Taylor & Francis
Taylor & Francis Group

TRANSPORT
ISSN 1648-4142 print / ISSN 1648-3480 online
2012 Volume 27(3): 276–285
doi:10.3846/16484142.2012.719839

PASSENGER PREFERENCE ANALYSIS: LIGHT RAIL TRANSIT OR BUS VERSUS CAR

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Submitted 6 May 2011; accepted 10 June 2011

Abstract. To begin with, his article studies the user's preferences when faced with the introduction of two completely different public transport systems: the bus and the Light Rail Transit (LRT). Also, it examines how the modal distribution varies between the private car and each of the new systems, in particular. In addition, the most important variables for users when travelling in a congested corridor are individualized and a study is made on how these variables influence on the modal distribution. The results of the stated preferences of surveys are modelled using mixed logit models. Values are estimated for user's time and the demand elasticity is determined with respect to the relevant variables. Different situations are created to analyse how user's behaviour changes with the changes in the most important variables. Furthermore, this article quantifies the effects of the more relevant variables and shows that the LRT can attract more demand than a bus service, but it must guarantee a regular and frequent service, at the same time as charging competitive fares. It is also shown that for the introduction to be more successful any taken action should be accompanied by policies that chastise the use of the private car such as increased parking charges or higher fuel taxes.

Keywords: light rail transit, bus system, stated preference surveys, user preference, passenger transportation.

1. Introduction

Most motorized journeys in medium and large sized towns are made by car, bus or metro and taking into account that congestion and atmospheric pollution are increasingly worsening people's quality of life, local and national authorities are placing even more importance on public transport so that to fulfil sustainable mobility goals.

The public transport users, particularly bus users, also suffer from the congestion effects, because they share the same road space as private car users. This is especially true in the most congested corridors which normally coincide, for obvious reasons, with the most common bus routes.

More and more bus lanes are being introduced to solve this problem along with services like Bus Rapid Transit (BRT). Transport modes like trams and Light Rail Transit (LRT) are once again in favour as they allow faster commercial speeds which reduce the time of the passengers using public transport.

Worldwide, the bus is the most popular form of public transport (Hensher 1999) due to its flexibility and low start up and operating costs, however, in recent years LRT has increased in popularity thanks to its safety record, efficiency, high capacity and respect for the environment (Kim *et al.* 2007; Martinelli 1996; Williams 1976).

Many authors agree that LRT systems have lower operating costs than the bus, above all when considering the operating costs per passenger carried, because of their greater capacity. They do have much higher start-up costs though and using the LRT has disadvantages in low demand areas as the cost per passenger carried increases greatly (Richmond 1998; Mackett, Edwards 1998).

Many studies have demonstrated that LRT systems play a central role in urban economic development (Hass-Klau *et al.* 2004), in improving the environment and in promoting people to focus on urban environment (Vuchic 2005; Girnau *et al.* 2000).

The case of Manchester (England) is worth mentioning as an example of a positive LRT experience. Knowles (1996) identifies the success of the Manchester Metrolink because of its low fares, direct connections with the city centre (lower In Vehicle Time) and high frequency of service.

There appears to be a lot of confusion in the international literature when differentiating between trams and LRT. This paper assumes that the most thorough definition is that of Vuchic (2005, 2007) who states that LRT are Right-of-Way (ROW) systems which in extremely exceptional cases share the roadway with cars. Tramways, on the other hand, are comparable systems to Streetcars which can travel amongst the traffic without any system of segregation while the LRT are mostly segregated from the other traffic.

This paper does not differentiate between trams and LRT, simply because there are several examples in Europe and the United States of mainly LRT systems which take on the function of trams in urban areas (Topp 1999).

The international bibliography provides few studies which look at the factors influencing the success of LRT from the point of view of attracting demand and those that do exist are limited to observing reality and comparing experiences without studying the behaviour of the user when making their modal choice (Babalik-Sutcliffe 2002; Denant-Boèmont, Mills 1999).

For that reason, this article studies how the modal distribution between private car and public transport is affected by the type of public transport used in an urban corridor.

The logical situation is that tram or LRT routes do not normally follow the same corridors as bus routes to avoid them competing for the same passengers. Bus, tram and LRT systems have to complement each other if sustainable mobility is to be achieved.

This is one of the fundamental reasons why this article studies the competition between car vs. bus and car vs. LRT systems.

Two cases are analysed in particular: the first looks at the modal distribution between private car and urban bus, and the second, between car and LRT. The study's main objective is to determine, from the point of view of capturing demand, which public transport mode is susceptible to increasing the modal distribution towards more sustainable modes of transport (Bus or LRT) and which variables should be acted on to make the use of said modes more successful, thereby answering the question 'Light Rail Transit or buses?' from a point of view of their attractiveness (expected captured demand) for the citizen. This phenomenon is studied by using stated preferences surveys to model user's behaviour and by estimating discrete choice models. An in depth analysis of the models will help us to understand the phenomenon and the results will be summarised in the corresponding conclusions.

The methodology is applied to the most congested urban corridor in the city of Burgos (174075 inhabitants located in northern Spain with a metropolitan area serving up to 350000 inhabitants), 5.5 km long connecting the city centre with the university.

The results of the research show that LRT is more attractive option in terms of journey times, but waiting times need to be improved to compete with the bus successfully. Furthermore, a modal split more in favour of public transport can only come by improving its characteristics (journey times, waiting times and fares) or by penalizing private transport (parking fees, fuel taxes or circulation charges).

The paper is structured in the following way: Section 2 explains the selection process for choosing the most relevant variables from the analysis of the corresponding focus group results. This is followed by Section 3 which describes the experimental design of the stated preferences survey and Section 4 explaining the discrete choice models used to determine the modal distribution and the values of time, along with the estimation of demand elasticities with respect to certain variables. In Section 5, various situations are proposed, the results of the analysis are discussed and finally, in Section 6, the most relevant conclusions are presented.

2. Focus Group: Choosing the Relevant Variables

A focus group was held to determine user's behaviour in the studied corridor and to choose the relevant variables.

The members of the Focus Group (FG) were sixteen travellers who regularly used the corridor in question. In this particular case the FG had 8 habitual car users and 8 frequent public transport users (Ibeas *et al.* 2011).

The characteristics of the users chosen for the FG are summarised in Table 1.

Table 1. Characteristics of the users participating in the focus group

	CAR		BUS	
Type of journey	Men	Women	Men	Women
No Work/No Study	70 years	35 years	39 years	69 years
No Work/No Study	35 years	62 years	69 years	32 years
Work/Study	57 years	20 years	21 years	45 years
Work/Study	22 years	44 years	55 years	25 years

The choice of users was based on the need to have the opinions of both sexes, with different reasons for their journeys and with ages ranging between 20 and 70 years.

The members of the FG were divided into two sub groups who were asked, with the support of a sociology expert on focus groups, about the main problems associated with mobility in the city and the corridor in question. They were also asked about the most important variables they consider when setting off on a journey and their attitude towards the idea of switching transport mode.

Many habitual car users said they were aware of the higher costs associated with using the private car rather than public transport, but their choice was based on the reason that their journey would involve too many transfers if using public transport and the resulting journey time would be unreasonable. It is worth pointing out the habitual car use had some correlation with the socio-economic level of the FG members. Nevertheless, they accepted that increased congestion and a more efficient planning regime for public transport could be the key to making their change.

The results of the FG showed that the car users would be happy to change transport mode because of the traffic congestion in the city. Many of the users of public transport complained about bus delays causing excessive waiting times and the high number of stops which mainly penalised people using the longest routes (longer In Vehicle Time).

The FG also studied the possible user's reaction to public transport systems with their own reserved space and to LRT. Surprisingly, they knew the advantages and disadvantages of these modes and expressed a preference for LRT systems and for BRT.

Finally, the FG discussions were useful in providing enough information to choose the variables used in modelling the behaviour of the users when faced with the two alternative modes of transport to the car (Bus and LRT).

It is important to underline that the available modes of transport in the study area are the car and the urban bus (currently without bus lane, therefore sharing the road completely with the car).

3. Survey Design

In the current paper, the transport users can only travel on the chosen corridor by car or bus, stated preferences of the surveys were best suited to model their behaviour when faced with two possible transport modes which are not actually present (light rail transit and a rapid bus service).

The design of the stated preferences of the surveys is the object of ample worldwide bibliography (Dell'Olio *et al.* 2009, 2011; Ibeas *et al.* 2009), where the work of reference is Louviere *et al.* (2000).

There are also two relevant articles to this line of investigation: Sándor, Wedel (2002, 2005) and Huber, Zwerina (1996). A further work of importance is Street *et al.* (2005) which compares the efficiency of different survey designs.

An experimental design must be carried out beforehand if the surveys are to be successful and the collected data useful enough to be modelled efficiently.

An experimental design consists of coming up with a group of hypothetical situations which are as realistic as possible and defined by a series of factors (variables) which are assumed to have a strong influence on choice. The most important factors were chosen in accordance with the results of the focus groups.

Placing themselves in the pre-established situation, the interviewees had to choose from nine different possibilities. The variables were the same for two modes being studied (bus and LRT).

It needs to be pointed out that it would be useful to be able to compare the three alternatives using the same scenario, however, because the authorities plan to use only one of them (bus or LRT) along the corridor, and it was decided not to include all three at the same time. This meant losing the chance to analyse how travellers would react when faced with the choice between using either of the two proposed modes.

The interviewees were given three possible levels for each variable in both comparisons (car vs. bus, car vs. LRT). These variables were taken directly from the results of the focus group.

The second of the three variables corresponded to the 'normal' situation, the typical values that would be expected. The Level 1 corresponded to a reduction of 33% of the typical values and the Level 3 to an increase of 33%.

The answers given in the interviews can be taken as realistic because the three levels considered for the variables were based on real data from the city in question (or from similar cities when there was no local data available, such as in the case of the LRT variables).

To calculate the average values shown in Table 2 (Level 2), the starting point was the real values of journey time, fare and intervals of buses in the city of Burgos.

Meanwhile, for calculating access time to bus services estimation was made between the possible distance to the stops and pedestrian walking speed. The design used the same time ranges for accessing bus and LRT stops because Burgos city council wanted to keep the same stops in either case. This criterion was used to avoid creating any social disadvantage if it was decided to introduce an LRT system where the stops are normally spaced at greater distances than bus stops.

To calculate the cost of the journey by car, the length of the corridor (5.5 km) and the average speed, a car could travel at were calculated, in addition to fuel, insurance, depreciation and maintenance costs (the latter three being marginal costs).

The cost of parking was calculated by analysing the hourly cost in different Spanish towns resulting in a cost of 0.65 €/h for this study. The value that appears in Table 2 is the result of multiplying the hourly cost by the number of hours that the vehicle will be in the car park (stated by the interviewee in each choice situation).

Despite the LRT values being calculated in a similar way to the previous case, the vehicle travelling time, the public transport fare and the interval between vehicles were considered differently to the rest.

The vehicle travelling time, at the second level, was considered smaller than for the bus because the LRT does not constantly share the roadway with the rest of the vehicles and therefore can travel at a faster commercial speed.

Because LRT systems come with a very high installation cost, the fare is reckoned to be higher (checks were made on different LRT fares in different Spanish cities) and the value assigned to waiting time is lower because the service could be improved by increasing the frequency.

Using three levels for the variables (typical values for Level 2, reduced by 33% for Level 1 and increased by 33% for Level 3), makes it possible to study how user preferences change as a function of consistent variations in the considered attributes.

After calculating the levels associated with each variable, the levels are then combined to form a series of situations to try and guarantee the orthogonality between the variables (orthogonal experimental design).

The result is two surveys with 27 situations, each survey divided into 3 blocks of 9 situations each, in other words, every interviewee is presented with 9 instead of the 27 in order to make the survey shorter so the interviewees are more likely to complete it and at the same time obtain a larger sample of users surveyed.

The survey presented to each user (looking at their choice between bus and car) – see Table 2.

Suppose you have to make a journey today in the corridor joining the city centre with the university. You can make the journey in your car or use a public transport bus service. Remember that you are going to pay 0.65€ for each hour of parking, make your choice (Table 3).

In the case of the LRT: Suppose you have to make a journey today in the corridor joining the city centre with the university. You can make the journey in your car or use a public transport LRT service. Remember that you are going to pay 0.65€ for each hour of parking, make your choice (Table 4).

Table 2. Experimental Design: variables and values of the attributes of the Bus and LRT

	Car vs. Bus			Car vs. LRT		
Variable	Level 1	Level 2	Level 3	Level 1	Level 2	Level 3
Access Time to Public Transport (min)	3	5	7	3	5	7
In Vehicle Time Public Transport (min)	20	30	40	14	20	27
Fare, Public Transport (€)	0.50	0.75	1.00	0.75	1.10	1.45
Waiting Time Public Transport (min)	7.5	10	12.5	3.5	5	6.5
In Vehicle Time, Car (min)	14	18	25	14	18	25
Cost of Travelling by Car (€)	1.10	1.65	2.20	1.10	1.65	2.20
Parking Cost (€)	0.65	1.95	3.25	0.65	1.95	3.25

Table 3. Form and results for the survey Bus vs. Car

BUS				CAR			CHOICE	
Access time	Waiting time	Journey time	Fare	Journey time	Cost	Cost of parking	BUS	CAR
3	7.5	20	0.50	14	1.10	1 h (0.65)	❐	❐
3	12.5	40	0.75	14	1.10	3 h (1.95)	❐	❐
3	10	40	1.00	25	1.10	5 h (3.25)	❐	❐
5	10	20	0.50	18	1.65	3 h (1.95)	❐	❐
5	7.5	30	0.75	18	1.65	5 h (3.25)	❐	❐
5	12.5	40	1.00	25	1.65	1 h (0.65)	❐	❐
7	7.5	20	0.75	18	2.20	3 h (1.95)	❐	❐
7	10	30	0.50	14	2.20	1 h (0.65)	❐	❐
7	12.5	30	1.00	25	2.20	5 h (3.25)	❐	❐

Table 4. Form and results for the survey LRT vs. Car

LRT				CAR			CHOICE	
Access time	Waiting time	Journey time	Fare	Journey time	Cost	Cost of parking	LRT	CAR
3	3.5	14	0.75	14	1.10	1 h (0.65)	❐	❐
3	6.5	27	1.10	14	1.10	3 h (1.95)	❐	❐
3	5	27	1.45	25	1.10	5 h (3.25)	❐	❐
5	5	14	0.75	18	1.65	3 h (1.95)	❐	❐
5	3.5	20	1.10	18	1.65	5 h (3.25)	❐	❐
5	6.5	27	1.45	25	1.65	1 h (0.65)	❐	❐
7	3.5	14	1.10	18	2.0	3 h (1.95)	❐	❐
7	5	20	0.75	14	2.20	1 h (0.65)	❐	❐
7	6.5	20	1.45	25	2.20	5 h (3.25)	❐	❐

In total, 2679 answers were obtained from sampling public transport users on the buses and car users at control points at both ends of the corridor. It is important to point out that before doing the stated preferences survey, each user was presented with an initial characterization survey to obtain socio-economic information on the interviewees (sex, age, income, reason for journey, etc.).

4. Modelling and Analysis of the Results

Discrete choice models were chosen for modelling the results of the surveys because of their ability to simulate the user's behaviour. The theory to generate discrete choice models is random utility theory (Domencich, McFadden 1975).

In spite of the fact that Multinomial Logit (MNL) models are more frequently used, there are other models which can more faithfully reproduce user's behaviour, such as the Mixed Logit (ML) model used in this research.

The utility associated with each individual for alternative j in choice t is as follows:

$$U_{jtq} = \sum_{k=1}^{K} \beta_{qk} x_{jtqk} + \varepsilon_{jtq},$$

where the parameter β_{qk} is worth:

$$\beta_{qk} = \beta_k + \delta'_k z_q + \eta_{qk}.$$

Imposing the typical logit model condition that random residuals distribute Gumbel IID (Domencich, McFadden 1975) leads to the mixed logit expression which differs from the multinomial logit expression in that the value of η_{qk} (random term whose distribution depends, in general, on underlying parameters) may have diverse kinds of functional distribution.

For a given value of the vector η_q, the unconditional choice probability is given by:

$$P_{jq}\left(X_q, z_q, \Omega\right) = \int_{\beta_q} \frac{\exp\left(\beta'_q x_{jq}\right)}{\sum_j \exp\left(\beta'_q x_{jq}\right)} f\left(\eta_q \middle| z_q, \Omega\right) d\eta_q.$$

Time was spent estimating various models to correctly identify the random parameters and their type of distribution.

The ML models were calibrated using simulation. A sequence of Halton (Bhat 2000) was chosen in this case for the Monte Carlo simulation, because it takes pseudo random values with a more uniform distribution throughout the interval.

After testing 1000 models, taking the MNL model which provided the best results as the starting point for each case (LRT vs. car, bus vs. car), the following utility functions were found, where the parameters are represented in lower case and the variables in capitals:

The explanation of the variables used in the utility functions can be found in Table A1 in the Annex.

Table 5 shows if the parameters are random or not along with their distribution for the best model in each case.

Table 6 presents the results of estimating two ML models, one for studying the modal choice between LRT and Car and another between Bus and Car. The table also shows the standard deviation values of the parameters of the estimated ML models. NLOGIT software was used for the calculations.

These ML models are preferable to the corresponding MNL models as they can be seen to perform the likelihood-ratio test (Table 7):

$$LR: -2\left\{l^*\left(\theta_r\right) - l^*\left(\theta\right)\right\}.$$

The Value of the Out of Vehicle Time (*VOVT* = *value of access time* + *waiting time*) and the In Vehicle Time (*VIVT*), by car, Bus and LRT, are also determined as microeconomic indicators as a ratio between the time parameters and the cost (being the linear utility functions). More generally, the value of time (*VOT*) is calculated in the following way:

$$VOT = \frac{\delta V_i}{\delta Time_i} \bigg/ \frac{\delta V_i}{\delta Cost_i}.$$

Table 8 presents the values of time obtained this way along with their relationship with the values of time when travelling by car (*VOT–L/VOT–C*).

Note that the value of the In Vehicle Time in the LRT (*VIVT–L*) and the In Vehicle Time by Bus (*VIVT–B*) is seen in a similar way by the LRT and Bus users if the reference is taken to be the value of the In Vehicle Time by car (0.57 ≈ 0.52). However, the case of the Out of Vehicle Time is very different, in fact, this value of time is much higher for the LRT users than for the Bus users (*VOVT–L>VOVT–B*). What is more, if the value of the In Vehicle Time by Car (*VIVT–C*) is taken as a reference it can be seen that the value of the Out of Vehicle Time for LRT users is almost double that of the Bus users. This means that the LRT users expect the system to work with greater regularity and efficiency than happens in reality and they are not prepared to tolerate delays such as happens with the bus users.

This also implies that there are users that do not really trust the bus mode very much (therefore, they travel by car) and that in the case of introducing a LRT system they would be prepared to change mode, but only with the guarantee that the system would provide good coverage, be more efficient and arrive at headways which guarantee acceptable waiting times.

To understand the user's behaviour in greater depth, the next step is to study the demand elastic-

$$\begin{cases} V\left(BUS\right) = asc\_bus + ovt\_bus \cdot OVTB + ivt\_bus \cdot IVTB + fare\_bus \cdot FAREB + age25\_29 \cdot AGE25\_29; \\ V\left(CAR\right) = ivt\_car \cdot IVTC + c\_car \cdot CC + vp \cdot VP + incomech \cdot INCOMEH; \end{cases}$$

$$\begin{cases} V\left(LRT\right) = asc\_lrt + ovt\_lrt \cdot OVTL + ivt\_lrt \cdot IVTL + fare\_lrt \cdot FAREL + age21 \cdot AGE21; \\ V\left(CAR\right) = ivt\_car \cdot IVTC + c\_car \cdot CC + vp \cdot VP. \end{cases}$$

Table 5. Distribution of the parameters for LRT vs. Car and for Bus vs. Car (NR: Non-random; N: Normal; U: Uniform).

LRT vs. Car				Bus vs. Car			
LRT		CAR		BUS		CAR	
Parameter	Distribution	Parameter	Distribution	Parameter	Distribution	Parameter	Distribution
asc_lrt	NR	*ivt_car*	NR	*asc_bus*	NR	ivt_car	N
ovt_lrt	N	*c_car*	NR	*ovt_bus*	N	c_car	N
ivt_lrt	N	*vp*	N	*ivt_bus*	N	vp	N
fare_lrt	N			*fare_bus*	N	incomeh	N
*age*21	U			*age*25_29	N		

Table 6. Results of estimating ML model for LRT vs. Car and for Bus vs. Car

LRT vs. Car					Bus vs. Car				
Mode	Var.	Estim. coeff.	Test–t	$P[\|Z\|>z]$	Mode	Var.	Estim. coeff.	Test–t	$P[\|Z\|>z]$
LRT	*Random parameters*				BUS	*Random parameters*			
	ovt_lrt	–1.470	–3.107	0.0019		*ovt_bus*	–0.913	–3.627	0.0003
	ivt_lrt	–0.630	–3.336	0.0009		*ivt_bus*	–0.693	–4.143	0.0000
	fare_lrt	–12.577	–3.031	0.0024		*fare_bus*	–10.738	–3.301	0.0010
	*age*21	6.649	2.956	0.0031		*age*25–29	–3.579	–2.131	0.0331
	Nonrandom parameters					*Nonrandom parameters*			
	asc_lrt	7.954	1.533	0.1253		*asc_bus*	9.221	2.228	0.0259
	Derived standard deviations					*Derived standard deviations*			
	Ns_ovt_lrt	1.022	3.342	0.0008		*Ns_ovt_bus*	0.386	2.990	0.0028
	Ns_ivt_lrt	0.648	3.597	0.0003		*Ns_ivt_bus*	0.204	3.260	0.0011
	Ns_fare_lrt	9.460	3.133	0.0017		*Ns_fare_bus*	4.411	2.103	0.0355
	*Us_age*21	18.662	2.786	0.0053		*Ns_age*25–29_ *bus*	12.511	2.864	0.0042
CAR	*Random parameters*				CAR	*Random parameters*			
	vp	–10.188	–2.825	0.0047		*ivt_car*	–0.749	–3.843	0.0001
						c_car	–6.710	–4.465	0.0000
						vp	–3.199	–2.909	0.0036
						incomeh	2.884	2.458	0.0140
	Nonrandom parameters					*Nonrandom parameters*			
	ivt_car	–0.463	–2.485	0.0130					
	c_car	–5.600	–3.017	0.0026					
	Derived standard deviations					*Derived standard deviations*			
	Ns_vp	3.238	1.265	0.2060		*Ns_ivt_car*	0.092	1.394	0.1634
						Ns_c_car	3.156	4.297	0.0000
						Ns_vp	3.196	1.602	0.1091
						Ns_incomeh	2.260	1.466	0.1425
No. observations		1287			No. observations		1392		
Log likelihood		–759.7748			Log likelihood		–800.2017		

Table 7. Likelihood-ratio test for LRT vs. Car and Bus vs. Car

	$l^*(\theta_r)$	$l^*(\theta)$	*LR*	*FD*	χ^2_{FD}
BUS	–807.0335	–800.2017	13.6636	8	13.3615
LRT	–764.8451	–759.7748	10.1406	5	9.2363

Table 8. Values of time for LRT vs. Car and for Bus vs. Car

LRT vs. Car					Bus vs. Car				
Mode	Variable	Estimated coefficient	Standard deviation	*VOT–L* / *VOT–C*	Mode	Variable	Estimated coefficient	Standard deviation	*VOT–B* / *VOT–C*
LRT	*VOVT–L*	7.125	1.017	1.44	BUS	*VOVT–B*	5.090	0.407	0.68
	VIVT–L	2.854	0.859	0.57		*VIVT–B*	3.882	0.220	0.52
CAR	*VIVT–C*	4.964	–	–	CAR	*VIVT–C*	7.437	7.429	–

ity with respect to certain variables. Analyzed results represented in Table 9 shows that for the Bus variable which has most effect on demand is the In Vehicle Time (*IVTB*), followed by the Out of Vehicle Time (*OVTB*) and by the fare (*FAREB*). Besides, a look at the values of the elasticities shows that a unit decrease in the In Vehicle Time has a doubling effect on the decrease in the Out of Vehicle Time and triple with respect to a unit decrease in the fare. Therefore, in the case of Bus vs. Car it is important to try to reduce the total journey time (In Vehicle Time) and it turns out that to increase the demand for bus journeys it is much better to increase the commercial speeds than increase the coverage (shorter access time) or increase the frequency (shorter waiting time) or reduce the fare.

Therefore, it is necessary to increase the commercial speed which is needed and, among other things, to construct bus lanes or introduce systems which give priority to the bus. At the same time, in order to decrease the car use, something must be done about the total cost of the journey by car (*CC*) increasing parking tariffs or increasing fuel taxes (the former being preferable to the latter, because the user does not see the system of parking tariffs in the same way as the consumption of fuel) or applying a congestion charge. It can be seen that the effect of the cost of travelling by car is double that of the time taken travelling by car (In Vehicle Time).

Table 10 shows that in the case of the LRT the elasticities of In Vehicle Time by LRT (*IVTL*) and the Out of Vehicle Time (*OVTL*) are practically the same and lower than in the case of the Bus, however, the elasticity of the fare (*FAREL*) is higher than for the Bus and of the same order of magnitude as the two beforehand.

This means, as mentioned earlier, that in general the LRT system is expected to work with a certain regularity, so to have any effect on increasing demand, action should be taken on the above mentioned variables. The same trend is maintained as in the previous case for the car variables, although with a reduced effect.

In order for the LRT to attract more demands than the bus, it must have much greater coverage, shorter headways and more competitive fares. At the same time, it is fundamental that any actions taken against the use of the car must be more convincing, such as increasing parking tariffs rather than fuel taxes.

5. Establishing the Situations

Given that in the study of elasticities in the previous section, the effect of each variable was considered taking into account all the other constants (ceteris paribus), an analysis was then performed with 8 different situations: 4 for the Bus vs. Car and 4 for the LRT vs. Car in order to consolidate the previously obtained results. The objective of this section is not only to study the separate effect, but also the combined effect of the variation of some variables thereby completing the work. These situations try to determine the possible effects of the variation of the fundamental variables on the modal distribution.

For Bus vs. Car the actual situation (*BUS*1) was studied and compared with the case in which the fare was increased (*BUS*2) with another case where a bus lane was introduced into the corridor in question (*BUS*3) and with another case where as well as the bus lane the frequency of service was also increased (*BUS*4). The journey times in situations *BUS*3 and *BUS*4 have been obtained by simulation and the increase in fares by adjusting to Spanish national averages.

The results shown in Table 11 confirm the predictions of the elasticities analysis done in the previous section, but it is interesting to note how the *BUS4* situation shows a consistent increase in the probability of going by bus due to the combined effect of improving the *IVTB* (bus lane) and waiting times (with increased frequencies).

Table 9. Direct elasticities of Bus vs. Car

	Variable	Direct elasticity $E_{P_{iq}, x_{ikq}}$
BUS	*OVTB* (min)	–0.848
	IVTB (min)	–1.360
	FAREB (€)	–0.497
CAR	*IVTC* (min)	–1.121
	CC (€)	–1.841

Table 10. Direct elasticities of LRT vs. Car

	Variable	Direct elasticity $E_{P_{iq}, x_{ikq}}$
LRT	*OVTL* (min)	–0.611
	IVTL (min)	–0.519
	FAREL (€)	–0.516
CAR	*IVTC* (min)	–0.802
	CC (€)	–1.831

The introduction of a bus lane into the corridor and increasing the frequency of service increases the modal distribution from 57% to 69%, even with an increased fare. The combination of greater bus use and at the same time higher fares could help cover the costs of introducing the bus lane.

Another 4 situations were proposed for the LRT vs. Car comparison (Table 12): the first considers the administration's potential plans for introduction (*LRT*1); the second proposes a reduction in the fare (*LRT*2); the third, the LRT using its own right of way along most of the route but is given priority by traffic lights at certain critical points, using the tariffs of the potential situation (*LRT*3) and finally, the fourth situation is the same as the third but with a lower fare (*LRT*4).

The values shown in Table 12 were obtained by simulation and the tariffs were determined by looking at the national average.

Comparing situation *LRT*1 with *LRT*2 shows that reducing the fare could be very favourable to increase the demand for travelling by LRT. Situation *LRT*3 reveals that if the fares are equal to the fares in the potential situation (*LRT*1) then a similar positive result can be obtained if the commercial speed of the LRT is increased, this is obtained by providing the LRT with its own space along most of the route with priority at traffic lights at certain critical points. If the fare of *LRT*3 is reduced, the LRT could become even more competitive than the bus using a bus lane in terms of capturing new passengers.

In general, it can be concluded that the systems mentioned here can compete with the car, that it is extremely important to increase their commercial speeds and guarantee low fares, as well as frequent and regular services.

6. Conclusions

This paper looked at user's preferences when faced with two different options for travelling along a congested urban corridor: one where cars compete with public buses and another where cars compete with a LRT. These two alternatives are studied to investigate which variables affect users mostly in the modal distribution. A stated preferences survey was performed and discrete choice models were estimated to calculate the modal distribution.

The most relevant conclusions are presented below:

- The users of both buses and LRT see the value of In Vehicle Time in the same way (0.52 and 0.57 compared with the private car, respectively), meaning the LRT is more efficient because it has shorter In Vehicle Times than the bus as it uses its own reserved space and has Right of Way.
- The value for Out of Vehicle Time is higher for the LRT users than for the Bus users (1.44 against 0.68, compared to the car value), meaning that to attract more passengers the LRT must offer a more trustworthy and more frequent service (fewer delays) than the Bus.

Table 11. Bus vs. Car situations

			*BUS*1	*BUS*2	*BUS*3	*BUS*4
BUS	Access time BUS (min)	*OVTB*	5	5	5	5
	Waiting time BUS (min)		10	10	10	5
	Total journey time BUS (min)	*IVTB*	30	30	25	25
	Fare BUS (€)	*FAREB*	0.75	1.1	1.1	1.1
CAR	Journey time CAR (min)	*IVTC*	18	18	18	18
	Cost of journey CAR (€)	*CC*	1.65	1.65	1.65	1.65
	Cost of parking CAR (€)		1.95	1.95	1.95	1.95
	P(*BUS*)		0.58	0.48	0.57	0.69
	P(*CAR*)		0.42	0.52	0.43	0.31

Table 12. LRT vs. Car situations

			*LRT*1	*LRT*2	*LRT*3	*LRT*4
LRT	Access time LRT (min)	*OVTL*	5	5	5	5
	Waiting time LRT (min)		5	5	5	5
	Total journey time LRT (min)	*IVTL*	20	20	15	15
	Fare LRT (€)	*FAREL*	1.1	0.75	1.1	0.75
CAR	Journey time CAR (min)	*IVTC*	18	18	18	18
	Cost of journey CAR (€)	*CC*	1.65	1.65	1.65	1.65
	Cost of parking CAR (€)		1.95	1.95	1.95	1.95
	P(*LRT*)		0.57	0.65	0.63	0.73
	P(*CAR*)		0.43	0.35	0.37	0.27

- Referring to the Bus vs. Car modal distribution, it is very important for the bus to increase its demand which must be improved, in order of importance: In Vehicle Time (introduction of bus lanes), Out of Vehicle Time (shorter headways and coverage of service) and reduce the fares. Action on all these variables (scenario BUS4) can accomplish a modal split of 69% using the bus rather than the car.
- Referring to the LRT vs. Car distribution, the situation is similar to above, but the effect of In Vehicle Time and Out of Vehicle time is practically identical and lower than in the case of the Bus. In this case, the most favourable scenario (LRT4) provides a modal split of 73% of travellers using LRT rather than the car.
- In both cases to achieve a reduction in car use it is necessary to act on parking tariffs, introduce higher fuel taxes and a congestion charge.
- The LRT systems can be a popular alternative to buses when they use their own right of way and operate at high frequencies with competitive fares (in the proposed scenarios and under these conditions, LRT would be used by an average of 6.5% more than the bus). These results are in agreement with Knowles (1996) and have been quantified here using a robust scientific prediction methodology.

As a general conclusion this paper describes an easily applied methodology to study the impacts of introducing alternative public transport systems based on the preferences of the user. It is important to underline that a system can be more profitable from the point of view of its introduction costs but highly loss making, when trying to capture demand. These sorts of inconveniencies can be avoided by counting on robust methodologies and optimization tools, as presented here, which will help decision makers to choose the best transport system for achieving sustainable mobility.

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ANNEX

Explanation of the Variables Used in the Utility Functions of the Models

Table A1 explains all the variables used in the utility functions used in the two models.

Table A1. Description of the variables used

Variables	Parameters	
–	*asc_lrt*	LRT Alternative Specific Constant
OVTL	*ovt_lrt*	LRT Out of Vehicle Time (*Access Time* + *Waiting Time*)
IVTL	*ivt_lrt*	LRT In Vehicle Time
FAREL	*fare_lrt*	LRT Fare
*AGE*21	*age*21	Dummy Variable, *AGE*21 = 1 if the user is < 21 years and 0 in other cases
–	*asc_bus*	Bus Alternative Specific Constant
OVTB	*ovt_bus*	Bus Out of Vehicle Time (*Access Time* + *Waiting Time*)
IVTB	*ivt_bus*	Bus In Vehicle Time
FAREB	*fare_bus*	Bus Fare
*AGE*25_29	*age*25_29	Dummy Variable, *AGE*25_29 = 1 if the user is 25 < age < 29 and 0 in other cases
IVTC	*ivt_car*	Car In Vehicle Time
CC	*c_car*	Car cost (Cost of travelling in car + Cost of parking)
VP	*vp*	Dummy Variable, *VP* = 1 if the user has a driving license and 0 in other cases
INCOMEH	*incomeh*	Dummy Variable, *INCOMEH* = 1 if the user has a high income and 0 in other cases.
VOVT–L	–	Value of Out of Vehicle Time for LRT
VIVT–L	–	Value of In Vehicle Time for LRT
VOVT–B	–	Value of Out of Vehicle Time for Bus
VIVT–B	–	Value of In Vehicle Time for Bus
VIVT–C	–	Value of In Vehicle Time for car