Journal of Transport & Health 14 (2019) 100583

Contents lists available at ScienceDirect

Journal of Transport & Health

journal homepage: www.elsevier.com/locate/jth

Factors affecting personal autonomy and perceived accessibility of people with mobility impairments in an urban transportation choice context

Factores que afectan la autonomía personal y la accesibilidad percibida de las personas con impedimentos de movilidad en un contexto de elección de transporte urbano

Fatores que afetam a autonomia pessoal e percebida acessibilidade de pessoas com deficiência de mobilidade em um contexto de escolha de transporte urbano

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ARTICLE INFO

Keywords:
Mobility impairments
Developing countries
Hybrid discrete choice model
Personal autonomy
Perceived accessibility*Palabras clave:*
Deterioro de la movilidad
Países en desarrollo
Modelo de elección discreta híbrida
Autonomía personal
Accesibilidad percibida*Palavras-chave:*
déficits de mobilidade
países em desenvolvimento
Modelo de escolha híbrida discreta
Autonomia pessoal
Acessibilidade percebida

ABSTRACT

Introduction: This paper studies factors affecting personal autonomy and perceived accessibility of people with mobility impairments in an urban transportation choice context, taking the city of Tunja, Colombia, as a case study.
Methods: In the context of our research, mobility impairments refer to a person's inability to use one or more of his/her extremities, or a lack of strength to walk. We conducted a survey in February 2018, using a face-to-face questionnaire consisted of three parts that were relevant to our study: facing a discrete choice experiment, rating a set of indicators of latent variables, and reporting the main socioeconomic characteristics. We estimated a hybrid discrete choice (HDC) model to identify the socioeconomic characteristics affecting personal autonomy and perceived accessibility and also test the hypothesis that these latent variables are determinants in the choice process of urban transportation mode for people with mobility impairments.
Results: The empirical results demonstrate that perceived accessibility is different for travelers with a low income, wheelchair users, mobility impairments caused by aging and transit dependents. We also find that personal autonomy varies depending on car owners, permanent mobility impairments, wheelchair users, and workers in comparison with other people. The population heterogeneity we obtained through the latent variables allows us to identify policies to improve the quality of life for people with mobility impairments.
Conclusions: This paper advances the knowledge of how tangible and latent attributes affect the transportation choice process for people with mobility impairments by estimating an HDC model that integrates waiting time, travel time, urban transportation costs, personal autonomy, and perceived accessibility. Our results also contribute to a better understanding of the transportation needs of people with mobility impairments in developing countries.

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https://doi.org/10.1016/j.jth.2019.100583
Received 21 September 2018; Received in revised form 26 June 2019; Accepted 26 June 2019
Available online 29 June 2019
2214-1405/

R E S U M E N

Introducción: Este artículo estudia los factores que afectan la autonomía personal y la accesibilidad percibida de las personas con problemas de movilidad en un contexto de elección de transporte urbano, tomando la ciudad de Tunja, Colombia, como caso de estudio.
Métodos: En el contexto de nuestra investigación, los impedimentos de movilidad se refieren a la incapacidad de una persona para usar una o más de sus extremidades, o la falta de fuerza para caminar. Se aplicó una encuesta en febrero de 2018, utilizando un cuestionario cara a cara que constaba de tres partes relevantes para nuestro estudio: primero, los individuos enfrentaron un experimento de elección discreta, luego calificaron un conjunto de indicadores de variables latentes y, finalmente, informaron sus principales características socioeconómicas. Se estimó un modelo híbrido de elección discreta (HDC) para identificar las características socioeconómicas que afectan la autonomía personal y la accesibilidad percibida y para probar la hipótesis de que estas variables latentes son determinantes en el proceso de elección de modo de transporte urbano para personas con impedimentos de movilidad.
Resultados: Los resultados empíricos demuestran que la accesibilidad percibida es diferente para los viajeros con bajos ingresos, usuarios de sillas de ruedas, personas con impedimentos de movilidad causados por vejez y los usuarios cautivos. También se encontró que la autonomía personal es diferente para los propietarios de automóviles, personas con discapacidad permanente, usuarios de sillas de ruedas y trabajadores, en comparación con el resto de personas. La heterogeneidad de la población modelada a través de las variables latentes permitió identificar políticas para mejorar la calidad de vida de las personas con discapacidades de movilidad.
Conclusiones: Este trabajo avanza en el conocimiento explicando cómo los atributos tangibles y latentes afectan el proceso de elección de transporte para personas con impedimentos de movilidad, mediante la estimación de un modelo HDC que integra el tiempo de espera, el tiempo de viaje, los costos de transporte urbano, la autonomía personal y la accesibilidad percibida. Los resultados también contribuyen a una mejor comprensión de las necesidades de transporte de las personas con impedimentos de movilidad en los países en desarrollo.

R E S U M O

Introdução: Este artigo estuda fatores que afetam a autonomia pessoal e a percepção de acessibilidade de pessoas com dificuldades de mobilidade em um contexto de escolha de transporte urbano, tomando a cidade de Tunja, na Colômbia, como um estudo de caso.
Métodos: No contexto de nossa pesquisa, as deficiências de mobilidade referem-se à incapacidade de uma pessoa em usar uma ou mais de suas extremidades ou falta de poder de locomoção. Fizemos uma pesquisa em fevereiro de 2018, usando um questionário de três partes face a face que foi relevante para o nosso estudo: experimentar um experimento de escolha discreta, classificar um conjunto de indicadores de variáveis latentes e relatar características socioeconômicas importantes. Estimamos um modelo discreto de escolha híbrida (HDC) para identificar características socioeconômicas que afetam a autonomia pessoal e acessibilidade percebida e também testar a hipótese de que essas variáveis latentes são determinantes no processo de escolha do modo de transporte urbano para pessoas com deficiência motora.
Resultados: Os resultados empíricos mostram que a acessibilidade percebida é diferente para viajantes de baixa renda, usuários de cadeira de rodas, dificuldades de mobilidade causadas pelo envelhecimento e dependentes de trânsito. Também achamos que a autonomia pessoal varia de acordo com os proprietários de carros, com deficiências permanentes de mobilidade, usuários de cadeiras de rodas e trabalhadores, em comparação com outras pessoas. A heterogeneidade populacional que obtivemos através das variáveis latentes nos permite identificar políticas para melhorar a qualidade de vida das pessoas com deficiência motora.

Conclusões: Este trabalho avança a compreensão de como os atributos tangíveis e latentes afetam o processo de escolha de transporte para pessoas com deficiência de mobilidade estimando um modelo HDC que integra tempo de espera, tempo de viagem, custos de transporte urbano, autonomia pessoal e acessibilidade percebida. Nossos resultados também contribuem para uma melhor compreensão das necessidades de transporte de pessoas com problemas de mobilidade nos países em desenvolvimento.

1. Introduction

A vast majority of activities require traveling for participation. The transportation system allows people to connect with work, study, social life, and services. Maintaining everyday mobility is important for health (Boniface et al., 2015; Mackett and Thoreau, 2015), however, people with mobility impairments can experience difficulties when using a transportation system that does not consider their specific accessibility needs (Sze and Christensen, 2017). Accessibility is not equally distributed across society and people with mobility impairments often find it difficult to reach their desired destinations, therefore it compels authorities and researchers to study the role of transportation as an enabling factor for people with mobility impairments (Farber and Páez, 2010; Schmöcker, 2009; Mohammadian and Bekhor, 2008).

In the same vein of Corran et al. (2018), Boniface et al. (2015), Mackett and Thoreau (2015), among others, we argue that to ensure cities promote health issues as much as possible more attention is needed to guarantee truly inclusive transportation systems, especially to improve the accessibility of people with mobility impairments, although they are only a small percentage of the total population of individuals with disabilities. Accessibility not only can help in reducing car use but also can help in increasing social equity (Preston and Rajé, 2007). Although several previous studies have addressed accessibility issues related to disabled people (e.g., Grisé et al., 2018; Sze and Christensen, 2017; Vale et al., 2017; Bombom and Abdullahi, 2016; Lättman et al., 2016; Ferrari et al., 2014; Banda-Chalwe et al., 2012; Schmöcker, 2009), they have not examined the effects of attitudes and perceptions on the transportation choice process.

By examining the factors affecting personal autonomy and perceived accessibility of people with mobility impairments, this study adds to the existing knowledge base on urban transportation preferences for people with mobility impairments through integrating tangible and latent attributes in a discrete choice model. Furthermore, utilizing the evidence in this paper, developing countries – particularly Colombia – are able to better understand how personal autonomy and perceived accessibility affect the transportation choice process of people with mobility impairments.

1.1. Hypothesis

Our behavioral hypothesis is that, in addition to traditional tangible attributes such as waiting time, travel time, and urban transportation costs, the choice process of an urban transportation alternative also depends on available transportation alternatives as well as individual attitudes and perceptions of the alternatives. Consequently, given a certain set of available transportation alternatives, we hypothesized that the choice of mode of transportation for people with mobility impairments depends not only on above-mentioned tangible attributes but also on personal autonomy, as an individual attitude, and the perceived accessibility of the transportation system.

2. Data and methods

To test our hypothesis, we conducted a survey in February 2018, using a face-to-face questionnaire to obtain a significant and representative sample of people with mobility impairments who travel in Tunja, Colombia. The design process of our survey took as a starting point a survey of trips applied to a representative sample of households in the city in 2012. Although the previous household survey was not specifically aimed at people with mobility impairments, it did contain relevant information relating households, individuals, and trips that helped us in identifying some design attributes and isolate the subpopulation of residents with mobility impairments inside the city.

2.1. Context

2.1.1. Urban transportation in tunja

The city of Tunja, which has approximately 200,000 residents, is located 130 km northeast of Bogotá, Colombia. The main transportation modes available in the city are a public transportation system, taxi service, walking, car, and bicycle. The network of the public transportation service includes a large fleet of buses which operates 16 h a day and has good spatial coverage, reaching practically all sectors of the city. The small size of the city promotes walking trips but its high slopes make it difficult to use the bicycle.

At present, Tunja does not have accessible transportation services and does not have adequate infrastructure for non-motorized trips, which makes it difficult to use wheelchairs, walkers, crutches and other ambulatory devices. According to modal split of the transportation of Tunja, presented by Poveda et al. (2017), walking predominates (42%) followed by the collective public transport (35%), car (11%) and taxi (4%). In general, urban trips are short, for example regular taxi services have waiting times of about 15 min, while trips by bus last about 35 min on average.

2.1.2. People with mobility impairments who travel in tunja

Mobility impairment is defined as a category of disability that includes people with varying types of physical disabilities. In the context of our research, mobility impairments, which may be caused by a number of factors, refer to a person's inability to use one or more of his/her extremities, or a lack of strength to walk. Mobility impairments can either be congenital, acquired with age or as a consequence of disease. Mobility impairments may result in the person using wheelchairs, crutches, or walkers that may be normally used to aid in mobility.

According to official statistics from the National Administrative Department of Statistics (2010), in Tunja, there are 5124 individuals registered in the Location and Characterization Registry of Persons with Disabilities (RLCPD for its acronym in Spanish), which is a tool that allows collecting basic information, such as location and status, of people with disabilities residing in Colombia. In the register 53% are women and 25% are people over 60 years. In the country, there are at least 10 data sources related to the population with disabilities, which are in a continuous update process to reduce underreporting, being the RLCPD the data source that currently has more relevant information on this population (Gómez-Aristizábal et al., 2015). This that leads us to believe that the number of individuals with disabilities in Tunja could be much greater, but we were not able to verify it.

As in other South American cities, Tunja exhibits an important accessibility disparity between non-disabled and mobility-impaired people who are more likely to be lower-income. In accordance with the results of the most recent household survey we applied in Tunja, in 2012, there were 1656 people with mobility impairments in the city, 975 of whom travel. Information on trips made by all household members by all modes of transportation during working days was gathered by the 2012 survey, providing good information on travel patterns in the city. It is important to highlight that in the case of non-disabled people, the proportion of individuals who do not travel is just 20% which is significantly lower than the 41% of mobility-impaired people who do not travel (Poveda et al., 2017).

In the city, people with mobility impairments claim that the accessibility of the urban transportation system is limited, the platforms do not have wheelchair ramps, accessing public transportation stops is difficult and boarding the vehicles is even more difficult because of the lack of sliding transfer boards and mechanical elevators for wheelchairs (Poveda et al., 2017). In general, based on the previous research, taxi use is predominant among people with physical disabilities, followed by buses and, to a lesser extent, walking and cars.

2.2. Survey

After developing the questions using focus groups of individuals with mobility impairments, we designed a pre-questionnaire that was reviewed and approved by the research team to make way for a pilot survey where any issues of design and presentation could be explored. The main tuning after the pilot test had to do with the number of levels that each attribute took. We had designed two levels for the attributes associated with time and three levels for costs. However, we noticed that respondents gave little importance to travel and waiting times, so we finally designed the experiment with three levels per attribute. The pilot test was also useful to adjust the semantics of the latent variables indicators.

Respondents were randomly selected from the database built in the previous research (Poveda et al., 2017) and data were collected anonymously. The questionnaire consisted of three parts that were relevant to our study. First, the individuals faced the choice experiment and then they rated the indicators of latent variables. At the end of the survey, individuals reported their main socioeconomic characteristics.

2.2.1. Discrete choice experiment

One of the major causes of social exclusion for people with mobility impairments is the difficulty to take part in different activities due to inadequate transportation services. For this reason, in addition to the existing alternatives, our discrete choice experiment added two transportation modes: paratransit and wheelchair-accessible taxis, which, in the short term, can help in reducing the noticeable gap in accessibility in the city, without having to make major investments in retrofitting transportation infrastructure (Grisé et al., 2018). As the respondents were not familiar with the wheelchair-accessible taxis nor the paratransit services, before starting the survey they received an explanation about the general characteristics of these services.

Although it includes various transportation modes (Joewono and Kubota, 2008) paratransit is, in general, a transportation system that provides services predominantly to disabled people (Deka and Gonzales, 2014; Bearse et al., 2004). Wheelchair-accessible taxis are usually wheelchair-adapted vehicles that have a ramp or a passenger elevator to assist the wheelchair user with getting into the vehicle. As wheelchairs are carefully designed to support a disabled person, wheelchair-accessible taxis allow people with mobility impairments to stay in the position that is best for their body and posture.

We selected waiting time, travel time, and cost, as the tangible attributes to be part of the discrete choice experiment. According to the expectations that individuals declared in the focus groups and after the proper changes we made to the pilot test, we decided to use the levels shown in Table 1. For the purposes of our experiment, we consider it reasonable to suppose that a wheelchair-accessible taxi service is arranged in advance, arrives on time and therefore does not cause waiting times for users. Furthermore, in order to

Table 1
Attributes, levels and specific values of the experimental design.

Attribute	Level code	Existing modes of transportation				Paratransit	Wheelchair-accessible taxi
		Non-motorized	Bus	Taxi	Car		
Waiting time (minutes)	0		5	0		0	Arranged in advance
	1		10	5		5	
	2		15	10		10	
Travel time (minutes)	0	30	25	10	20	20	10
	1	40	35	15	25	25	15
	2	50	45	20	30	30	20
Cost (COP)	0		1400	3500	2000	2000	5500
	1		1500	4500	2500	2500	6000
	2		1600	5500	3000	3000	6500

avoid a greater cognitive burden that could fatigue respondents, we decided not to add the reliability variable thereby reinforcing the idea that this service arrives on time.

We obtained a fractional factorial design that was composed of 27 treatments using Ngene software (ChoiceMetrics, 2012), as shown in Table 2. Because the number of treatments was too large to give all these choice situations to a single respondent, we also assigned three blocks using a *minsum* search that minimizes the total correlation values between the blocking column and all of the attributes. In this way, each respondent faced nine situations for the stated preference experiment. By way of example, Fig. 1 shows the block 3, choice situation 6, in which bus was the existing alternative used by an individual.

2.2.2. Latent variables and indicators

From the main concerns and expectations expressed by the focus groups participants, we identified two *a priori* latent variables and then we asked the participants to tell us which statements could better reflect them. Thus emerging several statements that we then synthesized into a set of indicators that were tested in the pilot survey. Preliminary modeling carried out with the data of the pilot test allowed us to verify the hypothesis that each of the two sets of indicators reflected a common idea, on the one hand, personal autonomy as individual attitude and, on the other, perceived accessibility.

Personal autonomy has its origin in the individual tendency to organize itself in the pursuit of goals. In this view, personal autonomy requires the absence of restraining forces that can limit this tendency. Perceived accessibility from the perspective of people with mobility impairments has to do with how easy it is to use the current transportation system, which is not necessarily the same thing as the objective standard of the system (Lättman et al., 2016) or geographical accessibility (Boisjoly and El-Geneidy, 2017). In general, personal autonomy has been identified as a key variable in occupational choices for physically-disabled adults (Collins and O'Mahony, 2015) while accessibility has been identified as a key attribute that may enhance activity participation, especially for individuals with impaired mobility (Sze and Christensen, 2017).

Latent variables cannot be measured directly but their effects on indicators are observable and can be collected through the survey (Bollen, 2002). In order to allow for the latent variables' identification, our survey included the effect indicators shown in Table 3. Indicators were designed to be manifestations of the underlying latent variables in order to obtain responses regarding their level of agreement or disagreement. We used four indicators per latent variable and a 5-point response scale in line with the most frequent practice in the field of transportation choice analysis based on the HDC modeling approach (Márquez et al., 2018).

Although the first indicator for personal autonomy, i.e. "I like to be treated equally like other people," focuses on individuals' equality with other people, we believe that it properly reflects the idea of personal autonomy, as an individual attitude. We believe that the greater the personal autonomy, the greater the preference will be for equal treatment with respect to others. Although

Table 2
Fractional factorial design.

Block	Situation	The specific existing mode used by individual			Paratransit			Wheelchair-accessible taxi	
		Waiting time	Travel time	Cost	Waiting time	Travel time	Cost	Travel time	Cost
1	1	0	0	0	0	0	0	0	0
1	2	1	2	2	0	1	0	0	1
1	3	2	1	1	0	2	0	0	2
1	4	2	0	2	1	0	2	2	0
1	5	0	2	1	1	1	2	2	1
1	6	1	1	0	1	2	2	2	2
1	7	1	0	1	2	0	1	1	0
1	8	2	2	0	2	1	1	1	1
1	9	0	1	2	2	2	1	1	2
2	1	2	1	2	0	0	1	2	1
2	2	0	0	1	0	1	1	2	2
2	3	1	2	0	0	2	1	2	0
2	4	1	1	1	1	0	0	1	1
2	5	2	0	0	1	1	0	1	2
2	6	0	2	2	1	2	0	1	0
2	7	0	1	0	2	0	2	0	1
2	8	1	0	2	2	1	2	0	2
2	9	2	2	1	2	2	2	0	0
3	1	1	2	1	0	0	2	1	2
3	2	2	1	0	0	1	2	1	0
3	3	0	0	2	0	2	2	1	1
3	4	0	2	0	1	0	1	0	2
3	5	1	1	2	1	1	1	0	0
3	6	2	0	1	1	2	1	0	1
3	7	2	2	2	2	0	0	2	2
3	8	0	1	1	2	1	0	2	0
3	9	1	0	0	2	2	0	2	1

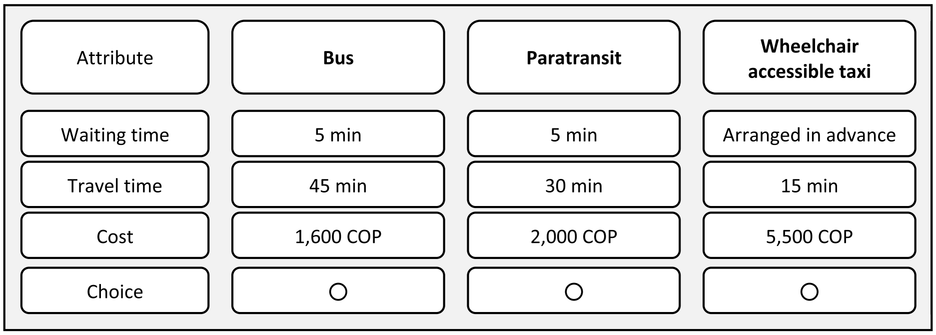

Fig. 1. Example of a choice situation.

Table 3
Indicators of latent variables.

Latent variable	Stem statement
Personal autonomy	I like to be treated equally like other people I like to be independent My physical condition is not an impediment for me I conduct my daily activities normally
Perceived accessibility	I access the transportation system easily I move easily in the transportation system I move in the system without risk of accident I do not need the help of others to move in the system

Table 4
Profile of the sample by current transportation mode.

Variable	Category	Non-motorized		Bus		Taxi		Car	
		n	%	n	%	n	%	n	%
Gender	Female	7	28.0	20	51.3	28	45.9	10	40.0
	Male	18	72.0	19	48.7	33	54.1	15	60.0
Age	Under 15 years	0	0.0	6	15.4	5	8.2	0	0.0
	15–24	4	16.0	4	10.3	10	16.4	3	12.0
	25–34	3	12.0	7	17.9	5	8.2	6	24.0
	35–44	7	28.0	4	10.3	7	11.5	2	8.0
	45–54	3	12.0	4	10.3	8	13.1	4	16.0
	55–64	4	16.0	9	23.1	7	11.5	3	12.0
	65–74	2	8.0	4	10.3	8	13.1	3	12.0
	75 or older	2	8.0	1	2.6	11	18.0	4	16.0
Occupation	Work	13	52.0	14	35.9	13	21.3	9	36.0
	Study	4	16.0	9	23.1	15	24.6	4	16.0
	Home	2	8.0	8	20.5	12	19.7	3	12.0
	Retired	5	20.0	3	7.7	11	18.0	7	28.0
	Other	1	4.0	5	12.8	10	16.4	2	8.0
Household income	Low	12	48.0	22	56.4	22	36.1	4	16.0
	Medium	8	32.0	14	35.9	24	39.3	7	28.0
	High	5	20.0	3	7.7	15	24.6	14	56.0
Transit dependent	Yes	0	0.0	39	100.0	0	0.0	0	0.0
	No	25	100.0	0	0.0	61	100.0	25	100.0
Car owner	Yes	0	0.0	0	0.0	2	3.3	18	72.0
	No	25	100.0	39	100.0	59	96.7	7	28.0
Permanent mobility impairments	Yes	17	68.0	24	61.5	51	83.6	19	76.0
	No	8	32.0	15	38.5	10	16.4	6	24.0
Wheelchair user	Yes	8	32.0	0	0.0	19	31.1	10	40.0
	No	17	68.0	39	100.0	42	68.9	15	60.0
Mobility impairments caused by aging	Yes	4	16.0	7	17.9	12	19.7	8	32.0
	No	21	84.0	32	82.1	49	80.3	17	68.0

autonomy is a relative concept we strongly believe that both the individual's equality with other people as well as their ideas about their own lives without mentioning other people properly reflect personal autonomy. Likewise, although the third indicator of perceived accessibility is related to safety we decided to keep it in the set of indicators because wheelchair transportation safety also reflects the user experience of riding a public transportation vehicle (Buning et al., 2007).

2.2.3. Socioeconomic characteristics

The socioeconomic characteristics collected by the survey were the following: gender, age, occupation, household income level, car ownership, education level, and some information regarding mobility impairments. Although our survey was specifically aimed at people with mobility impairments, information on individual conditions, i.e. permanent or temporary mobility impairments, wheelchair user or not, and mobility impairments caused by aging or other causes, were self-reported.

2.3. Sample

The sample size was 150 individuals, which represents 15.4% of people with mobility impairments who travel in Tunja. Table 4 gives an overview of the sample frequencies regarding the main socioeconomic characteristics of individuals and their current transportation modes. The distribution by current transport mode was presented as follows: 17% non-motorized, 26% bus, 40% taxi, and 17% car. This distribution is consistent with the current modal split of people with mobility impairments who travel in Tunja.

We highlight the fact that wheelchair users do not travel on buses due to the access difficulties inherent in this service which were previously described. Instead, workers represent the highest proportion of bus users which suggests they have greater autonomy to mobilize in the public transport system compared to others. Possibly people who work do it precisely because they have the least mobility impairments, which allows them to enter the labor market more easily than others and for that same reason they use the bus service more frequently. In addition, in our study context, workers with reduced mobility have less income than the rest of the population and for that reason have less access to other modes of transport that are more expensive such as car or taxi.

2.4. Modeling approach

In accordance with the design of our survey, we used the hybrid discrete choice (HDC) modeling approach to incorporate personal autonomy and perceived accessibility, as latent variables, in the discrete choice model through structural equations (Ashok et al., 2002). Specifically, we modeled the transportation mode preferences of people with mobility impairments through incorporating the latent variables as part of the systematic utility of alternatives to provide a better representation of the decision-making process.

Fig. 2 shows the full path diagram for our HDC model. We integrated two sub-models: a discrete choice sub-model and a latent variable sub-model. Our model representation follows the convention that latent variables are shown in ovals, observable variables in

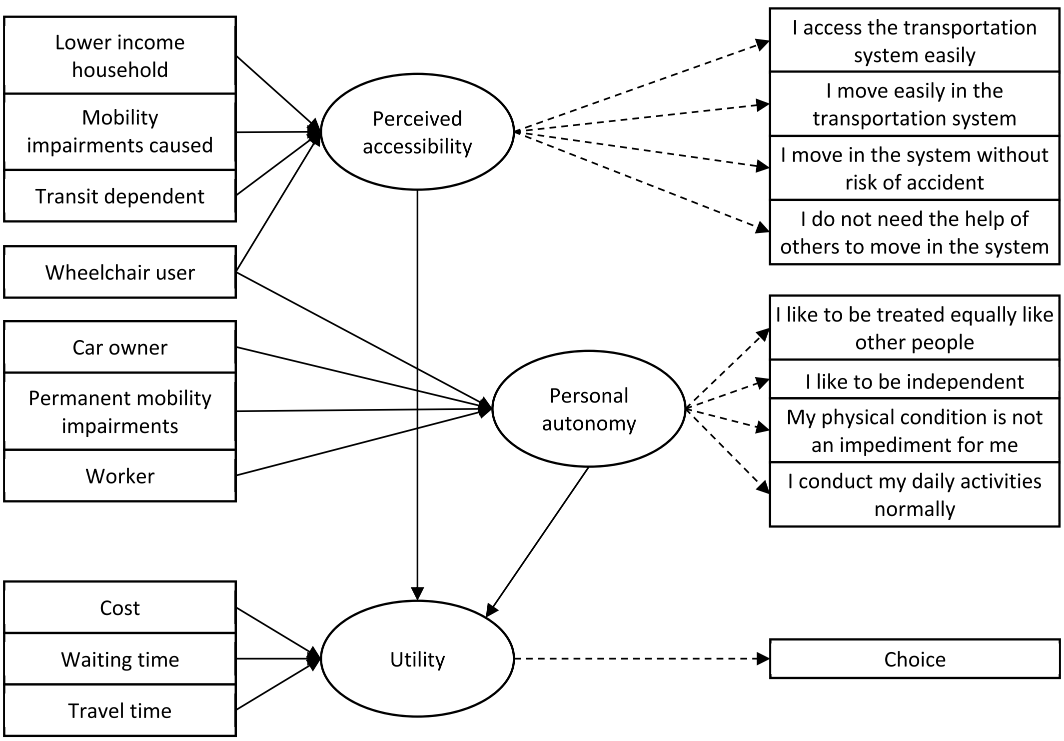

Fig. 2. Full path diagram for HDC model.

rectangles, causal relationships by solid arrows, and measurement relationships by dashed arrows. The advantage of this approach is that, in addition to specification of observable individual characteristics, attributes of alternatives and other tangible variables, this modeling framework extends the traditional models allowing us to form latent variables in order to include them as part of the systematic utility of alternatives, also providing a more productive explanation of the choice process.

A model specification similar to the one we used in the present work can be found in Soto et al. (2018). Except for the measurement equations that we specified as ordered logit models to capture the nature of the data, we specified the structural and choice models as linear based on our assumptions about how the variables enter these models. All socioeconomic characteristics entered the latent variable sub-model as dummy variables while the latent variables and the experimental design attributes entered the discrete choice sub-model as continuous variables with variance normalized to one.

The two structural equations defining latent variables were specified as a function of observable individual characteristics (S_q) as seen in (1), where q relates to an individual, l to a latent variable, and r to an explanatory variable. α is a set of parameters to be estimated, while υ_{liq} are error terms with mean zero.

$$\eta_{lq} = \sum_{r} \alpha_{lr} S_{rq} + \upsilon_{lq} \tag{1}$$

Regarding the measurement equations, we hypothesize that each discrete response k observed within each indicator p is obtained from the latent variables plus an error term through a censoring mechanism that defines different categories of response, according to (2) and (3), where each categorical response in the indicator C_{pq} was defined by a set of thresholds (τ) to be estimated.

$$C_{pq} = \begin{cases} 1 & if\ (-\infty) < C^*_{pq} \le \tau_{p1} \\ 2 & if\ \tau_{p1} < C^*_{pq} \le \tau_{p2} \\ \dots & \\ K & if\ \tau_{p(K-1)} < C^*_{pq} \le \infty \end{cases} \tag{2}$$

$$C^*_{pq} = \sum_{l} \gamma_{lp} \cdot \eta_{lq} + \zeta_{pq} \tag{3}$$

The error terms (ζ) were assumed to follow a logistic distribution and are independent from the set of parameters γ. If F is the cumulative distribution function, the probability of observing C_{pq} within a discrete indicator or category k, can be written as (4) and (5), where $\tau_{p0} = (-\infty)$ and $\tau_{pK} = \infty$.

$$P\{C_{pq} \in k|\eta_q\} = F\left(\tau_{pk} - \sum_{l} \gamma_{lp} \cdot \eta_{lq}\right) - F\left(\tau_{p(k-1)} - \sum_{l} \gamma_{lp} \cdot \eta_{lq}\right) \tag{4}$$

$$P\{C_{pq} \in k|\eta_q\} = \frac{1}{1 + e^{-\left(\tau_{pk} - \sum_l \gamma_{lp} \cdot \eta_{lq}\right)}} - \frac{1}{1 + e^{-\left(\tau_{p(k-1)} - \sum_l \gamma_{lp} \cdot \eta_{lq}\right)}} \tag{5}$$

The HDC model allowed for the inclusion of latent variables in the utility function, as shown in (6), where θ and β are sets of parameters to be estimated and they are associated with the modal attributes X_q and the set of latent variables η_q.

$$U_{iqt} = \sum_{k} \theta_{ki} X_{kiqt} + \sum_{l} \beta_l \eta_{lq} + \varepsilon_{iq} \tag{6}$$

The individual choices, given the choice set A_q, were expressed as a function of the utilities according to (7).

$$y_{iqt} = \begin{cases} 1 & if\ U_{iqt} \ge U_{jqt},\ \forall j \in A_q \\ 0 & otherwise \end{cases} \tag{7}$$

The joint probability of observing choice and latent variable indicators was built as seen in (8), where $P(.)$ is the choice probability of selecting alternative i, $f(.)$ is the density function of the indicators, and $g(.)$ is the density function of the latent variables.

Table 5
Estimated parameters for the structural model.

Latent variable	Explanatory variable	Estimate	Rob. *t*-test
Personal autonomy	Car owner	−0.8894	−3.99
	Permanent mobility impairments	−0.4735	−2.45
	Wheelchair user	−1.0111	−3.78
	Worker	0.83006	4.69
Perceived accessibility	Lower-income household	−0.5309	−2.70
	Wheelchair user	−1.7592	−7.34
	Mobility impairments caused by aging	−0.53021	−2.28
	Transit dependent	−0.80032	−3.27

$$\bar{P}(y_{iqt},\ C_q|X_{qt}, S_q, \theta, \beta, \tau, \gamma, \alpha, \phi, \Sigma_\varepsilon, \Sigma_\zeta, \Sigma_\upsilon) = \int_\eta P(y_{iqt}|X_{qt}, \eta_q, \theta, \beta, \Sigma_\varepsilon) f(C_q|\eta_q, \gamma, \tau, \Sigma_\zeta) g(\eta_q|S_q, \alpha, \phi, \Sigma_\upsilon) d_{\eta_q} \quad (8)$$

3. Results and discussion

3.1. Modeling results

We carried out all the work on a computer using OxMetrics™ (Doornik, 2015), which is a family of software packages providing an integrated solution for econometric analysis. The structural models were estimated with 150 observations while the discrete choice model was estimated with 1350 choice responses since the stated preference experiment consisted of nine choice situations for each individual. To simulate the likelihood, we used 500 draws for each individual obtained from a modified Latin Hypercube sampling.

Table 5 exhibits the estimates and the robust t-values for the structural model. The robust t-values indicate that all the estimates are statistically significant. Most of the signs obtained are negative which indicates that, with respect to the reference category, each individual condition specified in the models reduces, in general, both personal autonomy and perceived accessibility. For example, our results show that individuals with permanent mobility impairments feel a lower personal autonomy than those with temporary mobility impairments. The same applies to wheelchair users who feel less personal autonomy than those who do not use wheelchairs. In our model, only workers feel more personal autonomy compared to those who do not work.

Regarding perceived accessibility, modeling results show that wheelchair users perceive less accessibility, the same goes for transit dependents, people with mobility impairments caused by aging and people who live in lower-income households. In general, and according to our expectations, all the signs obtained go in the expected direction with the exception of the coefficient of the explanatory variable car owner. However, given the statistical significance of this coefficient, we have kept it in the model.

Table 6 exhibits the estimates and the robust t-values for the HDC model and a multinomial logit (MNL) model, which considered the panel effect produced by having nine different choices per respondent. Beside the name of each variable, in curly brackets, is the number of the utility function in which we specified the corresponding variable, namely {1} Non-motorized, {2} Paratransit, {3} Wheelchair-accessible taxi, {4} Bus, {5} Taxi, and {6} Car. For identification purposes, we have normalized to zero the specific constant for the non-motorized alternative. As all the other alternative-specific constants are positive, this means that *ceteris paribus*, people with mobility impairments in Tunja prefer, in that order, taxi, wheelchair-accessible taxi, paratransit, and bus. Additionally, modeling results show that maintaining constant all the other conditions, car owners prefer this transportation alternative above all others.

The estimated parameters and their robust t-values for the choice model demonstrated that both personal autonomy and perceived accessibility are decisive factors for the choice process in our urban transportation context. Furthermore, as it appears from the log-likelihood of the choice component of the models, the incorporation of the latent variables significantly improved the goodness of fit of the HDC model.

All estimated parameters for tangible attributes have the expected signs. It is obvious that additional times or higher transportation costs reduce the utility of the alternatives. The positive sign for the perceived accessibility is also correct because people with a greater perception of accessibility of the system perceive, consequently, a greater utility in their habitual modes of transport, which would motivate them to continue using them. With respect to personal autonomy, given its interaction with the cost of travel, the results of the model suggest that people who feel greater personal autonomy are more sensitive to cost. This leads in a lower willingness to pay and, therefore, greater flexibility to change mode as costs increase, which makes a lot of sense.

Table 6
Estimated parameters for the choice model.

Variable	HDC model		MNL model	
	Estimate	Rob. *t*-test	Estimate	Rob. *t*-test
Non-motorized specific constant {1}	0	Fixed	0	
Paratransit specific constant {2}	2.0329	6.05	1.8190	5.73
Wheelchair-accessible taxi specific constant {3}	3.3296	5.35	3.0321	4.98
Bus specific constant {4}	1.7371	4.95	1.6239	4.98
Taxi specific constant {5}	3.4170	6.59	3.0215	6.09
Car specific constant {6}	3.9346	5.59	3.8431	5.51
Waiting time {2, 4, 5}	−0.18236	−10.86	−0.1840	−10.99
Travel time {1, 2, 3, 4, 5, 6}	−0.11818	−10.78	−0.11713	−10.87
Cost {2, 3, 4, 5, 6}	−1.1064	−10.17	−1.0100	−10.40
Panel effect {1, 2, 3, 4, 5, 6}	−0.2335	−1.79	0.4597	6.51
Cost * Personal autonomy {2, 3, 4, 5, 6}	−0.15396	−4.14		
Perceived accessibility {1, 4, 5, 6}	0.14334	2.02		
Log-likelihood	−2451.01			
Log-likelihood for choice component	−1157.92		−1172.94	

3.2. Discussion

An apparently counterintuitive result was that car owners with disabilities had less personal autonomy than transit dependents and other people without a car. However, transportation literature has shown that car owners experience considerable limitations concerning their abilities to operate and have access to a personal car (Bascom and Christensen, 2017). This finding supports the critical importance of public transportation services in an effort to improve personal autonomy in people with mobility impairments.

As expected, our estimates showed that people with permanent mobility impairments and wheelchair users report having less personal autonomy than others, which is in accordance with the results of the Bascom and Christensen (2017) study that found that individuals with increasing disabilities were more likely to face transportation-related exclusion thus diminishing, in part, their personal autonomy.

The structural model also showed that workers have better personal autonomy, understood as a personal attitude, than other people with mobility impairments, which is in line with the findings of Casas (2007) who demonstrated that having a job increases mobility and opportunities. Unfortunately, our database does not have information regarding the required help to use transportation modes, which is a factor that affects the probability of being employed (Farber and Páez, 2010). Although more detailed information on the specific types of impairments and jobs would have been desirable it seems natural that a person who works is more autonomous than one who does not.

Like many other cities (Rachele et al., 2018), in Tunja, lower-income individuals often need to live in urban fringe areas where housing prices are lower but where there are precarious infrastructures and a lower quality of transport services. This, together with the fact that lower-income households have less access to a private car, explains why lower-income individuals perceive less accessibility of the transportation system. This idea is enhanced by the fact that transit dependents, also known as captive users or disadvantaged users, perceive less accessibility of the transportation system.

The difference in the perceived accessibility for wheelchair users can be explained by the lack of continuity of sidewalks in Tunja, which generates large gaps in the city where individuals in a wheelchair cannot access the transportation system, as it has been shown in previous research (Grisé et al., 2018). Furthermore, because there are no multi-modal interchange facilities in the city which could improve accessibility for individuals with impaired mobility (Ferrari et al., 2014), it seems logical that wheelchair users perceive less accessibility than other people with mobility impairments.

People with mobility impairments caused by aging perceive less accessibility in comparison with others. This is an important finding since aging populations are becoming common in many cities, leading to serious mobility problems (Wong et al., 2017) and affecting their perceived quality of life because of less accessibility (Banister and Bowling, 2004). In this regard, previous research has suggested that poor transportation accessibility is associated with lower propensity to travel among older people (Corran et al., 2018). In our case, the lack of better access conditions to the transportation system is reflected in a lower perceived accessibility for people with mobility impairments caused by aging (21% of all people with mobility impairments in the city).

The positive sign of perceived accessibility indicates that this variable positively affects the utility of existing alternatives, which is also clear and reinforces the idea that closing the gap in accessibility for a specific transportation alternative makes this alternative more attractive to the people with mobility impairments. The negative sign of the coefficient for the interaction between cost and personal autonomy implies that an individual with a greater autonomy is less willing to pay for reducing both waiting and travel times for the transportation alternatives.

4. Conclusions and policy implications

Despite the significant differences pointed out by previous research, in many policy documents adopted by transportation and planning authorities, measures aimed at improving transportation accessibility are presented as synonymous with universal design methodologies (Schmöcker, 2009). The fact is that there are differences even among people with mobility impairments that authorities should take into account in order to propose policies properly aligned with the needs of the people.

We demonstrated that, given a certain set of available transportation alternatives, in addition to traditional tangible attributes, such as waiting times, travel times and urban transportation costs, there are latent factors affecting choosing a transportation mode. According to our findings, when people with mobility restrictions choose a mode of transport, they take into account their personal autonomy and the perceived accessibility of the transportation system.

Although we found that having a job increases personal autonomy, we consider that this result is inconclusive. Previous research has demonstrated that people not actively working could be related to a type of mobility impairment because depending on the type of impairment, only certain specialized jobs can be performed (Farber and Páez, 2010). We lack information about the specific types of impairments and jobs, consequently, this issue cannot be fully addressed but should certainly be indicated as a direction for future/further research. In this regard, based on basic common sense we can also hypothesize that greater personal autonomy could be explained in part, by individual work income.

The heterogeneity demonstrated through perceived accessibility showed that people with mobility impairments caused by aging generally perceive less accessibility of the system than other people. Based on the findings of Banister and Bowling (2004) who found that the perceived quality of life of elderly people was more positive when they had better access to transportation, we can state that elderly people with mobility impairments see their quality of life reduced. Therefore, an initiative for providing better transportation accessibility for people with mobility impairments caused by aging in the city is necessary.

Although we studied perceived accessibility from the perspective of people with mobility impairments in terms of how easy it is to use the transportation system, we consider that further research can focus on a wider concept of accessibility that includes not only transportation system accessibility but also the accessibility of physical, economic and social environments to satisfy the movability needs of the people with mobility impairments. This all could effectively integrate them into the whole society through policies aimed at education and awareness, based on analyzing societal perception, attitudes, and acceptance of disability (Bombom and Abdullahi, 2016) as latent variables.

The following specific recommendations in this paper are for the city of Tunja. However, the methodology and results from our study could be an example for other cities, particularly in the case of cities in developing countries, with similar characteristics to the current ones in the city of Tunja. We hope our findings will be utilized by the local government for implementing solutions that will ultimately benefit the accessibility and health of people with mobility impairments. We also hope that the proposed methodology and the results obtained in the Colombian context serve as a basis for future research.

We agree with Grisé et al. (2018) that the process of retrofitting a public transportation system to ensure universal principles in the city are met is time-consuming due to the construction and financial challenges associated with infrastructural interventions. In contrast, in the short term, paratransit and wheelchair-accessible taxis can help in reducing the noticeable gap in accessibility for people with mobility impairments. Such a policy will likely increase the number of destinations accessible to individuals with mobility impairments (Grisé et al., 2018) but it also produces rising costs of paratransit and wheelchair-accessible taxis which would be transferred directly to the users unless local authorities subsidize part of their cost (Bascom and Christensen, 2017).

Following the lines of previous studies that have proposed land use and transportation strategies to reduce both car dependence and health inequities (Rachele et al., 2018), we consider that improving conditions of public transportation service is a good starting point for closing the gap in accessibility. This implies expanding route coverage to marginalized neighborhoods, providing suitable accesses with ramps and room for them to maneuver, and creating necessary conditions for ensuring the personal autonomy of people with mobility impairments through appropriate training and guidance for public transportation drivers (Wong et al., 2017). These actions will contribute to the improvement of perceived accessibility and the quality of life of lower-income individuals, wheelchair users, people with mobility impairments caused by aging and transit dependents.

In addition to the previous research findings that identified personal autonomy as a key variable of occupational choices for physically disabled adults (Collins and O'Mahony, 2015), we can conclude that personal autonomy is a key variable of the transportation choice process for people with mobility impairments. It is important for the local authorities to recognize that people with permanent mobility impairments and wheelchair users have less personal autonomy than others. In this context, it should be pointed out that the authorities could take actions aimed at increasing the personal autonomy of these people, through the provision of more inclusive public transportation infrastructure and services.

Regarding the specific context of our case study, although the present research was focused on people with mobility impairments who travel, we believe that further research is also necessary to study the share of the population with mobility impairments who do not travel since this situation may be affecting their health (Boniface et al., 2015; Mackett and Thoreau, 2015). It is estimated that there are over 681 people with mobility impairments who do not travel in Tunja, approximately 41.1% of the total. Our recommendation is that future research takes into account, not only the effect of tangible attributes but also the effect of perceptions and individual attitudes on their decision not to travel.

Finally, we believe that the implications of our research are important in the framework of the Colombian national policy that aims to reduce barriers related to accessibility and support independent life. The new National Development Plan (2018–2022) aims to strengthen the actions of the State so that physical facilities are accessible, considering the different types of disabilities. Our results can help to better define the strategies aimed at improving the perception of accessibility and increase the personal autonomy of Colombians.

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