Travel mode choice modelling of visually impair people through latent variables

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SHORT SUMMARY

It has been shown that people with disabilities perceive certain travel attributes differently, affecting their behaviour. It is relevant to understand the behaviour of people with disabilities to support public policies that address their needs. The objective of this research is to identify the factors that affect the mobility decisions of blind or visually impaired people, taking Santiago de Chile as a case study. With information from a total of 1,322 trips in Santiago made by people with and without disabilities, hybrid models of modal choice were estimated, including two latent variables: human interactions and use of technology. People who use more technology prefer ride hailing. Modes with direct contact with the driver are perceived more positively by people who assign importance to human interactions. Additionally, there is a significant difference in the perception of walking time. Walking time affects approximately 30% more blind or visually impaired people than people without visual impairment. Based on the results, there is proof of the relevance of having public policies that ensure subsidized taxi trips for people with visual disabilities or people with reduced mobility.

Keywords: hybrid discrete choice models, blind, visually impaired, latent variables, mobility, use of technology, human interactions

1. INTRODUCTION

Transport systems are vital for the development of society. Some people, particularly people with disabilities, may have difficulty entering a transport system that does not take their needs into account (Hallgrimsdottir et al., 2016). Although there have been advances to better support the needs of people with disabilities, there are still barriers that restrict independent travel for this group of people (Park and Chowdhury, 2018). It is relevant to understand more clearly the travel behaviour of people with disabilities to prevent depression, poverty, and other socioeconomic harms (Ermagun et al., 2016). Since social exclusion is often the result of the inability to use or access a public transport system (Park and Chowdhury, 2018).

The planning and design of integrated systems have been predominantly focused on public transport users without disabilities (Park and Chowdhury, 2022). Therefore, transport systems should aim to offer quality service for all users, by providing policies according to their needs, especially for those with disabilities. Certainly, not all people with disabilities have the same needs, specific and different needs respecting disability groups shall be also considered.

Low et al. (2020) state that "*common perceptions tend to focus on the provision of barrier-free access for wheelchair users. This group is of course important, but there are other types of disabilities, including those that are visually impaired*". In the context of Chile, the second most common disability within the adult population with some kind of disability, after physical difficulties is a visual impairment with 11.9% having difficulties seeing even when wearing glasses (MDS, 2016). Loss of vision or blindness makes it difficult for people to move and affects their independence when traveling (Low et al., 2020).

Therefore, it is essential to understand better the needs of Visually Impaired People (VIP) to develop more effective public policies, especially in developing countries with limited resources. However, disability has been treated in a general way, generating improvements that people with visual disabilities may not necessarily benefit from. The main objective of this research is to quantify aspects of the trip that affect VIP travel mode choices to support public policies that are aimed at the needs of VIPs, taking Santiago de Chile as a case study, using the information of VIPs trips captured by a revealed preferences survey. However, to the authors' knowledge, studies of mode choice decisions specifically among VIPs have not been carried out nor in developing countries.

There are various studies on the choice of mode and trip generation of elderly and disabled people but most of these have not considered the types of disabilities of the individuals. Also, most of the research has been carried out in developed countries, contemplating travel modes that are not necessarily available in underdeveloped countries, such as paratransit systems. In addition, the context of Santiago differs, in terms of social and cultural context, levels of services experimented on public transport, and non-rate reductions in the public system for people with disabilities, among others.

This short paper is structured as follows. Section 2 explains how the data was obtained and an analysis of the collected information is performed, while Section 3 describes the modelling approach, and the results are discussed. Finally, section 4 closes with the conclusions and the possible future research.

2. SURVEY DESIGN

This section describes the survey and how the information was collected. It also mentions how the service levels were obtained. Finally, it explains how the availabilities of travel modes were defined.

Accessibility aspects

To make an accessible instrument for VIPs, various considerations were taken. Firstly, it was relevant to keep the respondent constantly informed of the aspects of the survey, such as: duration of the survey with a screen reader, number of alternatives for drop-down alternative questions, structure of each section and total amount of questions by section. Secondly, the survey avoids the type of drop-down responses, especially if there are a lot of possible alternatives (for example, when asking about the commune of residence). In such cases, we prioritized open answers. To make the information retrieval process easier, we asked for more general aspects of the trip and then more specific aspects. It is important to mention the survey did not require the use of images. Finally, we used *Google Forms* because according to the Google Forms Accessibility Compliance Report (Google, 2019) it is compatible for people with vision limitations and partially compatible for blind people by providing important accessibility information for most interface elements.

Survey description

In the first section of the survey, we obtained information on the individual characteristics, such as gender, age, residence address, socioeconomic levels, visual condition, knowledge of braille, mobility support, and whether the person has reduced mobility. In the second section of the survey, we gathered information on the last trips made from the home of the respondent, respondents could declare at most three trips and at least one trip. We gathered information about each trip, which consisted of motive, day, time and travel mode of the trip, and destination address. The third section captures indicators of the individual's attitude related to possible latent variables, which can be seen in Table 1. The individuals had to declare through a *likert* scale from 1 to 7 if they agreed or disagreed with each statement.

Table 1- Attitude indicators

Potential latent variable	Attitude indicators	Abbreviation
Use of technology	"If I go to a place I don't know, I use technological Apps"	UT_1
	"I use technological Apps to have information about my trip"	UT_2
Human interactions	"It makes me feel safe knowing that there are people around me"	HI_1
	"I care about being treated cordially by people I don't know"	HI_2

Level of Services

We used the *Google API* to obtain the level of services. To have a more accurate representation of the level of services experimented on a trip we used the average travel times between the reported routes of the *API* (between 2 and 4 routes). In the case of taxis and Apps mobility services the same average time as the car was considered, and an extra time of 10 minutes was added for the case of taxis and 5 minutes for Apps mobility services. For public transport trips, in addition to the average time in the vehicle, we considered the average waiting times, average walking distance, and amount of transfer by mode (Metro/Bus).

For the cost of the alternative public transport, only bus and only metro we considered the current costs determined by the Metropolitan Public Transport Directory. For the cost of the car trip, we considered a cost by kilometre with a mixed performance of 14.6 [Km/l], the cost per kilometre was used because a priori it cannot be assumed whether the person had to pay for parking or pay a toll. For the price of gasoline, we used the average price of the different service stations in Santiago. For taxi costs we used the actual costs considering a base rate and a charge for every 200 [m] travelled. On the other hand, in the case of mobility apps services we considered the tariff system of the company Cabify. Finally, for the bicycle mode, we used a cost based on distance assuming a monthly subscription of a Chilean bike share company and a daily use of 8 [Km].

Mode availability

All individuals had the following modes of transportation available: walking, taxi, and application mobility services. VIP had the mode bicycle unavailable and if the individual did not have any visual impairment the bicycle was considered available in case if in other trips reported the travel mode was bicycle was declared or if there was a shared bicycle station in a radius less than or equal to 500 [m] from their home and destination. Similarly, in the case of a car (whether a driver or a passenger car), was considered available for all the trips of people who had used the car in one of the three declared trips and for those who did not declare having used a car were assigned availability by replicating the distribution of the socioeconomic groups of the people who used a car. Finally, in the case of public transport, the alternative to all trips was assigned to them. For the only bus and only Metro modes, availability was assigned in case there were routes available only with those modes.

Data Collection

We sampled 484 individuals with valid trips, 25 of those declared information on one trip, 80 on two trips, and 379 on three trips. Therefore, we obtained information on a total of 1,322 trips. We were able to collect trips through all sectors of Santiago, however, to replicate the distribution of gender, age, and socioeconomic group of the population more precisely in the sample, correction factors were used through Furness Method (1965).

After applying the correction factors, 22.5% of the trips were made by visually impaired people, while 77.5% were made by people without visual impairment. 80.6% of the total trips in the survey were made on a weekday, while 19.4% were made on the weekend. A low percentage of trips (6.8%) were made in active modes such as walking and cycling, the rest of the trips, were made by through motorized modes. 60.2% of the trips were made in public transport modes: Metro and bus, or the use of both. 24.6% of the trips were made by car. Among the modes with a lower use percentage are walking, taxi, Apps mobility services, and taxi, with 5.5%, 4.5% 4.0% and 1.3%, respectively. Most of the trips are in the range of 4 [Km] to 6 [Km] and the average of travel distances is 11.82 [Km] explaining why only 6.8% of the trips are made on active modes.

3. MODE CHOICE MODELLING

This section details the estimated hybrid model, the hierarchical structure of the discrete choice model, and then the values of the estimated parameters are presented. It is important to consider that the time is in hours and the costs are in euros (€).

Hybrid model

For the estimation of hybrid models, we considered the simultaneous method that considers estimating the MIMIC model and the discrete choice model simultaneously (Raveau et al., 2010). Two of the four potential latent variables were significant for the modelling, the other two did not explain the discrete decision of travel mode. The number of observations used to estimate the 51 parameters of the hybrid model was 1,322 observations. The final log-likelihood was -7,404 as shown in Table 2.

Table 2- Main model indicators

Number of observations	1,322
Number of estimated parameters	51
Final log-likelihood	-7,404

The structure of the MIMIC model incorporated into the hybrid model (shown in Figure 1) considers the characteristics of the individuals corresponding to the structural equations. In the case of the latent variable, “human interactions”, three binary variables associated with the characteristics of the respondents were considered, indicating if the person has: higher education, reduced mobility, or visual impairment. With respect to the measurement equations, the latent variable is composed by HI_1 indicator and HI_2 indicator. The specification of the structural equation of this latent variable can be seen in Equation (1). On the other hand, for the structural equation of the latent variable, “use of technology”, the following characteristics were considered: high income and older than 60 years. For the measurement equations we used the UT_1 and UT_2 indicators for the latent variable “use of technology”. The specification of the structural equation of the latent variable is found in Equation (2).

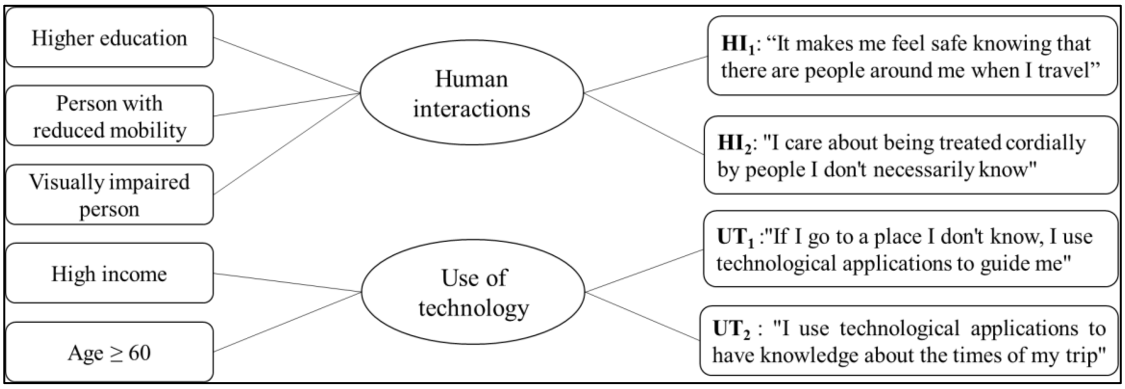

Figure 1 - MIMIC structure

$$HI = s_{HE} \cdot HigherEducation + s_{RM} \cdot ReducedMobility + s_{VIP} \cdot VisuallyImpaired + \sigma_{HI} \quad (1)$$
$$UT = s_{HI} * HighIncome + s_E * Eldery + \sigma_{UT} \quad (2)$$

The estimated parameters from the MIMIC model of the latent variable human interactions, presented in Table 3, are consistent with what is expected (only the structural equations’ results are presented). Parameter s_{HE} is positive, and therefore people with higher education value more human interactions when travelling. Parameters s_{RM} (significant with a confidence level of over 80%) and s_{VIP} are positive, so people with reduced mobility and VIP perceive human interactions as important, with VIP being the ones who most assign importance to human interactions.

Table 3- Estimated parameters of the latent variable human interactions

	Parameter	Description	Value	*t*-test
Structural equation	s_{HE}	Higher education	0.42	3.68
	s_{RM}	Reduced mobility	0.37	1.60
	s_{VIP}	Visually impaired people	1.17	5.93
	σ_{HI}	Standard deviation	0.78	5.81

Table 4 presents the estimated parameters for the structural equation of the latent variable use of technology. People with high income have a positive sign and people over 60 years of age have a negative sign, which indicate opposite effect. People with high income have a greater use of technology than people who are not part of this category and people over 60 years of age have a lower use of technology.

Table 4- Estimated parameters of the latent variable use of technology

	Parameter	Description	Value	*t*-test
Structural equation	s_{HI}	Higher income	2.11	7.13
	s_E	Elderly	-4.34	-9.02
	σ_{UT}	Standard deviation	-2.96	-10.70

Given that the Public Transport System in Santiago is fully integrated both physically and fare-wise (DTPM, 2022), it was decided to use a hierarchical structure in the discrete choice model. This structure will allow capture the correlation between the bus, Metro and Metro-bus alternatives, which will be grouped in a nest of public transport as shown in Figure 2.

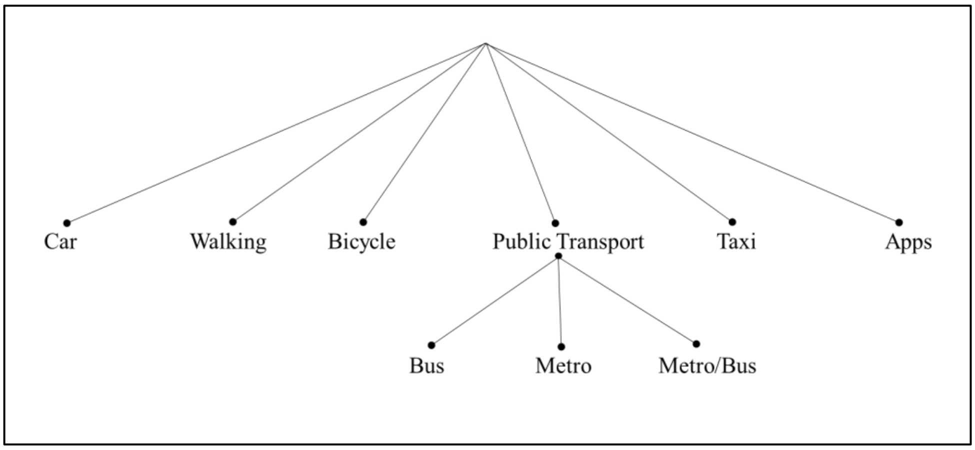

Figure 2- Hierarchical structure of the discrete choice model

Regarding utility functions by mode, the specification's contingency table is presented in Table 5. All modes have an associated modal constant, in the case of walking, the modal constant was set to zero. All modes except walk have a cost parameter associated with them. A generic parameter for time in the vehicle was considered, except for the bicycle mode, which has a specific parameter, since this mode involves an effort that the cyclist must do. We used a systematic variation of tastes in relation to the binary variable of VIP to analyse how walking time affects VIP. This interaction was included in the modes of walking and those related to public transport. For modes associated with public transport, a waiting time variable was also included to understand how this variable affects people. In addition, a variable for the number of transfers from bus to another bus was included in the bus and Metro/bus travel mode alternatives. For the mode only Metro, this variable is not included since, by design, it will always take the value zero. The latent variable of technology use was included in the utility function of the Apps mobility services where, in addition, a parameter associated with the variable latent variable of human interactions for this same alternative, finally, there is a specific parameter for the latent variable of human interactions for taxi.

Table 6 shows the estimated parameters from the mode choice model. Regarding significance, all variables (ignoring modal constants) are significant at a 95% confidence level. The value of the t-test with respect to 1 of the parameter $\lambda_{PublicTransport}$ is 4.95, validating the structure presented in Figure 2. Therefore, the correlation of the alternatives within the public transport nest is 87.8%.

Table 5- Utility function of the different travel modes

Travel mode	ASC	Bi-cycle time	Walking time with VIP in-teraction	Vehicle time	Waiting time	Cost	Bus-Bus transfer	Latent variable ***HI***	Latent variable ***UT***
Car	S			G		G			
Walking	*		G						
Bicycle	S	S				G			
Bus	S		G	G	G	G	G		
Metro	S		G	G	G	G			
Metro-Bus	S		G	G	G	G	G		
Taxi	S			G		G		S	
Apps	S			G		G		S	S

S: specific parameter / G: generic parameter / *: fixed parameter

Table 6- Estimated parameters for the choice model

Parameter	Value	t-test
ASC_{Car}	-0.13	-0.572
$ASC_{Walking}$	0.00	-
$ASC_{Bicycle}$	-1.32	-2.83
ASC_{Bus}	0.12	0.554
ASC_{Metro}	0.76	4.16
$ASC_{Metro-Bus}$	0.28	1.30
ASC_{Taxi}	-4.94	-4.41
ASC_{Apps}	-4.77	-4.14
$\lambda_{PublicTransport}$	2.86	7.63
$\beta_{transfersBusBus}$	-0.108	-2.75
β_{cost}	-0. 753	-7.52
$\beta_{TimeBicycle}$	-5.18	-3.28
$\beta_{TimeWalking}$	-3.4	-10.30
$\beta_{TimeVehicle}$	-0.898	-3.68
$\beta_{TimeWaiting}$	-1.60	-4.46
$\alpha_{WalkingVIP}$	-1.12	-2.37
θ_{UT}	0.389	3.66
θ_{IH_Apps}	2.64	2.74
θ_{IH_Taxi}	3.82	3.79

The parameters θ_{IH_Taxi} and θ_{IH_Apps} are statistically different with 90% confidence. The value of the latent variable, human interactions, is positive both for the taxi mode and for Apps, meaning that people who perceive human interactions as relevant tend to choose modes such as taxi or Apps, this may be because these modes are more personalized services where you must interact with a person (driver). Also, people who have a greater use of technologies will tend to use modes of transport that are requested through mobile applications.

The time parameters follow the relationship:

$$|\beta_{TimeVehicle}| < |\beta_{TimeWaiting}| < |\beta_{TimeWalking}| < |\beta_{TimeBicycle}|$$

In several practical studies the values of the walking and waiting time parameters are two or three times the value of the time in the vehicle (Ortúzar and Willumsen, 2011). In this case, the value of the waiting time parameter is approximately twice the value of the vehicle time parameter while the value of the walking time parameter is approximately four times the value of the vehicle time.

4. CONCLUSIONS

In this study, it was verified through discrete choice hybrid models that there is heterogeneity in the perception of tangible and non-tangible attributes in the choice of modes of transport by individuals. The main factors that affect the travel experience were identified according to the mode used by VIP or reduced mobility.

From the modelling, we obtained that people with visual disabilities perceive human interactions as relevant, which could influence their modal choice, preferring modes with direct contact with the driver. This same effect can be distinguished in people with reduced mobility, so they could prefer modes such as: taxi, Uber, Cabify or Didi due to the social relationships generated. This study has shown that the attitude we have and how we relate to each other as a society can affect people with visual disabilities and reduced mobility, leading them to prefer more expensive modes such as those mentioned above. There is heterogeneity in the perception of walking times, VIP are affected by approximately 30% more walking time than people without visual impairment. This implies that people who are blind or have low vision are willing to pay 30% more to save the same amount of walking time as a person without visual impairment.

The results of this research are a contribution since they can be used for the social evaluation of projects in Santiago as we quantify how much walking time affects people with visual impairments. Based on the results of the qualitative and quantitative study, the need to create transportation subsidies in Chile for people with visual disabilities is validated and we must also consider that in most countries various subsidised transport services are provided to service these population groups (elderly and disabled people) (Schmöcker et al., 2008). State subsidies are relevant to be applied in Chile, as mentioned above, people with visual disabilities are considerably more affected by walking time and, furthermore, both people with reduced mobility and people with visual disabilities tend to prefer modes of more costly transport like taxi.

It was expected in the modelling that the latent variable of human interaction would generate a positive impact on the metro mode given that within the functions of the metro attendants is assisting people with visual disabilities on the trip, however, this result was not obtained. A possible hypothesis to understand these results is the reduction of more than 1,500 Metro workers announced at the beginning of 2022. On the other hand, it was also expected that people with visual disabilities would be decisive in the latent variable of technology use. The Spanish disability observatory estimates that the population with disabilities is at a 33% disadvantage on the economic ambit in relation to the general population (OED, 2022). Therefore, there could be a correlation between the economic income variable that would not allow the visual disability variable to be included at the same time.

Finally, as studies to be carried out in the future, two areas of interest are proposed to deepen the research presented. In the first place, it would be interesting to study how the variability of travel and waiting times affects people with disabilities as it was mentioned in the qualitative analysis but not explored in the quantitative models. And, on the other hand, it would be relevant consider vehicle crowding in the estimation of the models, which were not considered in this analysis since these service levels could not be obtained from a reliable data source for the different travel modes.

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