistic. These values were tested once again through a simpler online survey, the results of which showed that variations in both volume and speed were easily distinguishable.

Once all attributes and levels, as well as survey questions, had been tested and adjusted where necessary, the survey was put together once again to be administered as the definitive survey instrument.

3.2. Final Survey Administration

The definitive version of the research tool was organized in the same manner as the pilot test: the first section focused on the respondent's socioeconomic status as well as household information; the second part related to mode and frequency of use of roundabouts; the third part provided revealed preference information on safety issues; and the fourth and final part was the Choice Task section. 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 island.
- Distance of Pedestrian Crossing from the Entrance of the Roundabout: Absence of pedestrian crossing, crossing at the entrance of the roundabout, a crossing 5 meters from the entrance. In this case there wasn't 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.

As explained above, a constant pedestrian volume was used in all simulations. FIGURE 1 shows screen shot of one of the Choice Tasks that were viewed as embedded YouTube videos showing VISSIM simulations.

FIGURE 1 Example of a Choice Task in the on-line survey.

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.

The final version of the survey was planned to be administered to 500 respondents. Thus, an experimental design of 500 different versions (different sets of the six Choice Tasks) was used. These versions were obtained from Sawtooth software, a software specialized in the development of survey tools for conjoint analysis. It offers different design strategies to create a fixed set of profiles by drawing from full factorial designs while considering possible prohibitions set by designers. In this research we used the balanced-overlap strategy. This strategy is a trade-off between the random and the complete enumeration (no overlap) strategies. It permits almost half as much overlap within the same task as the random method. While this approach is statistically less efficient than designs with minimal overlap, it can result in more thoughtful responses by encouraging them to trade-off between more alternatives (Sawtooth

Software 2013). The set design for this work was 24% less efficient than the 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; to live within a buffer of 1 km from a roundabout (based on 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 to have walked through a roundabout in the past three months. In order to select possible respondents within a 1km 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 necessary. To do this, 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) were removed from the analysis. Altogether this represented 14% of the respondents.

4. DATA ANALYSIS

Given that Quebec is a primarily French-speaking province, it is not surprising that 85% of respondents answered the French version of the survey. Additionally, 47% of the respondents were male, while almost 40% of them were between the ages of 40 and 59 years old, maintaining a proportion similar to the actual population in the greater Montreal area, where 52% of the population is between those ages. The location of respondents (entered by respondents as their 6-digit postal code) was mapped and corresponded with the location of roundabouts across the province. The statistical analysis of the survey data was done using a Multinomial Logit (MNL) model as well as a Mixed Logit Model (MMLM).

4.1. The Multinomial Logit Model and the Mixed Logit Model

The following description of the MNL draws primarily on Kenneth Train's book *Discrete Choice Methods with Simulation* (Train 2009). This description of the MNL is brief since comprehensive explanations can be found in many other references.

The logit model is used when trying to explain discrete choices; normally, choices among several mutually exclusive alternatives. Some of the applications of discrete choice modelling are the analysis and prediction of choices based on RP and SP data.

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; 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)*.

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

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 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 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:

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

Since the ε_{njt}'s are independent over time. 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.

4.2. Model Results

TABLE 2 shows the results for two different MNL models as well as MMNL model estimated with the data: the first multinomial model includes only the main attributes from the survey as variables. In this model, all variables have the expected sign and are significant at 95% confidence level, except for the presence of signs, which is significant at 90% confidence level.

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

	Base MNL Model			Segmented MNL Model			Segmented MMNL		
	Coefficient (β)	*t*-Statistic	exp (β)	Coefficient (β)	*t*-Statistic	exp (β)	Coefficient	*t*-Statistic	exp (β)
Regular signs	0.311	1.80	1.365	0.320	1.84	1.377	0.422	1.67	1.526
Flashing signs	0.706	4.07	1.483	0.715	4.10	2.044	1.117	4.29	3.055
Lanes	-0.531	-7.65	0.588	-0.695	-6.70	0.499	-0.997	-6.25	0.369
Lanes not in Great Montreal area	-	-	-	0.298	2.18	1.347	0.370	1.88	1.448
Island	0.506	7.29	1.659	0.509	7.32	1.664	0.737	6.78	2.091
Pedestrian crossing at the entrance	2.009	10.18	7.459	2.012	10.16	7.475	2.689	8.45	14.710
Pedestrian crossing 5 m from entrance	2.845	14.17	17.205	2.854	14.15	17.351	4.273	10.67	71.736
Traffic volume	-0.117	-6.80	0.890	-0.118	-6.83	0.889	-0.163	-6.64	0.849
Traffic speed	-0.605	-3.79	0.546	-0.477	-2.75	0.621	-0.648	-2.72	0.523
Traffic speed (People who mainly walk through a roundabout not in Great Montreal area)	-	-	-	-0.834	-1.89	0.434	-1.190	-2.00	0.304
Number of random coefficients	-			-			4		
Lanes Standard Deviation	-			-			0.686	2.96	-
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	-1014.85			-1010.04			-961.57		
Pseudo R2	0.4392			0.4352			0.4623		
Number of parameters	8			10			14		
Degree of freedom (above base MNL model)	-			2			6		
$\chi^2_{(observed)} = -2[LL_{(base\ model)} - LL_{(new\ model)}]$	-			9.62			106.56		

The difference between flashing signs and the presence of a sign (no matter which it is) shows how respondent are more sensitive to the presence of flashing signs, in fact, the presence of such a sign in a roundabout increases a roundabouts odds of being chosen by 48%. The presence of a pedestrian crossing in a roundabout is the design characteristic that increases the odds of preferring a given roundabout the most. If the pedestrian crossing is located far (5 meters) from the entrance, for instance, the odds of choosing it increase the most. As expected, the coefficients for number of lanes, traffic volume and traffic speed are negative, respondents prefer those roundabouts with fewer lanes, lower traffic volume and lower traffic speed.

While the base MNL model shows the preferences of all respondents, differences in preferences for different subgroups were also tested. The second MNL model in TABLE 2 shows a model with geographic and user-type segmentation. In particular: respondents from suburban and rural regions outside of Montreal were recognized as responding differently to the number of lanes; and respondents from outside of Montreal and who accessed roundabouts by foot frequently (more than 4 times a week) were recognized as responding differently to traffic volume. All coefficients for this model are right-sided and significant at the 90% confidence level. In this model, unlike the base model, it was possible to distinguish preferences between types of non-flashing signs. As such, the results are slightly different than the base model, but also allow for a richer interpretation. In this model, the presence of a regular sign in a roundabout would increase the odds of a roundabout being chosen by 38%, while the presence of flashing sign would increase its odds of being chosen by 104%. In the case of pedestrian crossing, the segmented model shows that as with the base model crossings located 5 meters from the entrance are preferred by respondents. With respect to the variables segmented by subgroup, those not living in the Greater Montreal area 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. In this model, the location of pedestrian crossings is still found to have an important impact on roundabout preferences with the presence of a crossing being the single most important design feature, with crossings further from the roundabout being preferred. The log likelihood ratio test (Train 2009) shows, in this case, that the segmented MNL model has a better explanatory power than the base model at the 99% confidence level.

So far, the segmented MNL model has captured systematic heterogeneity across respondents. Since this is stated choice data with multiple responses from each respondent, we wanted to be able to account for correlation across respondents using a panel MMNL. The MMNL shown in TABLE 2, as was the case for the MNLs, also has right-signed coefficients, all of which are significant at the 90% confidence level. Four variables (pedestrian crossing at the entrance of the roundabouts, pedestrian crossing 5m from the entrance, number of lanes and presence of island) are specified to have normally distributed random coefficients. This 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. 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, it is worth noting that 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 economical concept that defines the rate at which an individual is willing to give up one good (or characteristic) in exchange of another, while maintaining the same overall utility. The substitution rates for our results are calculated and shown in TABLE 3. It shows the substitution rates for the main attributes in all models. A clear example of the use of substitution rates in the base model is the case of number of lanes and the presence of a pedestrian island: TABLE 3 shows that when the number of lanes increases from one to two lanes, the negative effect of this utility can almost be compensated by adding an island to the intersection (0.95 substitution rate between this attributes). Similarly, the addition of a flashing sign could compensate for a 117km/h increase of traffic speed!

TABLE 3 also shows the substitution rates for the segmented MNL model. The substitution rates here suggest, for example, that it is more difficult to compensate users who frequently access roundabouts by foot and who live outside of Montreal for increases in traffic speed. At the same time, we see the opposite for people living outside Montreal with respect to the number of lanes: an increase of the number of lanes from one to two is more easily compensated with other attributes for them.

Substitution rates were also obtained for the segmented MMNL. TABLE 3 shows these rates that although have the same interpretation as the substitution rates of the segmented MNL model, the magnitude of them are different with some of the substitution rates being lower (e.g. number of lanes with respect to regular signs) while others are higher (number of lanes with respect to flashing signs).

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 degree of satisfaction that vulnerable users feel towards them.

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. Without a doubt, the results of the analysis can aid in proposing roundabout configurations that pedestrians prefer in terms of geometric and traffic control characteristics in Quebec.

TABLE 3 Substitution rates for base MNL model, segmented MNL model and segmented MMNL model

		Number of lanes	Number of lanes Outside Greater Montreal	Traffic Volume	Traffic Speed	Traffic Speed - Frequent Pedestrians Outside Greater Montreal
Base MNL Model	Regular signs	0.59	-	2.66	0.51	-
	Flashing signs	1.33	-	6.03	1.17	-
	Presence of Island	0.95	-	4.33	0.84	-
	Crossing at the entrance	3.78	-	17.18	3.32	-
	Five m crossing	5.35	-	24.32	4.70	-
Segmented MNL Model	Flashing signs	1.03	1.79	6.06	1.50	0.55
	Presence of Island	0.73	1.27	4.31	1.07	0.39
	Crossing at the entrance	2.89	5.03	17.05	4.22	1.53
	Five m crossing	4.11	7.14	24.19	5.98	2.18
Segmented MMNL Model	Regular signs	0.42	0.67	2.59	0.65	0.23
	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
	Five m crossing	4.29	6.82	26.21	6.59	2.32

5. DICUSSION AND CONCLUSIONS

Both the administration of the SP survey and the analysis of its results provide a rich field for discussion. First, it is necessary to highlight the methods used for delivering Choice Tasks to the respondents. As was alluded to in the literature review, there is little research where animations (simulated or recorded) are used in Stated Preference surveys. This research provides evidence for the feasibility of using micro-simulation videos in the context of SP surveys, particularly in the context of variables that would be difficult to communicate and be understood via text (e.g. traffic speed and volume).

The modeling results can be interpreted as recommendations for the improvement of roundabout configurations in order to improve how vulnerable users view these intersections. 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. In this sense it is quite clear that vulnerable users would more readily accept the implementation of a roundabout if it had a pedestrian crossing away from its entrance. 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. Many different means of reducing both attributes exist. The research has also confirmed that vulnerable users consider a pedestrian crossing flashing sign to be preferable to no signs or even regular signs. Evidently, it is difficult to imagine that all roundabouts in the area of study could be designed according to what pedestrians perceive to be their preferred characteristics: pedestrian crossing flashing signs, one-lane intersections, presence of an island, pedestrian crossing 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. However, the substitution rates obtained in this research can be a useful tool in the decision making process related to roundabouts by providing guidance on how to trade-off different design and operational characteristics of roundabouts.

Finally, this work presents a contribution to road safety research. As was previously shown, existing research exhibits no apparent use of SP survey data that considers pedestrians and vulnerable users of roundabouts. Moreover, this research explores methods not commonly used to deliver Choice Tasks to respondents.

6. FUTURE WORK

The innovative aspect of this current research suggests 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. Without a doubt, this is a next step to consider for consolidating the use of simulations in this area of research.

More important, however, is the comparison between safety perception and actual safety. 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 users) would allow future research to propose well-defined recommendations in terms of safety regarding this type of intersection for these users. Assuredly, the best scenario to offer to vulnerable users is that in which higher safety is closely linked to those items perceived as safer.

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