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Content

1 INTRODUCTION

Fast growing transport needs are a common concern in many cities, both in the developed and developing world. To address this issue, more than 70 cities have already implemented a Bus Rapid Transit (BRT) system, and many more are planning to do so in the following years. These systems relatively low costs, added to their fast implementation times and good performance statistics, are some of the main reasons for their increasing popularity.

However, most BRTs have been designed using an engineering standard of 6 or more passengers per square meter (which can be exceeded at peak times in some corridors), yet, according to Vuchic (2005), densities of 6.7 passengers per square meter result in “crashes loads, possible injuries, and forced movement”. Because of that, individuals are not willing to use the system under these conditions and travel by private transportation, preventing the increase BRT’s modal shift and the reduction of congestion and emissions. This is especially important in developing countries, where motorization is rapidly increasing and car emissions account for nearly half of the urban pollution. This situation urges the need for more detailed analysis of crowding costs in mass transit systems and its impact on travel decisions.

Users’ mode-choice process is complex as they consider many more characteristics than the usually included fare, in-vehicle travel time and waiting time (Ortúzar and Willumsen, 2011). Particularly, comfort level of the different alternatives has been empirically demonstrated to be a significant factor in travelling behavior by numerous authors (for example, Ben-Akiva et al., 2002; Cherchi and Ortúzar, 2002; or Raveau et al., 2011). Nevertheless, crowding is defined as a ‘psychological state characterized by stress and having motivational properties’ (Bell et al., 2001), that can also imply a perceived lack of control, stimulus overload, amongst other stressors. Thus, travel decisions involving comfort and crowding are complex mental process involving attitudes, psychological state, preferences and socioeconomic constraints.

For that reason, the question of how to measure crowding and what level of comfort is necessary for BRTs to promote modal shift is relevant. The general objective of this project is to analyze comfort attributes in existing BRT systems and formulate recommendations to enhance modal shift towards public transport. This evaluation will be carried out in Bogota and Santiago, and will offer a sample methodology for other cities with operating BRTs.

The research questions for this project are the following:

- Are the current BRT (in-vehicle) comfort standards adequate in order to attract new customers and promote modal shift?
- How does comfort compare in relation to other trip attributes such as travel time, costs, etc.?
- Can BRT agencies provide more comfortable trips while keeping additional costs under control?

The specific objectives are:

- Analyze BRT performance in two Latin American cities. Specifically, study (in-vehicle) comfort and user perception in relation to other trip attributes.
- Analyze the cost and benefit implications of different comfort policy scenarios, considering the additional impacts in operational costs and capital investments while accounting for additional ridership, modal shift, reduced congestion and emission reductions.

This document presents the first report of this study. Section 2 contains the literature review on method for valuation of crowding in public transportation and the information on the main characteristics of the public transport systems of Bogota and Santiago. Section 3 presents the main characteristics of the public transport systems under analysis. Section 4 reports the results of the exploratory studies in Santiago and Bogota. Section 5 presents valuation of crowding. It reports the survey design with focus on the experimental design of the stated preference scenarios, describes briefly respondents' information collected in the survey, reports the estimation model and the results. Finally, section 6 reports the analysis of policies for improving comfort level in the bus system of Santiago. This analysis is based on a simple simulation model built for this study and included as a product of it.

2 LITERATURE REVIEW ON VALUATION OF CROWDING IN PUBLIC TRANSPORTATION

This section provides a review on the literature, identifying relevant methodologies to measure the attribute of comfort and crowding in mass transport systems. Though not exclusively, the focus is set on in-vehicle travel crowding and the several econometric models that different authors have developed in order to further comprehend its implications. This section is organized according different methods for value comfort in public transit. Subsection 2.1 presents methods based on stated preferences (SP), both choice-based experiments and contingent valuation. Subsection 2.2 presents the use of revealed preferences (RP). Subsection 2.3 focuses on more sophisticated approaches such as models estimated with mixed RP and SP data, and the use of latent variables.

2.1 Methods based on stated preferences

Regarding the valuation of comfort in public transit systems, most of the works addressing this issue use choice-based stated preferences methods (Li and Hensher, 2011). Recently, Guerra and Bocarejo (2013), and Haywood and Koning (2013) apply contingent valuation to find the willingness to pay for reducing the overcrowding in the bus system of Bogota and the metro system in Paris, respectively.

Li and Hensher (2011) review public transport crowding valuation research, focusing on studies conducted in the UK, USA, Australia and Israel. They state that in recent years there has been growing interest in studying crowding, especially in a public transport context. Li and Hensher (2011) provide a summary of relevant public transport crowding valuation studies (Table 1).

Most of these studies used Logit models with SP data covering commuters, and focus mainly on in-vehicle congestion costs. Nevertheless, Douglas and Karpouzis (2005) estimated crowding costs in the platform (related to waiting time) and in the access-way/entrance to the train station (related to walking time).

In addition to the time multiplier (ratio of travel time with a certain level of crowding, and the equivalent travel time without crowding), authors present other measures of the value of crowding; a monetary value per time unit, and a monetary value per trip. Given that the majority of the studies their reviewed used choice-based SP data, Li and Hensher (2011) also analyze in detail the way crowding is represented in such experiments.

Amongst the reviewed studies, Whelan and Crocket (2009) conducted an SP experiment, using as a proxy for crowding the seat occupancy rate and the number of standing passengers. These parameters allowed them to calculate the load factor (number of passengers/number of seats) and passenger density (standing passengers per square meter), and specify time multipliers according to each level. In this respect, Wardman and Whelan (2011) suggest that passenger density is a better indicator of congestion, given that a same load factor may have different levels of crowding across different types of trains with varying seat composition.

Besides the time multiplier approach, crowding cost can be obtained directly as a monetary value. Lu et al. (2008) conducted an SP experiment for train users in Greater Manchester in 2005, and estimate values for crowding costs, which resulted more than twice as much as the value of in-vehicle time in a non-congested scenario. In their survey, crowding was represented as the combination of a probability of occurrence and length of time (for instance, two out of five times someone stands for the whole journey of 30 minutes).

As previously stated, crowding cost studies focus mainly on in-vehicle congestion, although crowding on platforms and access-ways also imply additional disutility. In this respect, Douglas and Karpouzis (2005) performed an SP experiment on Sydney train passenger. In their experiment, users were required to make a choice between two trips with varying levels of crowding in the access-way, entrance, and on the platform. Crowding was defined in three levels (un-crowded, average, or crowded), and the time spent walking or waiting in each congestion situation was also specified. Using this information, Douglas and Karpouzis (2005) estimated a series of multinomial Logit models. In their final model, the parameters related to crowding costs resulted the same for both access-way and entrance congestion.

A summary of the different studies and methodologies used to calculate values of crowding is presented in Table 2, showing which measure is used (time multiplier or monetary values), the way crowding is presented to surveyed passengers, and the WTP estimation for each case.

Regarding future research, Li and Hensher (2011) highlight the need for more complex utility function specifications, as most models adopt a linear form. Crowding levels may vary from trip to trip, and there is a probability that a vehicle will present a certain level of congestion, instead of being fixed as presented in the reviewed experiments. In this sense, the true decision making context is subject to a ‘risk’, and using a linear utility specification implicitly assumes that users are risk neutral, which is not necessarily true and must be properly addressed.

Guerra and Bocarejo (2013) developed a methodology to estimate the costs of crowding in TransMilenio BRT (located at Bogota, Colombia), which now has an average of 6.5pax/m^2 during morning peak period.

Based in Pigou’s externality theory, they argue that extra users cause an increase in other users traveling costs, because of discomfort caused by crowding. However, this paper does not take into account the decrease in the average waiting time caused by the inclusion of extra users into the system (as frequencies should increase to provide that extra capacity), as it assumes bus supply is fixed.

In order to measure the costs of crowding in TransMilenio, a stated preferences survey was conducted in which users were asked for their willingness to pay (WTP), measured in waiting time units, for a less crowded situation. Passengers were shown photos of varying congestion situations in the bus (4 pax/m^2, 3 pax/m^2, and 2 pax/m^2), and asked if they would be willing to wait an extra 5 minutes to travel in the first situation; if the response was positive they were asked if they would wait 5 more minutes (a total time of 10 minutes), and so on. When the user responded negatively, a similar questionnaire showing the second (and then, the third) congestion situation was applied. This process allowed the authors to determine the maximum time (in discrete 5 minutes steps) that each user would be willing to wait for each congestion situation.

Using the data obtained in the survey, WTP was estimated through different econometric models: Logit discrete choice models, exponential regressions, powered regressions, and linear regressions. The latter resulted in better significance result and goodness of fit (R^2 = 0.702), and was consequently selected. Finally, they used a model in which density reduction was directly linked to WTP and obtain that an average user is willing to wait 2.422 extra minutes to have one less passenger per square meter in his bus.

Table 1: Summary of crowding valuation studies reviewed by Li and Hensher (2011)

	Modelling framework	Mode	Location	Survey year	Sample size	Type of crowding	Way of representing crowding in experiments	Measure of the valuation of crowding	Trip purpose(s)
Whelan and Crockett (2009)	MNL (SP data)	Train	UK	2008	2314	In-vehicle	Number of standing passengers and the proportion seated	Time multiplier	Commuting, business, education, other
Lu et al. (2008)	MNL and heteroskedastic MNL (SP data)	Train	UK	2005	1321	In-vehicle	Probability of occurrence (seating or standing) and length of time	£/minute	Commuting
Douglas and Karpouzis (2006)	MNL (SP data)	Train	Australia	2005	584	In-vehicle	Seat (uncrowded or crowded) or stand for a number of minutes	$/minute and minutes/minute (similar to time multiplier)	Commuting mainly
Polydoropoulou and Ben-Akiva (2001)	Nested Logit (SP data)	Bus and mass transit	Israel	1999	1830	In-vehicle	Probability of getting a seat	$/trip	Commuting, shopping, education, other
Hensher et al. (in press-b)	Error components Logit (SP data)	Bus/light rail, train and proposed metro	Australia	2009	620	In-vehicle	Number of standing passengers and the proportion seated	$/trip and $/minute	Commuting
Pepper et al. (2003)	Conjoint analysis	Train	USA	1999	144	In-vehicle	Desirability level for increased seating capacity	$/trip	Commuting
Douglas and Karpouzis (2005)	MNL (SP data)	Train	Australia	2003	335	Walking	Three levels of crowding in the access-way/entrance associated of the length of walking time	$/minute and minutes/minute	Commuting mainly
Douglas and Karpouzis (2005)	MNL (SP data)	Train	Australia	2003	335	Waiting	Three levels of crowding in the platform associated of the length of waiting time	$/minute and minutes/minute	Commuting mainly

Table 2: An Overview of the empirical evidence on WTP for crowding (Li and Hensher, 2011)

Study	Units	Situation	WTP estimate	WTP estimate ($US2003[a])
In-public transport vehicle				
Whelan and Crockett (2009)	Time multiplier	Seat occupancy: 25–100%	1–1.83	1–1.83
		Load factor: 80–200%	1.5–2.37	1.5–2.37
		Standing passengers per metre square: 0–6	1.53–2.04	1.53–2.04
Lu et al. (2008)	£/minute	Prob. of occurrence and length of time standing	12.05 pence/min (£2005)	18.79 pence/min (or 11.27 $/h)

[a] All monetary values are converted into $US2003.

Table 2 (cont.): An Overview of the empirical evidence on WTP for crowding (Li and Hensher, 2011)

Study	Units	Situation	WTP estimate	WTP estimate ($US2003[a])
Douglas and Karpouzis (2006)	Minutes per minute[b] (increase relative to uncrowded seating)	Crowded seating	0.17 min/min	0.17 min/min
		Standing up for 10 min	0.34 min/min	0.34 min/min
		Standing up for 15 min	0.57 min/min	0.57 min/min
		Standing up for 20 min or more	0.81 min/min	0.81 min/min
	$ per person hour[c] (increase relative to uncrowded seating)	Crush standing up to 10 min	1.04 min/min	1.04 min/min
		Crowded seating	1.47 $/h	0.97 $/h
		Standing up for 10 min	2.83 $/h	1.87 $/h
		Standing up for 15 min	8.1 $/h	5.35 $/h
		Standing up for 20 min or more	11.5 $/h ($AUD2003)	7.59 $/h
Polydoropoulou and Ben-Akiva (2001)	$/trip	Probability of getting a seat for 0 and 1-plus cars owned If always get a seat	3.64 to 4.66 $/trip	0.87–1.11 $/trip
		50% chance of getting a seat	1.82–2.23 $/trip (Israeli shekel in 1999)	0.43–0.53 $/trip
Hensher et al. (in press-b)	$/trip	Based on 30 min trip and combination of percent of passengers seated and standing	2.76 $/trip ($AUD2009)	1.5 $/trip
		45% chance of getting a seat	9.9 Australian cents/min ($AUD2009)	5.5 Australian cents/min (or 3.32 $/h)
		50% chance of getting a seat		

Pepper et al. (2003)	$/trip	Additional seating capacity fare value per trip	2.2 $/trip ($US1999)	2.43 $/trip
Access and platform locations				
Douglas and Karpouzis (2005)	Minutes/minute	Waiting under high crowded conditions (increase relative to medium crowded)	0.7–1.5 min/min	0.7–1.5 min/min
		Walking under high crowded conditions (increase relative to medium crowded)	0.5–0.8 min/min	0.5–0.8 min/min
	$/person hour	Waiting on high crowded platform during peak hours (increase relative to medium crowded)	16.14 $/h	10.65 $/h
		Walking in high crowded access-way/ entrance during peak hours(relative to medium crowded)	11.56 $/h	7.63 $/h
		Waiting on high crowded platform during off-peak hours (increase relative to medium crowded)	13.36 $/h	8.82 $/h
		Walking in high crowded access-way entrance during off-peak hours(relative to medium crowded)	9.65 $/h ($AUD2003)	6.37 $/h

[a] All monetary values are converted into $US2003.

[b] The values plus one are equal to time multipliers of corresponding crowding levels relative to uncrowded seating.

[c] The uncrowded seating is valued as 8.45 Australian dollars per hour or 5.58 $US2003.

Then, using values of time per income group reported by Steer Davies Gleave (2011), Guerra and Bocarejo (2013) obtain the willingness to pay in monetary terms. Nevertheless, these values of time do not differentiate between the nature of the time (e.g., traveling or waiting), which can lead to potential bias on the methodology.

This WTP in monetary terms is considered equal to congestion costs (Cc), and the following individual cost function (IC) is proposed:

$$\mathrm{IC} = (\mathrm{Fare}) + (\mathrm{Travel\ Time} \times \mathrm{Value\ of\ Time}) + \mathrm{Cc}$$

Note that Cc is considered fixed and not related to travel time. This can lead to strange behavior, as users are supposed to be willing to wait 2.422 extra minutes to have 1 less passenger per square meter in the bus, whether they makes a 5 minutes or 1 hour trip.

Additionally, using data from previous studies on price-quantity elasticity of TransMilenio in 2003, a demand curve is determined. However, it is assumed that this price elasticity equals the generalized cost elasticity with no further comments on the impacts of this simplification. Moreover, the value of this elasticity is -0.67, which seems high for a peak-period (in which congestion costs are more relevant).

Finally, they estimate the potential benefits of reducing congestion in TransMilenio system. Due to equity constraints an optimal congestion charge is discarded. Instead authors suggest an alternative solution: optimal investment that guarantees the optimal passenger density is achieved. In this way, a new IC is calculated to include the general decrease in individual costs. However, investment costs are not taken into account, meaning that this new “optimal situation” is simply an adaptation of the system to reach the “optimal density” and by no means the system optimum.

Haywood and Koning (2013) conducted a similar study, in which they examine the utility of public transport crowding, using a survey collected in late 2010 in the Paris subway. Their formulation of the utility function includes fare, time and congestion measured in discrete conditions (the most simple case includes only two levels, peak and off-peak comfort levels). The effect of congestion is included multiplying travel time, as it is supposed to modify the cost of time.

They measure the equivalent variation (i.e., the variation in economic resources which makes individuals indifferent between states with different levels of congestion) with the stated preferences survey using the contingent valuation methodology.

Haywood and Koning (2013) propose two types of equivalent variations; WTP, which is the additional travel time in the less congested state which would leave individuals indifferent with the more congested state; and a time multiplier (TM), which is the marginal rate of substitution of travel time between peak and off-peak comfort levels. The relationship between both types of equivalent variations is direct.

The survey was applied in Paris subway during morning and evening periods. Users were first asked to state their expectation of passenger density using showcards. Then, a random hypothetical density reduction was proposed with a random first temporal bid (i.e., they were asked if they would be willing to travel extra *X* (a specified quantity) minutes to travel in a less crowded condition). Finally, users were proposed a second bid with a 25% increase or decrease in time, depending in their acceptance or refusal of the first one, respectively. This is a congestion valuation survey with double-bounded dichotomous choice (DBDC) format.

Using temporal bids instead of monetary bids avoid biases. First, it avoids potential strategic bias as users could freeride on others' contributions by under (or over) reporting, as the monetary costs of public transport in their case study are highly subsidized both publicly and by employers. Second, it reduces the hypothetical bias, as it makes it easier for individuals to envisage the proposed scenario because they sometimes decide in these terms (by modifying their departure times, use slower but less congested routes or letting a train pass whilst waiting for a less congested one).

With respect to previous studies, the Haywood and Koning (2013)'s survey incorporates several key innovations:

- Clearly defined congestion situations (instead of asking between subjective peak and off-peak conditions).
- Random bidding process with second offers to both accepting and rejecting users.
- Evening inclusion, as individuals may be more prone to reject the offer during morning peak (because of higher scheduling costs).

- Trip duration was measured using subway system information, instead of relying only on users' reports.

In order to estimate the parameters of the utility function, the authors use discrete choice model, like probit or Logit models. As the DBDC question format induces a relationship between the answers to the two rounds, Haywood and Koning (2013) propose two estimators: a bivariate probit model and a random effects estimators approach. Both estimators provide measures of the correlation between answers to the first and second bid. It worth to notice that the right approach is consider the answers give interval data and estimate a discrete choice model consistent with the DBDC (Hanemann and Kanninen, 1999).

Finally, and in consistency with other authors and their own initial results, the random effects model is preferred. Using this model, time multipliers (TM) are calculated for different levels of comfort, using as a reference level of crowding 1 pas/m^2 (as initial results indicate, that this situation is preferred over the one with empty wagons).

The results show that users are indifferent between travelling 1 minute in the worst travel condition (6 pax/m^2) and travel seated for 1.6 minutes. Furthermore, as expected, users value time more during morning peak period, compared to evening peak.

Regarding policy implications, Haywood and Koning (2013) calibrate TM as a function of in-vehicle passenger density in linear terms.

$$T_m(d_j) = d_o + 0.11 d_j \ \ (d_o = 1)$$

Using this function, optimal design can be applied for public transport networks (for example, following Jara-Diaz and Gschwender (2003), de Palma et al. (2011) or Prud'homme et al. (2012). Such function can also be used to assess the impacts of crowding costs in the total generalized costs of the system. For instance, neglecting public transport crowding costs implies underestimating by 27% the welfare costs of transport activities during rush hours in the Paris subway. Welfare gains from reducing density are also calculated.

Considering these costs may change the Net Present Value (NPV) and Internal Rate of Return (IRR) of new projects that decongest subway system, Haywood and Koning (2013) calculate such indices for a recent investment in an automatic driving system for the subway. NPV and IRR result higher than the current threshold for transport projects in France.

2.2 Methods based on revealed preference

Congestion and comfort in public transport has been also studied through revealed preferences choice models. In this respect, Raveau et al. (2011) proposes a new model of route choice. Instead of only using the usual factors related to service level (in-vehicle travel time, waiting time, access time, etc.) and users' characteristics (income level, purpose of trip, etc.), this study suggests three hypotheses, with the third one being particularly relevant for the purpose of our research:

1. Users tend to penalize routes that deviate from a direct path to the final destination (authors define this as the angular cost of the route).
2. Users tend to prefer routes that are better known or more heavily travelled (as knowledge is hard to measure, the model includes a variable that measure the use level of each route as a proxy).
3. Users also consider factors such as comfort, reliability, and vehicle and stations physical characteristics (existence of mechanical escalators, for example).

To prove their hypotheses, authors collected data from an origin-destination survey conducted at Metro stations of Santiago, from which only trips that could have been performed by more than one route were considered.

Raveau et al. (2011) calibrated two models, both in a Logit multinomial design, with one of them considering only traditional variables whilst another model also includes the novel variables linked to the main hypotheses of the study.

Using detailed information available on the load profiles of each Metro line, the *average occupancy rate* variable was added for each route. This variable represents the level of crowding, and indirectly also captures train capacity restrictions and the probability that a user is unable to board the first-arriving train.

Additionally, two dummy variables relating to comfort were included. If occupancy rate is greater than or equal to 85%, there is a chance that users will be unable to board the first train and the first dummy variable allows to capture this effect. On the other hand, if occupancy rate is less than or equal to 15%, there is a chance that the user can ride seated, and the second dummy variable enables the study of this effect.

As fare was left out of the model specification (due to the flat fare policy), the model cannot produce monetary valuations of the various attributes. However, marginal rates of substitutions are obtained between the various time factors.

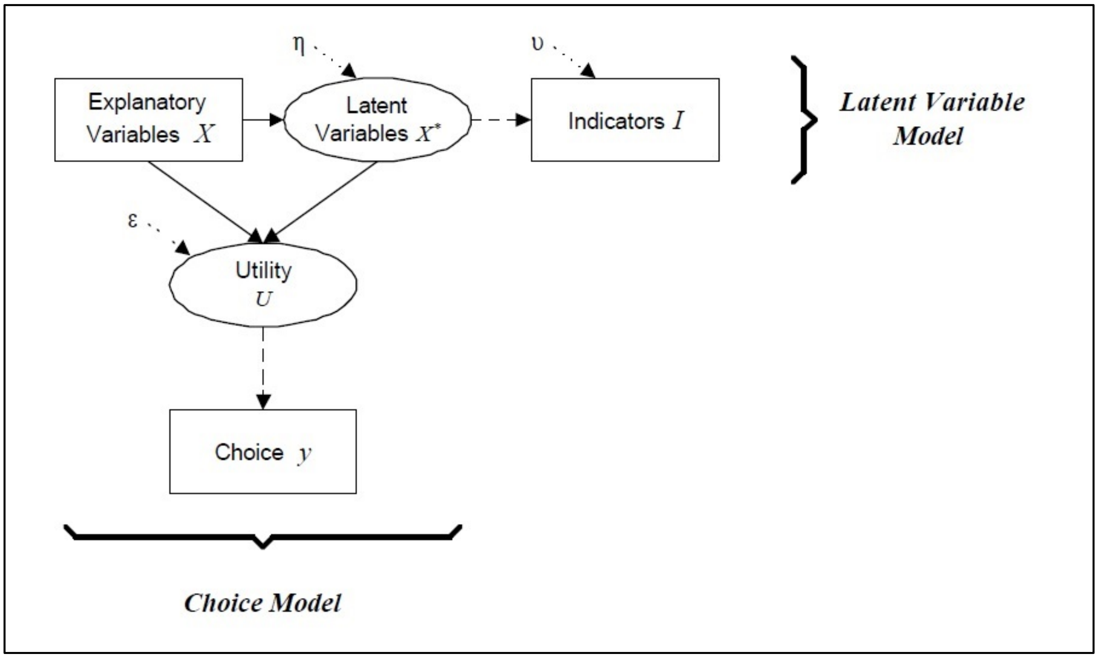
2.3 Models with mixed RP/SP data and latent variables

Another modeling alternative is the use of both RP data and other type of surveys to model user's decision-making process, with the inclusion of latent variables. Ben-Akiva et al. (2002) follow this approach, and presents a general methodology for the inclusion of latent variables in discrete choice models, which are incorporated through psychometric data. Authors use a maximum likelihood estimation method for the integrated latent variable and discrete choice model, which results in consistent and efficient estimates of the model parameters.

The model structure is presented in Figure 1, and as Ben-Akiva et al. (2002) indicates:

> "Follows the convention of depicting a path diagram where the terms in ellipses represent *unobservable* (i.e. latent) constructs, while those in rectangles represent *observable* variables. Solid arrows represent *structural equations* (cause-and-effect relationships) and dashed arrows represent *measurement equations* (relationships between observable indicators and the underlying latent variables)."

Figure 1: Integrated choice and latent variable model structure (Ben-Akiva et al., 2002)



In this framework, using both the structural and measurement equations, and making an assumption about the distribution of the disturbance, ε, choice probabilities conditional on both observable and latent explanatory variables can be obtained. For instance, if the distributions of disturbances ε are i.i.d. Gumbel, a Logit model is obtained.

It is important to note that, once the model is estimated, forecasting can be done with no need for latent variable measurement models or indicators. Namely, choice probability can be expressed in terms of observed variables only.

Authors show that, although it is possible to calibrate a choice model with limited latent variables using only RP data and without using indicators, it is likely that in such a model the effects of individual-specific latent variables would remain unidentified.

Furthermore, Ben-Akiva et al. (2002) identify three types of latent factors: attitudes, perceptions, and preferences.

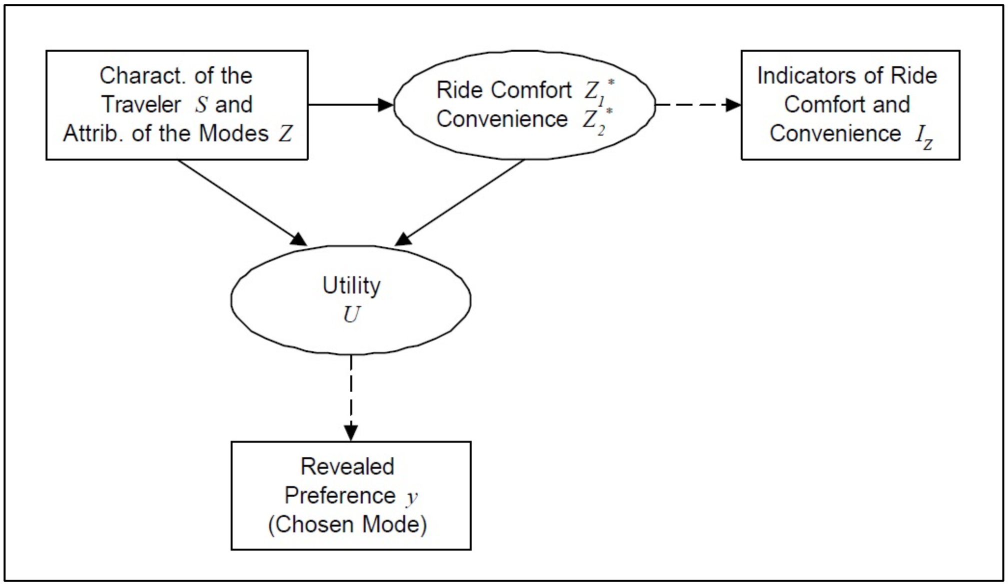
Attitudes are latent variables corresponding to the characteristics of the decision-maker, and reflect individuals' needs, values, tastes, and capabilities. Examples given for this factor are *the importance of reliability* or *preferences for a specific mode*.

Perceptions are the individuals' beliefs or estimates of the levels of attributes of the alternatives. Examples given for this factor are *safety*, *convenience*, and *reliability*.

Preferences represent the desirability of alternative choices, and they are translated to decisions via a decision-making process (which can be a utility maximization process, for example).

Having presented the general methodology and theoretical framework for the inclusion of latent variables in choice models, case studies are then presented to illustrate the benefits of this method. One of them is particularly interesting for the purpose of our work: Mode Choice with Latent Attributes.

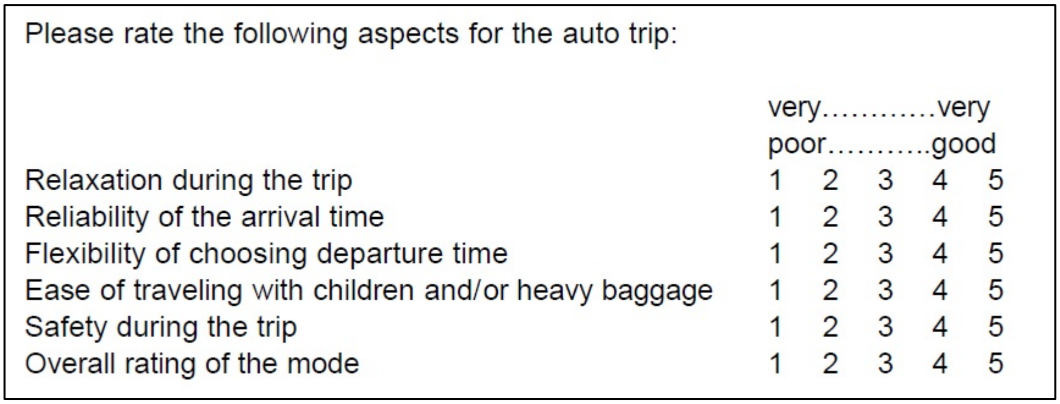
Figure 2: Modeling framework for mode choice with latent variables (Ben-Akiva et al., 2002)



In this case study, Ben-Akiva et al. (2002) incorporate latent constructs of convenience and comfort (identified through exploratory factor analysis) in a mode choice model, between rail and car for intercity travel through data collected in the Netherlands. Figure 2 shows the framework for this model.

Data includes revealed choices and also subjective evaluation of trip attributes for both the chosen and unchosen modes, obtained through a survey (with questions such as those shown in Figure 3).

Figure 3: Indicators for ride comfort and convenience (Ben-Akiva et al., 2002)



Please rate the following aspects for the auto trip:

	very…………very poor……….good				
Relaxation during the trip	1	2	3	4	5
Reliability of the arrival time	1	2	3	4	5
Flexibility of choosing departure time	1	2	3	4	5
Ease of traveling with children and/or heavy baggage	1	2	3	4	5
Safety during the trip	1	2	3	4	5
Overall rating of the mode	1	2	3	4	5

Results show a significant increase in the predictive capability of the model, with respect to the choice model without latent variables.

Authors also indicate that, in general terms, it can be difficult to find causes for the latent variables, and suggest that this issue needs to be thoroughly addressed in the data collection phase. Additionally, they suggest that modelers should first make behavioral hypotheses behind the choices, then develop the framework, and finally design the survey to support the model.

Another relevant research that follows a similar methodology is the one presented by Espino et al. (2006), which includes the usage of both RP and SP data in a mode choice model including latent variables and interaction effects, for the Grand Canary island.

In order to understand the transport context and plan the SP survey, a (recorded) focus group (managed by a psychologist) was made. Also, they tried several designs and in each case conducted a thorough pre-test pilot, in order to improve the SP experiment with the learning of each one of them.

Moreover, through a detailed analysis of the sample, captive, lexicographic, and inconsistent individuals were detected; and the possibility of removing these observations was studied.

Authors were interested in analyzing the effect of the latent variable *Comfort*, and considered two alternative specifications. The first one included *Comfort* as a dummy variable, with three levels (low, standard, and high); thus, two dummy variables were incorporated. The second specification considered an interaction between *Comfort* and *Travel time*, as longer times traveling under a low comfort situation should have a greater impact in the decision-making process than shorter trips; hence, a non-linear term of *Comfort* dummy variables multiplying *Travel time* was included. They showed that the subjective value of time decreases as comfort is improved.

Finally, it is important to note that, when interactions are present willingness to pay (WTP) is not constant across individuals. For instance, in their analysis authors found models in which the subjective value of time (SVT) for the bus mode was expressed in terms of the level of comfort, the frequency, the individual's expenditure rate, and if the person works or not.

Likewise, the relevance of comfort for public transport users' decisions is shown in the modeling of a new suburban train service in Cagliari (Italy), in Cherchi and Ortúzar (2002). In this model, mixed RP and SP data was used, and the analysis included level-of-service variables, latent variables (such as comfort), and interaction variables.

In order to collect the data, three types of surveys were used; a focus group (to obtain qualitative information on the decision-making process), a RP study, and a SP survey to learn about user preferences for the new train system.

Comfort variables were included only in the SP survey, and three different levels were defined: poor, sufficient, and good. These levels were described in the survey respectively as "very crowded, you may have to let one bus pass before you can get on", "bus arrives with space but almost full: you must travel standing", and "bus arrives almost empty: you can travel seated". Finally, comfort was introduced into the model through two dummy variables, as three different levels were considered in the surveys.

Cherchi and Ortúzar (2002) conclude that non-linear utilities models appear significantly superior to their linear counterparts. They also remark the importance of high quality data, and provide several suggestions to achieve it. First, they highlight the importance of using focus groups or other qualitative techniques to further comprehend the transport and cultural situation. It is also important to make personal contact with the surveyed families, to gain their confidence and achieve high levels of response rates. Lastly, the fact that SP and RP was done to the same group ensures that individuals perceive proposed trips as more realistic or feasible.

3 CHARACTERISTICS OF THE PUBLIC TRANSPORT SYSTEMS OBJECT OF STUDY

This section reports the main operational characteristics of the public transport system of Bogota and Santiago. In particular, the section reports trips attributes. The primary source of information is the study carried out by the Center BRT-ALC (2012), which collects information on several variables characterizing the public transport systems of six cities in Latin America. Santiago and Bogota are part of this study.

The methodology involves collecting field information on travel times, waiting and access times of a representative sample of trips of the city. The way the sample is selected and the information on service level collected is common to all cities in the study. The methodology is implemented in conditions as similar as possible in each of the cities and it is intended to be independent of points of judgment that could bias the results.

To carry out this study a morning rush hour public transport commute sample is carried out in the in each city, which is representative of the total trips made. That is, it identifies a set of representative trips, regarding indicators of interest, which make possible for comparing the cities. In principle, these trips are not carried out, but relevant average attributes and their variability are estimated. For this, it is assumed that the trips are made in order to minimize travel time between origin and destination.

After determining the origin and destination of specific trips to be analyzed, the legs in which trips would take place are identified, along with stops to get on and off for each of these. Then, for each leg, the service or services the user would have as travel alternatives is established. With this information of legs and services available, the average walking time, waiting time, vehicle travel and transfers times for each trip is determined. With this information we proceed to determine the average indicators and their variances for different length trips in the city.

To determine travel and waiting times, field measurements are carried out that make it possible to estimate these variables. The measurements consist of a representative sample of services for each mode in the city and recording the time of successive buses passing through of each of these services at different points of their route. With this information it is possible to estimate the speed of operation (mean and standard deviation) and the distribution of the duration of the intervals between buses (of particular interest is the mean and standard deviation). To capture the heterogeneity in the operation of the various modes and public transport services within each city, services are grouped into categories where the desired variables to be measured are relatively homogeneous. These categories are defined according to the infrastructure used by the services (for example, segregated lane or exclusive corridor) or based on geographical areas they cover. Then, based on the defined categorization, an average speed and headway is given to each service used in the trip sample.

Table 3 shows the main characteristics of the transport system of Santiago and Bogota. In the case of Santiago, modal share is grouped in three alternatives: Bus, Subway and Bus-Subway. This is because the integrated transport system makes it difficult to differentiate the trips modes in non-combined modes. It is apparent that the participation of other modes that require specialized infrastructure, as Subway or BRT, is limited by the extent of such infrastructure and its relationship with the size of the city.

In Santiago, the number of people using the bus is very similar in magnitude to the people who use the subway. Each mode transports approximately 2.3 million passengers daily. In Bogota, the BRT system demand (trunk and feeders) is 1.6 million passengers daily and 165,000 in the morning peak. The other bus services carry 3.6 million passengers daily and 350,000 in the morning peak.

Table 3: Characteristics of the public transport system

	Santiago	Bogota
Motorization rate (veh/inhab)	0.34	0.12
Motorized trips per day (mill.)	9.5	10.1
Public transport participation on motorized trips	60%	68%
Share of captive users of public transport on motorized trips	40%*	60%*
Fleet of buses (thousand)	6.1	15.7
Modal share of public transport		
Bus	38%	73%
Subway	31%	
BRT		27%
Bus-Subway	31%	

* Estimated as the public transport participation on motorized trips times one minus the motorization rate

Table 4 presents a set of indicators that describe the main aspects of the operation of a public transport system from the point of view of users. The indicators shown are times of traveling, walking, waiting, in-vehicle and speed. In addition, two types of variability in the level of service are included. One is the intrapersonal variability, which measures how dissimilar are the conditions for the same trip (or the same user) at different times. The other is the interpersonal variability, which measures how dissimilar are the conditions for journeys made in different parts of the city (or by different users).

Table 4: Level of service for Santiago and Bogota

	Santiago	Bogota
Travel distance (km)	12.2	11.7
Travel speed (km/h)	14.5	14.2
Distance in vehicle (km)	11.3	11.5
Speed in vehicle (km/h)	23.9	19.0
Travel time (min)	50.8	49.6
Interpersonal variability (min)	22.5	24.2
Intrapersonal variability (min)	7.1	10.4
Time in vehicle (min)	28.5	36.2
Interpersonal variability (min)	15.7	23.3
Intrapersonal variability (min)	3.5	9.1
Waiting time (min)	8.6	4.8
Interpersonal variability (min)	4.7	2.3
Intrapersonal variability (min)	5.8	5.0
Walking time (min)	13.8	8.6
Interpersonal variability (min)	10.1	2.2

The first type of variability is related to the experience that a user who makes the same trip repeatedly may have, for example the commute to work. The more variable are the traveling conditions, the worse the service offered by the system. This type of variability is measured as the average of the standard deviation of time (traveling, in-vehicle and waiting) experienced in each sample trip. Such standard deviation is rooted in the irregularity of the speed of vehicles and the intervals of passing through and was measured in the field.

The second type of variability is related to the homogeneity of the quality of service in the city. These comparisons can also be made by category of distance between the different cities. This variability is measured by the standard deviation of times experienced in the city (traveling, in-vehicle, waiting and walking). This can be considered as a measure of the fairness of the system of public transport in the city. The lower the variability within a distance range, the more equitable the service received by different users of the system.

Regarding the distance and speed on board the vehicles, Santiago shows a marked difference from Bogota, attaining an average speed of 24 km/h. This is due to the effect of the subway, which has higher operating speeds than other bus systems and almost two-thirds of city travelers use it. Table 5 shows the average speeds of bus, subway and BRT. It is observed that the Santiago subway reaches speeds much higher than other modes in both cities. Slightly slower, the Bogota BRT reaches very high speeds for a bus-based system, which is explained by an express services operation scheme and exclusive lanes.

Table 5: Speed onboard the vehicle by mode of transport (km/h)

City	Santiago	Bogota
Bus	17.1	16.3
Subway	33.4	
BRT		27.2
Total	23.9	19.0

An important indicator of the level of overcrowding in transportation systems is the probability that passengers can board the first vehicle arriving at the stop or station. This measure reflects two effects: bus does not stop at the bus stop corresponding, despite having available capacity, and bus comes with full capacity and it is impossible to board.

In the case of Santiago, the results of Center BRT-ALC (2012)’s study did not distinguish the reason for not boarding the bus because the two phenomena described are highly correlated and impossible to separate them in the estimation. In the case of Bogota, probability of not boarding because the bus is full was correctly measured. Table 6 shows this variable in each city by type of service.

Table 6: Probability of boarding the arriving bus (train) at stop (station)

City	Service	Probability of boarding				
		1st bus	2nd bus	3th bus	4th bus	5th bus
Santiago	Trunk	0.707	0.121	0.111	0.030	0.030
	Feeder	0.738	0.179	0.083	0.000	0.000
	Subway	0.598	0.279	0.085	0.037	0.000
Bogota	Trunk	0.725	0.199	0.055	0.015	0.004
	Feeder	0.640	0.230	0.083	0.030	0.011

In Santiago there are three types of bus services: trunk, express trunk and feeders. The express only operate on weekdays at peak periods (morning and evening). Table 7 presents the number of bus lines of each type in Santiago. The average nominal frequencies for the different types of services are presented in Table 8.

Table 7: Number of bus lines in Santiago

Type of bus services	Peak	Off-peak
Feeder	79	79
Express	16	0
Trunk	218	185

Table 8: Average nominal frequency in Santiago (bus/h)

Type of bus services	Weekday	Weekend
Feeder	6.6	5.4
Express	5.4	0
Trunk	9.0	7.2

The Santiago subway has two types of services: normal and express. The latter is a service that skips some stations alternately. The supply of both services depends on the time and day of the week. Table 9 summarizes this information.

Table 9: Subway services in Santiago

	Peak	Off-peak and weekend
Normal	2	5
Express	3	0

Three lines out of five operate express services in peak periods. The average frequency of the five lines is 25 trains per hour, which gives an average headway between trains of 2.38 min.

In Bogota, services can be grouped into three types: conventional buses, feeders and trunks. The first ones are buses that operate outside the exclusive bus corridors. The feeder buses also operate outside the corridors, but their routes connect TransMilenio stations with neighborhoods without BRT service. The trunk services are operating in the corridors and correspond to Bogota BRT system. Note that there is no change in the number of services throughout the day. That is, express services operating in both peak and off-peak periods. Table 10 shows the number of bus lines by type of service and Table 11 shows nominal frequencies.

Table 10: Number of bus lines in Bogota

	Lines
Conventional bus	505
Feeder	82
BRT	102

Table 11: Average nominal frequency in Bogota (bus/h)

	Weekday	Weekend
Conventional bus	15	15
Feeder	6	6
BRT	30	30

In Santiago, the average daily speed of buses is 24 km/h, but in the morning, this speed decreases to 20 km/h. For the subway, the opposite happens, the average daily speed is 32 km/h and the average speed in the morning peak period is 35 km/h. In Bogota, the daily average speed of buses outside the BRT corridor is 21 km/h, but in the morning this speed decreases to 19 km/h. For BRT, the average speed of the day is 26 km/h and the average speed in the morning peak period is 25 km/h.

4 EXPLORATORY STUDY ON PUBLIC TRANSPORT COMFORT PERCEPTION

Exploratory studies are based on qualitative research methodologies. One of these methodologies is the focus group. The most prominent feature of this type of study is that it looks for the interaction among respondents.

Focus groups allow studying problems in which the researchers have no clear idea of what they are going to find, but where they may have a hypothesis that needs not to be rigorously tested. These studies are also useful to support the design of questionnaires and stated response experiments, and to explore the language used by ordinary individuals in a specific issue of a survey. The data provided by this type of survey have no statistical significance and are usually qualitative.

Focus groups consist of a group of people, usually between five and nine, that discuss and exchange experiences and views on a specific topic. There is no questionnaire or a set of predefined question to ask. The discussion is led by a moderator to issues of interest of the study. The moderator also encourages the group to explore issues that are important and arise during the discussion, and watch the body language of the participants. The persons involved in each group are selected according to criteria that depend on the objectives of the survey. A criterion may be that participants have similar feature, for example, that all are users of public transport. Another criterion may be that respondents be different, for example, several socioeconomic strata.

In this study, we want to analyze the comfort-related attributes of transit systems, and to elaborate recommendations to increase its modal share. However, we do not have a clear idea of what users understand by comfort, how crowding is perceived, in what extent crowding is relevant in transport decisions, and what comfort related variables are the most important for mode choice. Thus, we carried out a focus group study to identify and explore comfort-related variables other than crowding, which are important for transport users, and their relative importance.

Four focus groups were carried out in each city. Only people from the medium and low income socioeconomic groups were considered (i.e. no individuals from the highest or lowest income groups were included). Participants were classified based both on their income and whether they could avoid using public transport during the peak hours or not (captive and non-captive transit users). The four focus groups rose from combining both classifications, i.e. low income captive transit user, low income non-captive transit user, medium income captive transit user, medium income non-captive transit user.

The focus groups were carried out following a predetermined guideline prepared by a psychologist expert in this type of studies. We summarize the guideline in what follows.

- General aspects
    - Reasons for the use of public transport
    - General opinion of the public transport system of the city
- General attributes of public transport
    - Ranking of strengths and weaknesses for each mode
- In-depth discussion on comfort concept. To investigate on
    - what users understand as comfort and the relation of comfort with passenger density
    - comfort differences between transit alternatives (bus, metro and BRT)
    - what users define as a comfortable trip
    - comfort and time trade-off
- Comparative analysis of comfort with respect to other attributes
    - To ask respondents for ranking of attributes from less to more important
- Ideal comfort and suggestions
- Willingness to change
    - ¿Do you think that you would use more frequently public transport if it were more comfortable?

All the previous issues are discussed in open format without a set of structured questions that require answers by the respondents.

The next sections present the results of the exploratory studies conducted in Santiago and Bogota.

4.1 Perception of Santiago Public Transport

In the case of Santiago, the specific objectives of the exploratory study are:

- To study the perception and relative importance of (in-vehicle) comfort, from the travelers' perspective.
- To investigate whether current comfort levels are enough to attract new users to the public transportation system.
- To explore how comfort impact traveler's decisions.
- To identity attitudes that may impact travelers' decisions.
- To evaluate how comfort is perceived by different socioeconomic segments.

The respondents were selected by a specialized firm on marketing research. The respondents fulfill the requirements set for the segmentation: low and medium income, and captive and non-captive users of public transport in peak hour. Four focus groups were conducted with 6 participants each one.

4.1.1 Results

General perception of public transport in Santiago is not good, mainly because (i) is too crowded on peak hours, (ii) buses are in bad shape and drivers are careless, and (iii) bus trips are long and slow. Perception improves on off-peak hours. Metro is perceived more positively than buses. Fare is not an issue for medium income individuals, but low income travelers feel that public transport is increasingly expensive, even though its poor quality doesn't improve.

According to users, main attributes of public transport are presented in Table 12 in order of importance.

Table 13 summarizes strength and weaknesses of each transport mode, also in order of importance.

Table 12: Main attributes of public transport in order of importance (more important attributes are higher in the table)

Attribute	Description
Speed	It includes both the waiting and the (in-vehicle) traveling time.
Safety (accidents)	How unlikely is for travelers to participate on a road accident, or other accidents at bus stops or metro stations.
Security (crime)	How unlikely is for travelers to robbed or sexually molested.
Comfort	It considers several aspects, such as available space, comfortable seats, availability and accessibility of handles, boarding and getting off easiness, ventilation, temperature, route information, hygiene.
Fare	It is often taken with resignation. Lower income individuals seem more affected by it. Fare is perceived as too high for the quality provided.

Table 13: Strength and weaknesses of each transport mode in order of importance

	Strengths	Weaknesses
Metro	1. Fast (low waiting and in-vehicle time) 2. Safe (few accidents and low crime) 3. Clean 4. Comfortable in off-peak hours	1. Uncomfortable on peak hours (too hot on summer, lacks ventilation) 2. Lacks night services 3. Expensive
Bus	1. Low access time 2. Windows allow to look outside 3. Provision of night services	1. Uncomfortable (all hours) 2. Unsafe (both accidents and crime) 3. Slow (long waiting and in-vehicle time) 4. Unreliable frequency 5. Carelessly driving

Regarding the importance of attributes, there seems to be two groups of attributes. Higher relevance core attributes, expected to reach at least a minimum level by all transportation modes. Second order set of attributes, which are appreciated but are not critical. The core attributes are safety (concerning accidents), security (concerning crime), and speed of traveling (low waiting and in-vehicle time). Lower income individuals also include fare in this group. The second, less relevant set of attributes includes comfort and all its components:

space and ventilation for metro; and seats, maintenance, careless driving, in-vehicle information, and cleanliness for buses. Medium income individuals include fare in the second group of attributes. Table 14 presents the most important attributes according to type of respondent.

Table 14: More relevant attributes by type of respondent in order of importance

	Low income	Medium income
Captive user	1. Price and safety 2. Speed and security 3. Comfort	1. Speed 2. Security 3. Safety 4. Comfort 5. Price
Non-captive user	4. Safety 1. Speed 2. Security 3. Comfort and price	1. Safety and security 2. Speed and comfort 3. Price

Comfort comprises several aspects. Their relevance and perception varies depending on the particular mode considered. Public transport captive users are the most critical ones of the system, because they undergo the most uncomfortable travel conditions. The non-captives users tend to avoid using public transport on peak-hour; therefore they can avoid uncomfortable conditions. The main aspects of comfort, ordered by decreasing relevance, are shown in Table 15.

Regarding the comfort, the main problem of Metro is crowding on peak hours (Table 16). Crowding translates on little space for each person, difficulties during boarding and getting off the wagon, and lack of ventilation (mainly on summer). The physical design of stations and trains seems good for passengers, except the narrowness of some station’s platform, which could lead to accidents. On off-peak hours, Metro is perceived as fairly comfortable.

Bus is perceived as uncomfortable disregarding the hour. Main issues are slippery and hardly accessible seats; inconvenient handles; inconvenient turnstiles; lack of maintenance; difficulty to board and get off; lack of in-vehicle route information; carelessly driven (sudden stops and accelerations, and lack of respect toward other drivers and pedestrians); the driver is not aware of what happens in the bus (Table 16). However, the main concern about buses among passengers, seems to be their unreliable frequency (bus bunching is perceived as the main cause).

Table 15: Main components of comfort ordered by decreasing relevance

Attribute	Description
Space	Available space for each traveler, i.e. how crowded the vehicle is. High levels of crowding are perceived as insecure. Crowding is the main issue for transit users on peak hours, especially for the captive.
Seats	Travelers don’t want to hold handles if they are seated. Seats should not be slippery. This is an issue mainly on buses.
Handles	There should be plenty for all standing passengers, and they should be easy to access. It is mainly an issue on buses.
Boarding and getting off easiness	In buses is associated with lack or presence of steps. In metro, it’s associated with people not letting board or get off the train.
Ventilation and temperature	Mainly an issue on Metro, during summer.
Maintenance	Mainly an issue on buses. It is associated with non-functioning buzzers and windows in bad shape.
Route information	Mainly an issue on buses. Passengers would like main stops to be announced.
Cleanliness and Hygiene	Mainly an issue on buses.
Driving	Mainly an issue on buses. Passengers dislike sudden stops or high accelerations.

Table 16: Perception of comfort of each mode

	Positive	Negative
Metro	• Comfortable seats • Well design handles and poles • Easy to move around inside the train • Easy to board and get-off on off-peak hours • In-vehicle route information available • Cleanliness	• Too crowded on peak hours • Lack of ventilation
Bus	• Allows to look at the window • Ventilation	• Uncomfortable seats • Narrow aisles • Poorly design handles • Lack of in-vehicle route information • Carelessly driven • Hard to board and get-off

Besides each individual’s personal preferences, context also plays a role on determining the attribute’s relevance. Comfort becomes more relevant for the following situations and type of users, who might be prone to change their usual mode for a more comfortable one:

- Travelling with children
- Travelling with packages or luggage
- When aching
- Long trips
- Reduced mobility passengers
- When tired
- Pregnant women

Most suggestions for buses aim to make them more like Metro (Table 17). Users would like to be able to relax and rest during their trips. Suggestions for metro, instead, focus on crowding, mainly inside trains, but also in the platform. Passengers are willing to travel standing, but not too crowded.

Table 17: Suggestions to increase comfort by respondents

	Attribute	Suggestion
Bus	Seats	Anti-slip seats. Make the seat over the wheel more comfortable.
	Less crowding	Especially on peak hours. Limiting the amount of passengers per bus at first stop. Increase frequency on peak hours. Avoid bus bunching.
	Getting on/off	Increase use of access platform.
	Handles	Improve handle design and positioning. Install poles similar to the ones on metro trains.
	Maintenance	Improve maintenance, specially buzzers.
	Movement inside the bus	Increase aisle width to improve mobility inside the bus, making easier to get off at peak hours. Reduce steps height.
	In-vehicle trip information	Put maps with bus stops inside the vehicle (similar to metro). Announcement of next stops using screens or audio.
	Turnstiles	Wider turnstiles to allow strollers and packages to go through.
	Driving	Controlled speed, to avoid sudden stops. Improve driver's training, improve their relationship with passengers.
	Music	Play soft, neutral music.
Metro	Space	Less crowding (on peak hours). Less bunching while boarding and getting off.
	Ventilation	Improve ventilation both on trains and stations. Install air conditioner systems on trains.
	Music	Play soft music.

Regarding the willingness to change from car to bus, users perceive car usage as expensive and stressful. Main causes are increasing gas and parking price, and stressful driving during peak hours. They would be willing to change to buses if they were more reliable (i.e. they could predict their total travel time) and –less importantly– buses were more comfortable. Information on buses arrival delivered by phone text messages is valued by users, but is not known to all. Comfort seems more important for leisure trips, even though medium income car users would probably not change to bus when travelling with kids.

Users' willingness to change from car to metro is high. Users state to already use metro instead of car, if it is available. They would not change from metro to bus, unless buses were as reliable and comfortable as metro.

4.1.2 Summary

Perception of public transport on Santiago is bad. Main negative aspects are peak hour congestion, poorly maintained buses, careless driving, and unreliable travel times on buses.

Most important attributes of travel modes are safety (accidents), security (crime) and speed (short waiting and in-vehicle time). Comfort and fare are less important, except for low income users, who value fare as much as safety and speed.

Comfort has different aspects, the main being crowding, comfortable seats, well design handles, boarding and getting-off easiness, mobility inside vehicles, ventilation, temperature control, in-vehicle route information, and measures to makes a trip more pleasant like music.

Metro is perceived more comfortable on off-peak hours. Buses are perceived uncomfortable on all hours. The following table summarizes the perception of comfort on each mode.

Increasing gas and parking price is an incentive to use public transport, but car users would not use buses unless they were more reliable in terms of travel time. Comfort is a secondary concern. Metro seems to be already used every time it is available.

4.2 Perception of Bogota Public Transport

In Bogota, the public transport system currently comprises three types of bus services:

- *TransMilenio*: Includes both main lines (with large 250, and 150 passenger buses that use exclusive lanes) and feeder lines (80 passenger buses). It is a BRT system operating since 2000. It concentrates most of the public transport demand.
- *Sistema integrado de transporte* (SITP): Operating since June 2012, it will replace the traditional system. It is planned for interoperability with TransMilenio.
- *Traditional system*: It is the traditional public transport system. It will cease operation as SITP becomes fully functional.

The exploratory study considers this three bus systems as different transport modes. In this case, the specific objectives are:

- To study the perception and relative importance of (in-vehicle) comfort, from the traveler's perspective.
- To investigate whether current comfort levels are enough to attract new users to the public transportation system. In Bogota, despite the increasing population, public transport demand has decline. It is the researchers' hypothesis that demand has migrated from Public Transport to motorcycle.
- To explore how comfort impact travelers' decisions.
- To identity attitudes that may impact travelers' decisions.
- To evaluate how comfort is perceived by different socioeconomic segments.

The respondents were selected by a specialized firm on transportation studies in Bogota. The respondents belong to four groups: low and medium income, and captive and non-captive users of public transport in peak hour. Four focus groups were conducted with 27 participants in total. The distribution of participants in each focus group is the following:

- Low income, captive user: 8 respondents
- Low income, non-captive user: 4 respondents
- Medium income, captive user: 4 respondents
- Medium income non-captive user: 4 respondents.

4.2.1 Results

Users are unsatisfied or very unsatisfied with service provided by the city's public transportation system. Users report to be more unsatisfied by TransMilenio (56%), and less with SITP (19%). Users' main concerns are (i) too much crowding at peak hours and (ii) robbery on buses. Price does not arise as an issue, unless asked directly about TransMilenio fare, which is considered too high.

Users identify the general attributes of public transport systems. Table 18 presents the more relevant attributes of public transport of Bogota. Table 19 presents the same results for each type of respondent.

Table 18: Main attributes of public transport in order of importance

Attribute	Description
Speed	Understood as “getting faster to destination”. It involves both frequency (waiting time) and in-vehicle time. Access time (walking distance) is not considered.
Safety (accidents)	Understood as not being victim of an accident. Users’ concerns include TransMilenio’s closing door time and handicap people.
Comfort	Considers space, seats, handles, boarding and getting off, trip information, and hygiene.
Security (robbery)	It is understood as not becoming a victim of robbery when travelling, either in the vehicles or at the bus stops (stations).
Fare	It is not users’ main concern. However, they do point out the TransMilenio off-peak discount, as well as the possibility of (informally) asking for discounts on the traditional system.

Table 19: More relevant attributes by type of respondent in order of importance

	Low income	Medium income
Captive user	1. Price 2. Comfort 3. Speed 4. Safety 5. Security	1. Comfort 2. Price 3. Security 4. Safety 5. Speed
Non-captive user	1. Price 2. Comfort 3. Speed 4. Safety 5. Security	1. Security 2. Safety 3. Comfort 4. Speed 5. Price

In general, all Bogota system is perceived as uncomfortable during peak hours due to crowding. Captive transit users complain about careless driving and lack of seats. Non captive users mention the lack of information, especially on SITP. Dirty traditional buses are also a generalized complaint. Table 21 presents the main aspects that comfort comprehends.

Table 20 summarizes strength and weaknesses of each transport mode.

Table 20: Strengths and weaknesses of each mode in order of relevance

	Strengths	Weaknesses
TransMilenio	1. Speed 2. Capacity 3. Lower off-peak fare 4. Route information 5. Image 6. Efficiency 7. Integrated fare 8. Comfortable if seats are available 9. Infrastructure 10. Room for handicap people	1. Too crowed 2. No synchronization 3. Hard to board and get-off due to crowding 4. Robbery 5. Buses with missing route information 6. It is hard to move inside buses for handicap people 7. Handles are placed too high 8. Insecure doors, that also close too fast 9. Some station doors do not open 10. Vulnerable to protests 11. Dangerous floors on stations 12. Traffic jams on exclusive lanes 13. Poorly maintained exclusive lanes
SITP	1. It is possible to travel seated 2. Cheap bus transfer 3. Segregated bus stops 4. One passage can be on credit 5. New buses 6. Large route coverage	1. Deficient information 2. Scarce paying card charging points 3. Lengthy routes, with many twists and turns 4. It also has old hard to board buses 5. Driver does not know his own route 6. Badly positioned bus stops 7. People boards disorderly 8. Few buses for handicap people 9. Buses congest private network
Traditional system	1. User can negotiate fare 2. Buses stop anywhere 3. Many different routes, covering more neighborhoods 4. Late hour service 5. Lower waiting time 6. Plays music 7. City perimeter routes 8. Users can sleep on the bus	1. Rude drivers 2. Dirty buses 3. Unsafe (robbery) 4. No integrated fare 5. Cent war (*Guerra del centavo*): Drivers compete for passengers 6. Illegal commerce 7. No ventilation 8. Hard to get off, as drivers do not stop

Table 21: Main components of comfort ordered by decreasing relevance

Attribute	Description
Seats	Seats should be comfortable, hopefully with a cushion.
Space	Standing passengers should be able to move easily along the aisles, therefore, crowding should be avoided.
Handles	Handles should be low enough to be accessible
Doors	Closing time in TransMilenio is perceived as too fast. Users do not complain about steps to board or get off SITP or traditional buses.
Ventilation	Even though air conditioning is not necessary, people appreciate air extractors on TransMilenio, and miss them on traditional buses.

TransMilenio is largely considered the most crowded system on peak hours, while SITP is perceived as very little crowded. At the same time, TransMilenio is perceived as the fastest system, while SITP is considered normal and the conventional buses are considered slow. Concerning safety (accidents), TransMilenio seems to be the safest, being considered as very safe by lower income participants, and normal by medium income. SITP follows as it is considered normal, while traditional buses are considered very bad when it comes to safety. Robbery is perceived as worst in traditional buses, followed by TransMilenio and finally SITP, where security is only considered normal, but not good. TransMilenio is considered the best when it comes to information, followed by traditional buses, while SITP information is considered very bad. The fare is considered normal on traditional buses and SITP, but too high on TransMilenio.

Users poorly evaluate comfort on TransMilenio, especially due to peak-hour crowding (and even during off-peak hours crowding is high, users say). The great amount of “In transit” (off service) buses during peak-hours also annoys users. Crowding also generates problems such as long waiting lines, pushes, and disorder on stations and when boarding buses. Users also worry about their safety (robbery) on the system. Fare is not considered particularly high, given the level of service.

Due to less usage of SITP, little information about this system was collected from the focus groups. This system is associated with little crowding and well defined bus stops (unlike the traditional system). Main sources of discomfort are the lack of information and the small amount of places to buy and charge the paying card.

Users are not satisfied with the comfort provided by the traditional system. Main concerns are dirty buses, careless driving, the lack of information about bus stops, and badly design handles. They are also perceived as very crowded on peak hours, slower than other modes, and less safe and secure, with the latter perceived as extremely bad.

Comfort is not the most relevant attributes for users, but speed. Fare is not considered a relevant attribute to differentiate modes either. When considered by mode, the most relevant comfort-related attributes are: carelessly driving and seats on the traditional system; crowding on TransMilenio; and lack of information on SITP.

Users do not spontaneously mention occasions on which comfort is relevant. Instead, they focus their attention on reduced mobility passengers, like the elderly, pregnant women, or handicap people.

Regarding suggestions to increase comfort, passengers would like to travel with enough space (Table 22). Traveling seated is considered lucky, but not a requirement.

Table 22: Suggestions to increase comfort by respondents

Attribute	**Suggestion**
Seats	Clean, available seats. Seats for the handicap and space for wheel chairs.
Space	No crowding. Crowding increases the chances of being robbed or sexually molested. Crowding also makes it difficult to board and get off buses.
Driving	Driving more carefully. Avoid sudden stops or accelerations. Well maintained streets (no potholes).
Information	Announcement of bus stops along the route (audio)

Captive transport users -especially the medium income group- seem willing to change from private transport to TransMilenio, if it improves its comfort levels. Among the non-captive users, the low income group seems very willing to use TransMilenio, if it were more comfortable. The medium income group is slightly less willing to change to TransMilenio. The same happens concerning SITP among the non-captive users.

Among the participants who own a private vehicle (car or motorcycle), 56% claim they would definitely use public transport, if it were more comfortable, 33% say they probably would, and only 11% claim that they might or might not.

When asked, users mentioned that (i) are willing to wait more to travel seated, (ii) would not pay more for higher comfort, (iii) some don't use public transport because is slower than private transport, (iv) annoying in buses is due to lack of education, and (v) motorcycle is not better than public transport.

4.2.2 Summary

Crowding is the main factor decreasing comfort on public transport, followed by lack of information.

Most users claim they would use public transport more, if it were more comfortable. Users owning car or motorcycle claim they would probably use public transport.

Motorcycle seems to be the mode were most past public transport users have migrated. However, focus group participants did not considered motorcycle as a better alternative than public transport.

5 CROWDING VALUATION

This section presents the methodology and the results of valuing the crowding in public transportation. We analyze valuation of crowding in bus and metro, in the case of Santiago, and conventional bus and BRT, in the case of Bogota.

5.1 Modeling framework

The framework for model specification is the random utility theory. In the context of the choice of transport mode, the random utility theory can be summarized in the following assumptions about the individual's behavior.

- There is a (finite) set of transportation alternatives, mutually exclusive, for the individual's trip.
- Individual preferences on alternatives can be represented by a utility function that depends on attributes of the alternatives and individual's characteristics.

- Individual chooses the mode that generates the highest utility among all available alternative in the choice set.
- In the individual's utility function, there are variables that are only she observes. This way, two individuals with the same choice set and the same observable characteristics may choose different transportation mode.
- It is assumed that the unobservable individual utility components are random and independently distributed in the population.

The utility random component comes from different sources. For example, any non-observable or non-measurable attribute of the alternatives, or unobserved individuals' taste variation.

In practical terms, the theory of random utility involves defining a utility function for each mode, which has as variables modal attributes, individual characteristics and a random component that distributes over the population. Analytically, the random utility of alternative m for individual i is written as $V(x_m, z_i, e_{mi})$, where the vector x_m with m mode attributes (travel time, cost, etc.), z_i is a vector with characteristics of individual i (income, driver license, etc.), and e_{mi} is the random component. This utility is also a random variable.

Since it is assumed that individuals choose the alternative that their maximizes utility, then the mode m is chosen if $V(x_m, z_i, e_{mi}) \geq V(x_k, z_i, e_{ki})$ for all k mode in the set of available modes of individual. Since the utility is a random variable, we can write the probability that individual i chooses alternative m as Prob(i chooses m) = Prob ($V(x_m, z_i, e_{mi}) \geq V(x_k, z_i, e_{ki})$, for all k). According to the assumptions made about the functional form of the utility and the probability distribution of the random component, different models are obtained. In particular, the Logit model is obtained assuming that the random component is additively separable in the utility function and distributes Gumbel (or double exponential).

Moreover, it is generally assumed that the observable part of the utility function is linear in mode attributes. Thus, if the utility function includes time and cost, the parameters associated with them represent the marginal utility of such variables. For example, if $V_i = a_i + bC_i + cT_i + e_i$, where C_i is travel cost and T_i is travel time, then b is the marginal utility of income and c is the marginal utility of time (in simplified terms).

The marginal rate of substitution between money and time corresponds to the subjective value of time (SVT). Therefore, this value can be calculated as the ratio between the parameters of time and cost (c/b) of the linear utility function. Also, the ratio of the parameter associated with any attribute, such as headway regularity, to cost parameter corresponds to the monetary value that the individual assigns to changes of that attribute.

In this study, we assume that the marginal utility of travel time depends on the level of in-vehicle crowding (bus and train). This approach is consistent with time multipliers approach (Li and Hensher, 2011). In addition, the marginal utility of travel time is specified linear in passenger density. Following Haywood and Koning (2013), we write c as a function of in-vehicle passenger density d in linear terms as

$$c(d)= c_0 + c_1 d.$$

This specification captures the increasing discomfort for traveling in crowding conditions, and also implies that total discomfort is proportional to travel time. For consistency, both c_0 and c_1 must be negative.

The variables used in the utility specification include only those presented in the experimental designs. These variables are travel cost, travel time (in-vehicle), average waiting time, range of waiting time, and level of crowding measured in passenger density.

In addition, we consider systematic taste variations. To do so, we write the crowding parameter c_1 as linear function of individual's characteristics. The variables that we consider as source of taste variation are individual's gender, age, income, and car ownership.

Summarizing, the discrete choice models we estimate are Logit models with linear utility functions and time multiplier to capture crowding effects. Therefore, the choice probability is given by the following equation

$$\text{Prob}\left(i \text{ chooses } m\right) = P_{im} = \frac{e^{\lambda V_{im}}}{\sum_k e^{\lambda V_{ik}}}$$

The parameter λ is the scale factor and measures the variance of the error term in the utility function. Usually, this factor is not identifiable with a unique sample of individuals, thus it is normalized to one. However, when estimation data come from different samples, it is possible identify the scale factors for every sample except one. Difference between samples depends on the nature of the data. For instance, data coming from stated preferences and revealed preferences, or data from responses of stated preferences surveys with different experimental designs have different nature and, thus, choice probabilities with different scale factor.

The utility function specification for the model without taste variation is

$$V_{im} = \alpha_m + \beta C_m + (\gamma_0 + \gamma_1 (D_m - 1)) T_m + \delta W_m + \varepsilon R_m$$

where C_m is the cost of mode m, T_m is travel time, D_m is passenger density, W_m is waiting time, and R_m is frequency regularity. The utility function for the model with systematic taste variation is

$$V_{im} = \alpha_m + \beta C_m + \left[\gamma_0 + \sum_j \nu_j z_{ij} + \left(\gamma_1 + \sum_j \mu_j z_{ij} \right) (D_m - 1) \right] T_m + \delta W_m + \theta R_m$$

where z_{ij} is the characteristic j of individual i, and μ_j is the parameter associated to the characteristic j. This specification allows us to control for personal characteristics influencing marginal disutility of travel time and crowding effect.

5.2 Survey Design

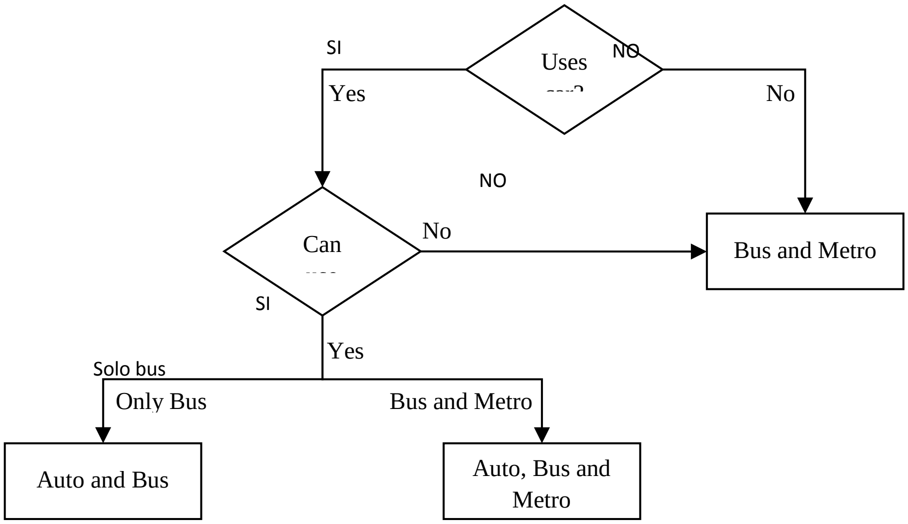
The experiment considers six choice scenarios with two alternatives each one. Alternatives are described by six attributes: transport mode, travel time, travel cost, average waiting time, waiting time variability (by means of the coefficient of variation), crowding level in the vehicle (bus or train).

Transport modes were presented to individuals according to the real availability in the reported trip. Hence car was included as alternative only when the respondent actually used car for the reported trip in the survey. Therefore, if the respondent reports to use public transportation, the choice scenarios only include bus and train as alternatives. If the respondent declared to use car, he was asked whether he is able to use public transportation for trip. In this case, if respondent can use only bus (no train available), the choice scenario includes car and bus; otherwise the choice scenarios include car versus bus or train. If the respondent cannot use public transportation, the scenarios presented are totally hypothetical and the choice situations are based only on public transportation alternatives. Depending on mode availability, three optimal designs were built. Figure 4 summarizes the selection of experimental design for the case of Santiago. Similar scheme is used in Bogota, but Metro is replaced by BRT (TransMilenio).

The level of attributes is determined according to the actual level reported by the respondent in a reference trip. Levels of travel time were pivoted on the actual travel time of the longest leg of the reference trip. In the final design, after a preliminary survey, a lower bound of 20 minutes was set to control for very small variations on the level presented in the choice scenarios.

Travel cost level depended on the transport mode. If the mode was bus or train, travel cost levels were 590 or 650 CLP (Chilean pesos). In turn, if the alternative was car, travel cost levels are 100% or 110% of the actual travel cost computed on basis of travel time, average speed and average fuel consumption. If the respondent paid for parking or urban highway toll in the reference trip, they were added to the car travel cost, only in the final survey design.

Figure 4: Selection method of experimental design presented to respondents.



Average and variability of waiting time levels were different for every mode. Average waiting time was zero for car, 5 or 10 minutes for bus, and 3 or 5 for train and BRT. Waiting time variability is measured with the coefficient of variation, which was zero for car, and 0; 0.5; 0.7 and 1.0 for public transportation. This attribute was presented in the survey as a range of time within which the next bus or train arrives with uniform probability. In the preliminary survey in Santiago, waiting time variability considered 0; 0.5; 1.0 and 1.5 for the levels of the coefficient of variation; however some intervals of possible waiting time results in too high values. The headway regularity was classified as one of the most important attribute for the participants of the focus group, therefore we introduce waiting time variability in the experiment design as measure of regularity even is not the focus of the study.

Crowding levels for bus and train were presented in six levels by means of figures (Table 23). Each figure was associated to a level of crowding starting in 1until 6 passengers by square meter. In the preliminary survey in Santiago, we also include as an attribute the crowding level uncertainty. This attribute was represented with three levels of crowding with equal probability. However, the experiment was too complex for the respondents, and we did not include crowding level uncertainty in the final design for both Santiago and Bogota.

The experimental design is represented by a matrix where the columns represent the attributes of the alternatives, and the rows represent choice scenarios. The design matrix summarizes the choice scenarios that the respondents face in the survey.

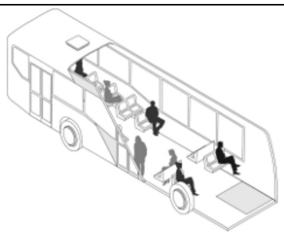
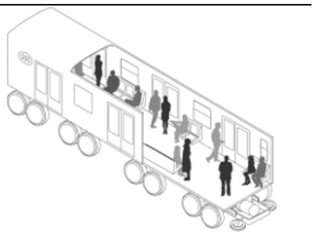
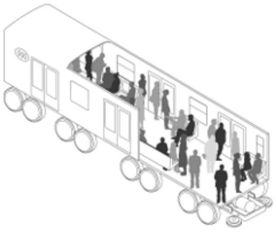
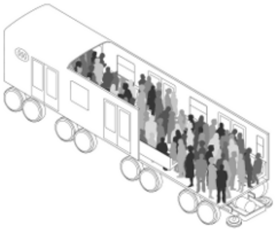
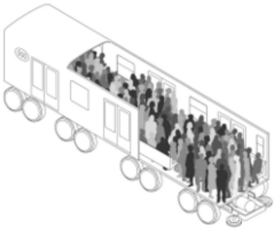
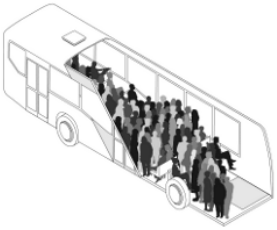
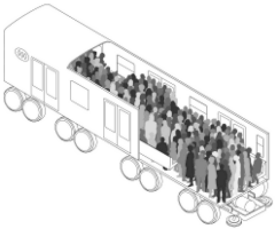
There are several ways to define the matrix design. The more traditional and more suitable matrix for linear models consists in an orthogonal design, which ensures that all the columns are orthogonal each other (i.e. linear independent). This design minimizes the variance of the estimated parameters. For nonlinear models, in particular for Logit models, the levels of the variables (attributes) are not relevant, but the differences between them are. Therefore, the design is built orthogonal in differences (called optimal designs). However, for nonlinear models, in general, the covariance matrix (Ω) of the estimated parameters is not proportional to $(X'X)^{-1}$ as in the case of linear model. Moreover, Ω depends on the specific model to estimate.

Based on these considerations arises the idea of developing the so-called efficient designs (Rose and Bliemer, 2009). They propose minimizing the variance Ω as function of the attribute levels in every choice scenario of the design. This means adjust the matrix design to minimize Ω. To do so, Ω is transformed to a scalar by some metric. Different metrics to transform Ω turn out to be different methods in the efficient design family. For instance, if the metric is the trace of the matrix, the design is called A-efficient; if the metric is the determinant of the matrix, the design is D-efficient.

The main difficulty of this type of design is that Ω cannot always be derived analytically. In the case of simple Logit model (MNL) it is possible, but it is not for mixed Logit models (ML). For the latter model, it is necessary to simulate the integrals that define the choice probabilities, and even to simulate data under some circumstances. Thus, the process of finding an efficient design may become computationally demanding.

Since the D-efficient designs are the most popular in the scientific literature (Kessels et al., 2006), we decided to use to this type of design. We sought an efficient design for a MNL model, even though the model to be estimated considers data panel treatment. This panel data model is a ML model with error component that correlates the observations corresponding to the same individual. The designs of both types of model vary only slightly and searching for an efficient model in the panel data case is significantly more time consuming (Rose, 2009).

Table 23: Passenger density and figures used to represent level of crowding

Level of crowding (passenger/m^2)	Bus	Train
1		
2		
3		
4		
5		
6		

An additional difficulty in finding efficient designs is that they require a priori values of the parameters to estimate, because the matrix Ω depends on them. Since these values are unknown at the beginning of the search of an efficient design, other sources must be used. An alternative is to use zero as prior value for the parameters. Although these priors seem to be absurd, as it is to say that the model estimates are not significant, they avoid raising unfounded assumptions. Based on this design, a pilot survey can be carried out in order to obtain initial parameter estimates. These values are, in a second stage, used as priors obtaining a second pattern, which is used to apply a second survey. This process can be repeated as often as required. To define the final experimental design, we start with an efficient design with priors equal to zero. After, we carried out a pilot survey and used estimated parameters as priors. For all designs we use the software Ngene (http://choice-metrics.com/). Tables 24 to 28 summarize the final designs for different mode availability. Columns present the attributes of the alternative (A or B). Rows represent choice situations with corresponding values of the attributes in each one. Travel time is the pivotal variable obtained from the actual respondent's travel; therefore its level and variations are presented as percentage. Car cost is related to travel time and also based on actual respondent's trip; therefore its level and variation are proportional actual trip cost.

Table 24: Final experimental design for individuals that can travel by bus or subway in Santiago. Columns present the attributes and rows represent choice situations

Block	Alternative A						Alternative B					
	Mode	Travel Time	Travel Cost	Waiting Time	W. T. Coef. Var.	Crowding Level	Mode	Travel Time	Travel Cost	Waiting Time	W. T. Coef. Var.	Crowding Level
1-1	Bus	100%	590	10	0	4	Bus	130%	590	5	0.5	2
1-2	Bus	100%	590	10	0.7	1	Bus	120%	590	5	0.7	4
1-3	Bus	100%	590	10	1	3	Subway	80%	650	5	0	4
1-4	Bus	100%	650	5	0.7	3	Bus	120%	590	10	1	6
1-5	Bus	100%	590	5	0.5	6	Subway	130%	590	3	0	3
1-6	Bus	100%	650	5	0.7	2	Bus	80%	650	10	0.5	3
2-1	Bus	100%	590	5	0.5	5	Bus	100%	590	5	1	1
2-2	Bus	100%	590	10	0	2	Bus	100%	590	5	0	6
2-3	Bus	100%	650	5	0	1	Subway	120%	650	10	0.7	5
2-4	Bus	100%	650	10	1	5	Subway	130%	590	5	0.5	1
2-5	Bus	100%	590	10	1	6	Subway	80%	650	3	0.5	2
2-6	Bus	100%	650	5	0.5	4	Bus	100%	650	10	0	5

Table 25: Final experimental design for individuals that can travel by car in Santiago. Columns present the attributes and rows represent choice situations

Block	Alternative A						Alternative B					
	Mode	Travel Time	Travel Cost	Waiting Time	W. T. Coef. Var.	Crowding Level	Mode	Travel Time	Travel Cost	Waiting Time	W. T. Coef. Var.	Crowding Level
1-1	Car	100%	1.0*C	0	0	1	Subway	130%	650	5	0	1
1-2	Car	100%	1.0*C	0	0	1	Bus	80%	650	10	0	3
1-3	Car	100%	1.0*C	0	0	1	Bus	100%	590	10	0.5	5
1-4	Car	100%	1.1*C	0	0	1	Subway	120%	590	3	0.5	4
1-5	Car	100%	1.1*C	0	0	1	Bus	120%	650	5	1	1
1-6	Car	100%	1.1*C	0	0	1	Bus	100%	590	5	0.5	6
2-1	Car	100%	1.1*C	0	0	1	Subway	100%	590	3	0	5
2-2	Car	100%	1.0*C	0	0	1	Subway	80%	650	5	0.5	2
2-3	Car	100%	1.1*C	0	0	1	Bus	80%	590	10	0.7	4
2-4	Car	100%	1.0*C	0	0	1	Bus	130%	650	5	0	2
2-5	Car	100%	1.0*C	0	0	1	Bus	120%	650	10	1	6
2-6	Car	100%	1.1*C	0	0	1	Bus	130%	590	5	0.7	3

Table 26: Final experimental design for individuals that can travel by car or bus. Columns present the attributes and rows represent choice situations

Block	Alternative A						Alternative B					
	Mode	Travel Time	Travel Cost	Waiting Time	W. T. Coef. Var.	Crowding Level	Mode	Travel Time	Travel Cost	Waiting Time	W. T. Coef. Var.	Crowding Level
1-1	Car	100%	1.1*C	0	0	1	Bus	80%	590	10	0.5	4
1-2	Car	100%	1.0*C	0	0	1	Bus	120%	650	5	0.7	2
1-3	Car	100%	1.0*C	0	0	1	Bus	120%	650	10	1	5
1-4	Car	100%	1.1*C	0	0	1	Bus	130%	590	10	0.7	1
1-5	Car	100%	1.0*C	0	0	1	Bus	130%	650	5	0	4
1-6	Car	100%	1.1*C	0	0	1	Bus	100%	590	5	0.5	5
2-1	Car	100%	1.1*C	0	0	1	Bus	80%	590	10	0.7	3
2-2	Car	100%	1.0*C	0	0	1	Bus	100%	650	10	0	2
2-3	Car	100%	1.0*C	0	0	1	Bus	130%	650	5	0.5	3
2-4	Car	100%	1.1*C	0	0	1	Bus	80%	590	5	1	1
2-5	Car	100%	1.0*C	0	0	1	Bus	120%	650	10	1	6
2-6	Car	100%	1.1*C	0	0	1	Bus	100%	590	5	0	6

Table 27: Final experimental design for individuals that can travel by bus or BRT in Bogota. Columns present the attributes and rows represent choice situations

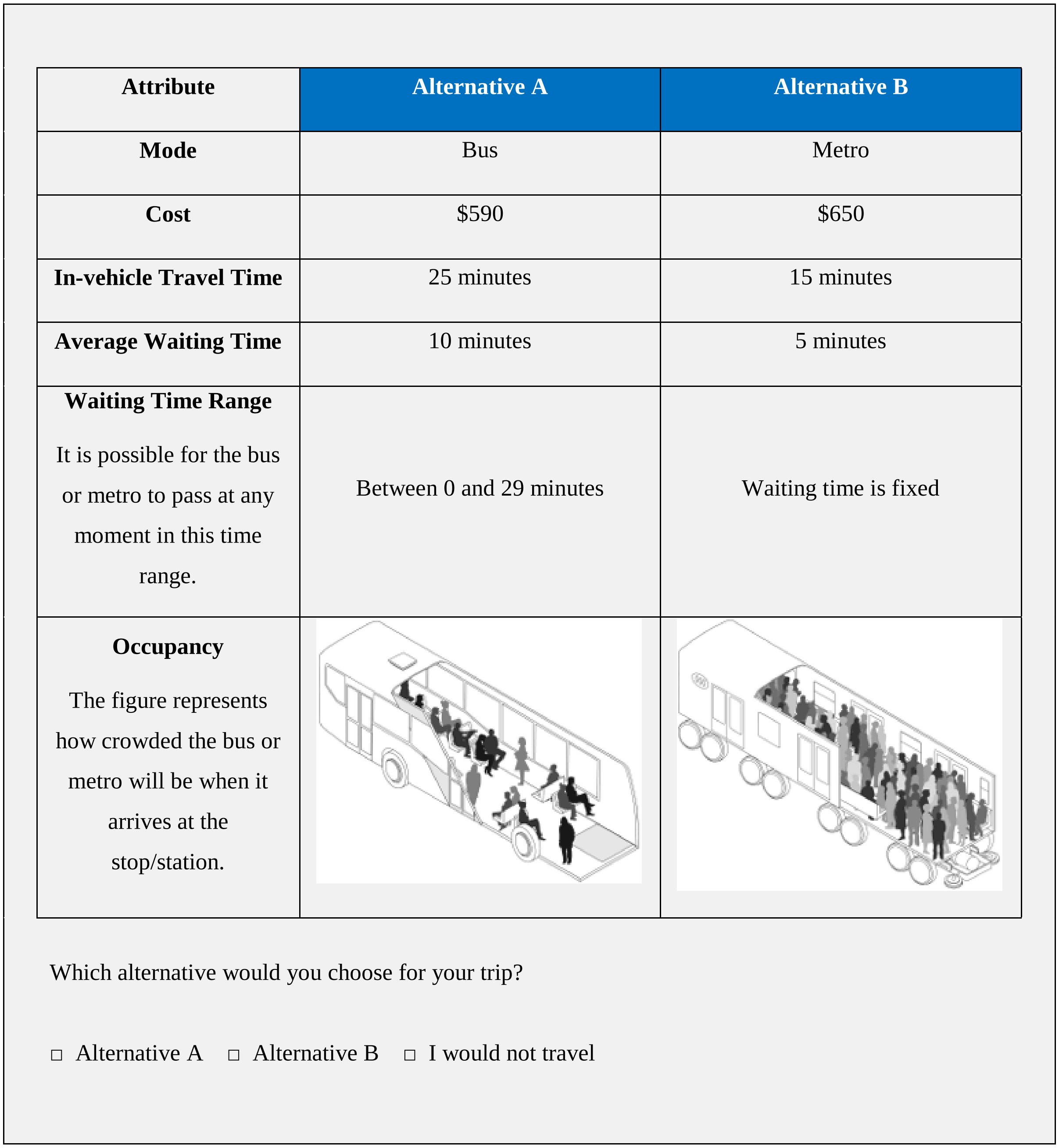
Block	Alternative A						Alternative B					
	Mode	Travel Time	Travel Cost	Waiting Time	W. T. Coef. Var.	Crowding Level	Mode	Travel Time	Travel Cost	Waiting Time	W. T. Coef. Var.	Crowding Level
1-1	BRT	30	300	10	0.7	4	Bus	20%	0%	5	1	3
1-2	Bus	30	300	12	1	5	BRT	-20%	30%	7	0.5	3
1-3	Bus	30	300	7	0.5	6	BRT	-30%	40%	10	0	5
1-4	Bus	30	300	15	0	2	BRT	40%	-30%	3	0.7	5
1-5	BRT	30	300	3	1	2	Bus	40%	-20%	15	0	1
1-6	BRT	30	300	7	0	3	Bus	-30%	20%	10	0.5	4
2-1	Bus	30	300	10	0.5	5	BRT	30%	-20%	7	1	4
2-2	Bus	30	300	5	0.7	1	BRT	30%	-30%	12	0.5	2
2-3	BRT	30	300	15	0.7	3	Bus	20%	40%	3	0	6
2-4	Bus	30	300	5	0	4	BRT	0%	30%	12	1	1
2-5	BRT	30	300	3	0.5	1	Bus	-20%	0%	15	0.7	6
2-6	BRT	30	300	12	1	6	Bus	0%	20%	5	0.7	2

Table 28: Final experimental design for individuals that can travel by car in Bogota. Columns present the attributes and rows represent choice situations

Block	Alternative A						Alternative B					
	Mode	Travel Time	Travel Cost	Waiting Time	W. T. Coef. Var.	Crowding Level	Mode	Travel Time	Travel Cost	Waiting Time	W. T. Coef. Var.	Crowding Level
1-1	Car	30	5250	0	0	1	BRT	20%	2380	5	0.5	6
1-2	Car	30	9000	0	0	1	Bus	0%	1700	15	0.5	5
1-3	Car	30	9750	0	0	1	Bus	40%	1360	3	0.5	2
1-4	Car	30	10500	0	0	1	BRT	30%	1190	12	1	1
1-5	Car	30	7500	0	0	1	BRT	30%	2040	3	1	5
1-6	Car	30	6000	0	0	1	BRT	0%	2210	15	0	2
2-1	Car	30	6000	0	0	1	Bus	-20%	2210	12	1	4
2-2	Car	30	7500	0	0	1	Bus	60%	2040	10	0	3
2-3	Car	30	10500	0	0	1	Bus	20%	1190	10	0.7	6
2-4	Car	30	9000	0	0	1	BRT	-20%	1700	7	0.7	3
2-5	Car	30	5250	0	0	1	Bus	60%	2380	7	0.7	1
2-6	Car	30	9750	0	0	1	BRT	40%	1360	5	0	4

The survey was implemented in computer and was applied by a surveyor face to face. The survey was carried out in the workplace of the respondents because the interview took 15 to 20 minutes. Figure 5 shows a choice scenario presented to the respondents. All choice scenario include an answer “I would not travel in any alternative”, as recommended in the literature (Ortúzar y Willumsen, 2011).

Figure 5: Example of SP choice scenario presented in Santiago



Attribute	Alternative A	Alternative B
Mode	Bus	Metro
Cost	$590	$650
In-vehicle Travel Time	25 minutes	15 minutes
Average Waiting Time	10 minutes	5 minutes
Waiting Time Range It is possible for the bus or metro to pass at any moment in this time range.	Between 0 and 29 minutes	Waiting time is fixed
Occupancy The figure represents how crowded the bus or metro will be when it arrives at the stop/station.		

Which alternative would you choose for your trip?

☐ Alternative A ☐ Alternative B ☐ I would not travel

The survey form also includes questions to get information on respondent’s characteristics, a reference trip to work, and attitudes towards comfort in public transportation. The former type of information is gender, age, car ownership, income. The information on a trip of reference is travel time, frequency, legs of the trip, and for every leg, mode, in-vehicle travel time, waiting time, comfort level (sit, standing with room around, standing with little room, standing in a quite crowding vehicle), and parking and toll cost if necessary. This information is used for pivoting the attributes presented in the choice scenarios.

The attitudes were collected by asking for the degree of agreement to three statement related to the comfort in public transportation by means of a 5-point semantic scale. The statements were presented for bus and train separately. They are:

- Bus (train) has an adequate comfort level
- Bus (train) is very full and people travel in very crowded conditions
- Bus (train) needs more seats

5.3 Estimation with SP data from Santiago

The estimation sample is composed of 3,380 choice situations corresponding to 580 individuals. This sample comprise the individuals surveyed using both preliminary and final experimental design and with the three different experimental design. These differences in the designs imply that model estimation should consider different scale factors into the Logit model. We consider four data sets: preliminary design with and without car availability, and final design with and without car availability. For identification we normalize to one the scale factor of the sample from preliminary design without car available.

Table 29 summarizes estimation results. Parameters associated to waiting time and crowding uncertainty are not presented because we focus on the direct effect of crowding in time valuation. To reduce the impact of these variables on other parameters of the utility, we model the effects with dummy variables.

One important assumption of our model is that the comfort level for a car trip is the same as for a bus or train trip with passenger density of 1 passenger/m^2 (the best case in terms of comfort). The results indicate that crowding produce significant increase in disutility. Marginal disutility increase 34% for an increase of 1 passenger/m^2 in the passenger density. A minute of traveling in the higher density condition (6 passenger/m^2) produce a discomfort 2,8 times greater than that produced in the lower density condition (1 passenger/m^2).

Regarding systematic taste variation, crowding effect on the marginal (dis)utility of travel time depends only on the gender, since this individual characteristic is the only one statistically significant. The effect of gender is that women perceive higher disutility than that perceived by men under the same level of crowding. This result is very consistent with the focus group results, where women state strong aversion to crowding in public transportation.

To see the impact of changes of passenger density on the demand for public transportation and car, we compute the own and cross passenger-density elasticities for public transportation and car respectively (Table 30). For Logit model, passenger-density elasticity depends on travel time and crowding level; therefore we present the results for the average travel time (28 min) in Santiago and the six levels of crowding presented in the survey. In addition, since elasticity depends on the modal share, we use actual shares of public transportation in Santiago (41%). As expected, the elasticity increases with the crowding level. Both public transportation and car demand are relatively inelastic to passenger density in public transportation, however, they become elastic for high level of crowding.

Table 29: Model estimation results and implied subjective values of travel time for Santiago

Parameters	Estimates	t-test	Estimates	t-test
Bus constant	0	-	0	-
Train constant	-0.5218	-5.814	-0.5282	-5.919
Car constant	1.4085	1.671	0.8387	1.483
Travel cost	-0.0011	-3.554	-0.0010	-4.145
Travel time	-0.0290	-4.156	-0.0293	-4.273
Waiting time	-0.1257	-10.876	-0.1265	-10.987
Crowding level (passenger density)	-0.0099	-14.7		
Systematic taste variation on crowding parameter				
Constant crowding effect			-0.0076	-7.851
Gender (1 = female)			-0.0036	-3.056
Scale factor design 1	1	-	1	-
Scale factor design 2	0.5791	3.593	0.7262	4.235
Scale factor design 3	1.0915	9.193	1.0597	9.210
Scale factor design 4	0.5165	3.520	0.6425	4.138
Log-likelihood	-1742		-1737	

Subjective value of travel time (CLP/min)		
1 passenger/m^2	25.7	30.2
2 passenger/m^2	34.4	41.7
3 passenger/m^2	43.2	53.2
4 passenger/m^2	52.0	64.8
5 passenger/m^2	60.7	76.3
6 passenger/m^2	69.5	87.8

Table 30: Own passenger-density elasticity of demand for public transportation and cross passenger-density elasticity of demand for car

Passenger density (passenger/m^2)	Own passenger-density elasticity	Cross passenger-density elasticity
1	-0.164	0.114
2	-0.327	0.227
3	-0.491	0.341
4	-0.654	0.455
5	-0.818	0.568
6	-0.981	0.682

5.4 Estimation with SP/RP data from Santiago

For the case of Santiago, Chile, in addition to the SP data, we have a RP dataset with which we can analyze the public transport users' perceptions towards comfort and crowdedness. These two datasets are complementary, as they come from two different choice situations.

As mention, stated preferences data comes from hypothetical choice scenarios, on which the individuals must choose between different modal alternatives based on the characteristics provided. The alternatives differ in terms of monetary cost, in-vehicle travel time, waiting time, and crowding level inside the vehicle. This database consists of 3,380 choices.

Revealed preferences data comes from real (i.e. observed) choices made by travelers inside the Santiago Metro network. In this case, the alternatives are the potential routes to be taken between the travelers' origin and destination, which differ in terms of in-vehicle travel time, waiting time, walking time (when transferring), number of transfers, and crowding level inside the trains. This database consists of 28,961 choices.

While it is possible to analyze and model the individuals' preferences using either database, it is recommendable to propose a joint SP/RP model, in order to benefit from the advantages of both preference approaches.

The utility function is the same proposed for the case of pure SP data. This means the crowding level is interacted with the in-vehicle travel time. This way, the travelers' perception of time (i.e. their subjective value) while depend on how crowded are the vehicles. The utility functions are

SP Data: $$V_m = \alpha_m + \beta C_m + \sum_j \gamma_j D_{jm} T_m + \delta WT_m$$

RP Data: $$V_m = \alpha_m + \sum_j \gamma_j D_{jm} T_m + \delta WT_m + \rho W_m + \theta TR_m$$

where C_m is the cost of mode m, T_m is travel time, D_{jm} is a dummy variable for passenger density j, WT_m is waiting time, W_m is walking time and TR_m is transfers in the subway network. Note that crowding effect is modeled with dummy variables; therefore it is possible to capture a nonlinear effect. Note also that RP utility function does not includes the cost of the alternative, because data correspond to individuals making route choices inside the subway network without having to pay extra for changing between the lines. Thus, all alternatives have the same cost.

The specification assumes that the crowding level on car is equal to the lowest crowding level on public transport: 1 passenger/m^2. The SP survey is comprised of four different experimental designs, which are differentiated by specific scale factors. The RP survey also possesses a specific scale factor, to differentiate it from the SP survey. Table 31 summarizes the estimation results for three proposed models: (i) SP data, (ii) RP data, and (iii) joint SP/RP data. In this case, the utility specification considers a nonlinear effect of crowding into travel time by means of using dummy variables for representing the levels.

All explanatory variables are significant on the three estimated models. Only the metro constant is not statistically different from the bus constant. Marginal disutility of in-vehicle travel time increases as the crowdedness levels increase. Waiting and walking times present a higher disutility than the in-vehicle time (due to uncertainty and physical effort, respectively).

Table 31: Model Estimation for Santiago with mixed data

	SP Data		RP Data		SP/RP Data	
Parameter	Estimate	t-test	Estimate	t-test	Estimate	t-test
Monetary Cost	-0.001	-3.67	-	-	-0.0008	-4.37
Travel Time at 1-2 pax/m^2	-0.042	-6.41	-0.117	-51.17	-0.035	-9.24
Travel Time at 3-4 pax/m^2	-0.054	-8.41	-0.132	-56.65	-0.045	-8.87
Travel Time at 5-6 pax/m^2	-0.091	-11.71	-0.194	-43.99	-0.078	-8.63
Waiting Time	-0.098	-9.69	-0.183	-8.24	-0.079	-13.18
Walking Time	-	-	-0.257	-13.00	-0.076	-7.65
Transfers	-	-	-0.698	-10.26	-0.241	-5.13
Bus Constant	0.000	-	-	-	0.000	-
Metro Constant	0.017	0.21	-	-	0.031	0.44
Car Constant	1.64	2.39	-	-	1.93	8.37
SP Scale Factor Design 1	1.000	-	-	-	1.000	-
SP Scale Factor Design 2	0.692	3.62	-	-	0.692	3.62
SP Scale Factor Design 3	1.150	9.35	-	-	1.150	9.35
SP Scale Factor Design 4	0.519	4.05	-	-	0.519	4.05
RP Scale Factor	-	-	1.000	-	3.821	8.84
Sample Size	3,380		28,961		32,341	
Log-Likelihood	-1,870		-13,480		-15,609	

To further analyze the individuals' perceptions, Table 32 presents the marginal rates of substitution between variables (most notably, the values of time) for the joint full-data SP/RP model. Value of in-vehicle time varies from \$ 2,626 CLP/hr to \$ 5,894 CLP/hr depending on the crowdedness levels. Valuations for waiting time and walking time are higher. Individuals are willing to pay \$ 250 CLP to avoid a transfer.

Table 32: SP/RP Marginal Rates of Substitution for Santiago

Parameter	Valuation
Travel Time at 1-2 pax/m^2	$ 2,626 CLP/hr
Travel Time at 3-4 pax/m^2	$ 3,389 CLP/hr
Travel Time at 5-6 pax/m^2	$ 5,894 CLP/hr
Waiting Time	$ 4,903 CLP/hr
Walking Time	$ 4,642 CLP/hr
Transfers	$ 250 CLP/transfer

5.5 Estimation with SP data from Bogota

In the case of Bogota, the estimation sample is composed of 4,242 choice situations corresponding to 712 individuals. This sample comprises the individuals surveyed with two final experimental designs. Therefore, we introduce two scale factors into the Logit model by considering two data sets: design with and without car available. For identification we normalize to one the scale factor of the sample from design without car available. However, the estimated scale factor do not result significantly different form one in the preliminary estimation, and we normalize both scale factor to one.

Crowding produces significant increase in disutility (Table 33). A minute of traveling in the higher density condition (6 passenger/m^2) produce a discomfort 6,8 times greater than that produced in the lower density condition (1 passenger/m^2). Regarding taste variation, crowding effect on travel time valuation is affected only by the numbers of cars in the household. Other individual characteristic are not statistically significant. The effect of car ownership is such that individuals with more cars in the household perceive higher disutility than that perceived by individual with fewer cars, when traveling with the same level of crowding.

Table 33: Model estimation results and implied subjective values of travel time for Bogota

Parameters	Estimates	t-test	Estimates	t-test
Bus constant	0.0000	-	0	-
BRT constant	0.0701	1.214	0.0698	1.207
Car constant	-0.5921	-1.998	-0.6036	-2.032
Travel cost	-0.0001	-3.048	-0.0002	-3.256
Travel time	-0.0064	-1.884	-0.0064	-1.89
Waiting time	-0.0391	-7.563	-0.0392	-7.567
Crowding level (passenger density)	-0.0075	-16.503		
Systematic taste variation on crowding parameter				
Constant crowding effect			-0.0069	-13.079
Number of car			-0.0011	-2.119
Scale factor design 1	1	-	1	-
Scale factor design 2	1	-	1	-
Log-likelihood	-1874		-1872	
Subjective value of travel time (COP/min)	*Without taste variation*	*Without car*	*1 car*	*2 cars*
1 passenger/m^2	46.2	42.7	42.7	42.7
2 passenger/m^2	100.0	88.3	95.7	103.1
3 passenger/m^2	153.8	133.9	148.7	163.6
4 passenger/m^2	207.6	179.5	201.8	224.0
5 passenger/m^2	261.3	225.1	254.8	284.4
6 passenger/m^2	315.1	270.7	307.8	344.9

5.6 Estimation with SP/RP data from Bogota

For the case of Bogota, Colombia, in addition to the SP data, a RP survey was conducted in the TransMilenio BRT system, where the public transport users' perceptions towards crowdedness can be analyzed jointly with other variables not included in the SP survey (such as walking time and transfers). This survey was designed based on the RP survey from Santiago, detailed in Section 5.4, and it is complementary to the SP data described in Section 5.5.

The RP data comes from actual choices made by travelers inside the TransMilenio network. The alternatives are the potential routes to be taken between the travelers' origin and destination, which differ mainly in terms of in-vehicle travel time and waiting time (due to the different all-stop and express services of the system). This database consists of 1,113 choices. We propose a joint SP/RP model, in order to benefit from the advantages of both types of information.

The utility function is the same proposed for the case of pure SP data. This means the crowding level is interacted linearly with the in-vehicle travel time. This way, the travelers' perception of time (i.e. their subjective value) while depend on how crowded are the vehicles.

SP Data: $$V_m = \alpha_m + \beta C_m + (\gamma_0 + \gamma_1 (D_m - 1))T_m + \delta WT_m$$

RP Data: $$V_m = \alpha_m + (\gamma_0 + \gamma_1 (D_m - 1))T_m + \delta WT_m + \rho W_m + \theta TR_m$$

Note that RP utility function does not includes the cost of the alternative. Likewise in Santiago, data correspond to individuals making route choices inside the BRT network without having to pay extra for changing between the lines.

As in the previous models, the specification assumes that the crowding level on car is equal to the lowest crowding level on public transport: 1 passenger/m^2. The SP survey is comprised of two different experimental designs, which are differentiated by specific scale factors. The RP survey also possesses a specific scale factor, to differentiate it from the SP survey. Table 34 summarizes the estimation results for three proposed models: (i) SP data, (ii) RP data, and (iii) joint SP/RP data.

All explanatory variables are significant on the three estimated models. None of the modal constants is statistically different from zero (the base bus constant). As expected, marginal disutility of in-vehicle travel time increases as the crowdedness levels increase. To further analyze the individuals' perceptions, Table 35 presents the marginal rates of substitution between variables (most notably, the values of time) for the joint full-data SP/RP model. Value of in-vehicle time varies from \$ 67 COP/min to \$269 COP/min depending on the crowdedness levels. Valuations for waiting time and walking time are higher. Individuals are willing to pay \$170 COP to avoid a transfer.

Table 34: Model Estimation for Bogota with mixed data

	SP Data		RP Data		SP/RP Data	
Parameter	Estimate	t-test	Estimate	t-test	Estimate	t-test
Monetary Cost	-0.0001	-3.048	-	-	-0.0002	-3.651
Travel Time	-0.0064	-1.884	-0.0180	-3.117	-0.0053	-3.214
Waiting Time	-0.0391	-7.563	-0.1112	-6.210	-0.0308	-5.118
Walking Time	-	-	-0.1030	-1.318	-0.0534	-1.695
Transfers	-	-	-0.1641	-6.246	-0.0339	-6.117
Crowding Level	-0.0075	-16.503	-0.0230	-8.414	-0.0081	-14.097
Bus Constant	0.0000	-	-	-	0.0000	-
BRT Constant	0.0701	1.214	-	-	0.0912	1.414
Car Constant	-0.5921	-1.998	-	-	-0.3093	-1.431
SP Scale Factor Design 1	1.000	-	-	-	1.000	-
SP Scale Factor Design 2	1.000	-	-	-	1.000	-
RP Scale Factor	-	-	1.000	-	3.612	4.014
Sample Size	4,242		1,113		5,355	
Log-Likelihood	-1,874		-514		-2,384	

Table 35: SP/RP Marginal Rates of Substitution for Bogota

Parameter	**Valuation**
Travel Time at 1 pax/m^2	\$ 67 COP/min
Travel Time at 2 pax/m^2	\$ 108 COP/min
Travel Time at 3 pax/m^2	\$ 148 COP/min
Travel Time at 4 pax/m^2	\$ 188 COP/min
Travel Time at 5 pax/m^2	\$ 229 COP/min
Travel Time at 6 pax/m^2	\$ 269 COP/min
Waiting Time	\$ 154 COP/min
Walking Time	\$ 267 COP/min
Transfers	\$ 170 COP/transfer

6 EVALUATION OF POLICIES FOR IMPROVING COMFORT

To evaluate different policies for improving quality of BRT services, it is developed a model that allows us to estimate the benefits of changes in some rules of operation of a transit system in a corridor (origin-destination pair) given total travel demand. This simplified model simulates the operation of the system according to several variables relates to the capacity supplied. It is possible to simulate different technologies (conventional bus, BRT, metro) by changing operating variables such as speed, capacity, frequency or coefficient of variation of the interval. In what follows, we describe the model.

We assume a corridor of length L where the average distance travelled by the passengers is l. The frequency of the service is f (veh/hr) with a coefficient of variation c_f . The average vehicle capacity is k (pax/veh), which implies that the average supplied capacity of the system is

$$Q = \frac{L}{l} kf \quad \text{(pax/hr)}$$

Operation speed in the corridor depends on the type of infrastructure. We consider two types of infrastructure along the corridor. For instance, mixed traffic and segregated bus lanes. We specify a fraction a of the corridor operating with one type of infrastructure, and a fraction $(1-a)$ operating with another one. The average speed in corridor, s, is the weighted average of the speed in each type of infrastructure. Circuit time of the vehicles includes a fixed time due to operations in the extremes of the route and dwell time due to passengers boarding and alighting. If average speed includes dwell time, boarding and alighting time should be equal to zero.

The required fleet is determined by the operation frequency, the circuit time and the fraction of operative fleet. Likewise, the total run distance results from frequency and length of the corridor. Fleet and run distance are relevant for compute the cost of the system.

Demand is estimated with the binary logit model estimated in previous chapters. The relevant variables are fare level, travel, waiting and walking time, crowding level and number of transfers. Travel time is obtained from this operation speed and boarding time. As boarding time depends on the demand of the service, the travel time is the result from an equilibrium condition.

Waiting time is determined by the frequency and its coefficient of variation. The expression for average waiting time is

$$t_w = \frac{1}{2f}(1 + c_f^2)$$

This expression does not consider congestion effects due to insufficient capacity for boarding the bus arriving to the stop. In addition, if there are users that should make bus transfers in the corridor, the total average waiting time is t_w multiplied by the average number of transfers per user.

The average crowding level is determined by the ratio total demand to the supplied capacity. To obtain a crowding level in terms of passenger density, the ratio is multiplied by the maximum passenger density acceptable for the vehicle under consideration. This maximum density is not independent of the vehicle capacity specified. Both variables should be consistent. Crowding level also is the result from an equilibrium condition, because the demand depends on the passenger density, which depends on demand.

The simulation model solves the equilibrium conditions to estimate consistently the demand of the service, taking into account the effect on travel time and crowding.

To evaluate the policies, the model compute the operation costs depending on the estimated fleet, total driven kilometers, total demand and other fixed costs. Consistent information on cost should be provided.

The benefits of the policies are estimated using the compensating variation. In the case of the logit demand model, the exact analytical expression for the compensating variation was derived by Small and Rosen (1981). For changes in level of service that imply changes in the utility from U^0 to U^1, the expression for the compensating variation is

$$CV = \frac{N}{\lambda}\left[\ln \sum_{i=1}^{M} \exp(U_i) \right]_{U^0}^{U^1}$$

The term inside the brackets is the logsum or maximum expected utility; λ is the marginal utility of income, which equals the cost coefficient in the estimated discrete choice models, and N is the total number of users.

Finally, we evaluate two policies for improve quality in Santiago and Bogota. These are increasing the average bus capacity and increasing the frequency of the services. The results are summarized in Tables 36 and 37.

In the case of Santiago, we observe significant benefits for increasing frequency from 15 bus/h to 20 bus/h, which counterbalance the costs increase of the system in one year of operation. In the case of increasing bus capacity from 100 pax/bus to 160 pax/bus, the benefits are even greater than the case of increasing frequency. In both cases the benefits are larger than the costs, so both policies are profitable. In terms of modal share, the analyzed measures produce a change of up to 9% of users from car to bus.

In the case of Bogata, both policies are also profitable, as the benefits are greater than the costs. Unlike Santiago, in Bogota an increase of frequency results on better results than an increase of vehicle capacity. In terms of modal share, the analyzed measures produce a change of up to 3% of users from car to BRT.

Table 36: Results of operation simulations of policies for improving comfort in Santiago

	Base case	**Frequency increasing**	**Capacity increasing**
Operation			
Fare ($CLP)	600	600	600
Frequency (bus/h)	15	20	15
Bus capacity (pax)	100	100	160
Crowding level (pax/m2)	5.74	4.91	4.14
Required fleet	46	61	46
Run kilometers	600	800	600
Benefits and costs			
Annual benefits (MM$CLP)	-1,180,228	- 1,120,235	- 1,113,109
Annual operation cost (MM$CLP)	-75,000	- 100,000	- 90,000
Annual fleet capital cost (MM$CLP)	-434	- 575	- 578
Annual infrastructure cost (MM$CLP)	-	-	-
Annual variation of benefits (MM$CLP)		59,993	67,120
Annual variation of costs (MM$CLP)		-25,141	-15,145

Annual net benefit (MM$CLP)		34,852	51,975
Annual net benefit (MM $USD)		63	95
Bus share	57%	65%	66%

These results implies that improving comfort (in this case crowding level) has great potential to control the use of car in cities in developing countries such as Chile or Colombia.

Table 37: Results of operation simulations of policies for improving comfort in Bogota

	Base case	Frequency increasing	Capacity increasing
Operation			
Fare ($COP)	1,700	1,700	1,700
Frequency (bus/h)	20	25	20
Bus capacity (pax)	160	160	200
Crowding level (pax/m2)	4.22	3.49	3.46
Required fleet	43	53	43
Run kilometers	800	1,000	800
Benefits and costs			
Annual benefits (MM$COP)	-3,180,442	- 2,882,145	- 2,926,139
Annual operation cost (MM$COP)	-320,000	- 400,000	- 416,000
Annual fleet capital cost (MM$COP)	-1,297	- 1,599	- 1,297
Annual infrastructure cost (MM$COP)	-	-	-
Annual variation of benefits (MM$COP)		226,297	182,303
Annual variation of costs (MM$COP)		-80,302	-96,000
Annual net benefit (MM$COP)		145,995	86,303
Annual net benefit (MM $USD)		83	49
BRT share	77%	80%	79%