ANALYSIS OF ACCESSIBILITY DISTRIBUTIONS FOR INTER-CITY TRAVEL BY PUBLIC TRANSPORT

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ABSTRACT

Intercity travel by public transport typically involves interconnecting modes and this implies access to long distance transport such as trains, or aircraft using short distance transport such as urban buses, cars or walking. The time for such access is sometimes omitted from some transport models, and at other times, it is assumed constant. This work aims at identifying the variability of such access times using the case of residents in Lisbon, Portugal making a Lisbon-Madrid trip, and then estimate the effects of changing access time on intercity mode choice.

Keywords: inter-city travellers, access-time distribution, accessibility modal choice, Lisbon

INTRODUCTION

Access time has been the focus of several studies due to its significant effect on travel patterns, with this time often valued higher than in-vehicle travel time (IVTT) likely due to its perceived onerousness versus the latter (and perceived lack of ‘progress’ to one’s destination versus the time spent moving in the vehicle). While the term “access” is generally understood and often used in the literature, often “egress” is ignored, and assumed to be identical to access although research suggests otherwise. We shall mention egress in this work where relevant.

Within urban transport research, “access” is typically interpreted as the time from one’s door (home or work) to the first transportation infrastructure used in the city. Typically this is spent walking to a metro or bus station or stop or even to one’s own car, although time is often taken as 0 to some extent abusively. However, we might think that private car users do not really value this time when making their choice in the very first place. On the contrary, in intercity transport research, the term “access” is often interpreted to mean all the time spent getting to the main long distance mode of interest. For a flight, this access time could therefore mean the time spent on a metro or bus or in one’s own car (in addition to walking). There therefore seems to be a double standard in defining access. It may be interpreted by travellers as that initial portion of the travel chain that is not the most progressive (in terms of speed to destination). For this work, we've adopted the definition of access according to (Murray et al. 1998) as "*the opportunity for system use based on proximity to service and its cost*", but focus on the access time.

For long distance travel, access really involves the entire urban transport system as long distance terminals can be at any location within an urban area, and often in larger cities, multiple terminals are available, including those within city limits, and those much further away like airports. Sometimes special infrastructure is available for these high demand terminals, at other times it is not. Availability of a high capacity, high frequency service (such as rail) from an airport directly to a city centre was identified as key factor to high use of public transport for airport access, especially in combination with other services. This is particularly relevant for cities which are "downtown-focussed" and where trip ends are more likely to be in the city itself (Coogan 2008).

Access Time use in Research

There is some variety in the approaches used to include access or egress time in choice models. In some cases researchers vary the method of inclusion of access time and select the model with best results. Some of the varieties identified include use of an overall "Time" variable which combines access time, egress time and travel time (Ortúzar & Simonetti 2008; Limtanakool et al. 2006), use of an out of vehicle time variable which combines access, waiting and egress time (Aljarad & Black 1995; Bhat 1995; Koppelman & Wen 2000) and use of an access time variable alone (Pels et al. 2003). No models have been identified which isolate both the access time and the egress time however, and some researchers have fixed the access/egress time for some or all of the travel alternatives presented (Limtanakool et al. 2006).

One thing is certain, and that is that inadequate modelling of access and egress times can bias estimation of modal shares, particularly for new public transport modes such as high-speed rail. This is so due to under representation of the disutility of access and egress times on a potential traveller. This research aims to aid in understanding how variable access and egress can be and how significant can be their effect on mode shares. The case examined is Lisbon, Portugal.

LITERATURE REVIEW

Access and egress are not necessarily substitutable or equivalent in research. (Krygsman et al. 2004) found that egress time from railway stations in the Netherlands was 32% higher than access time on average. This may be due to greater familiarity with the transportation options at one's origin (home, work) versus that at the destination for a long distance trip (whether on business or pleasure).

The interconnectivity ratio is the measure used to compare the sum of access+egress times to total trip time (De Stasio et al. 2011; Krygsman et al. 2004). This ratio can easily be high for short distance air trips, or low for overnight bus trips. A flight journey from Lisbon to Madrid for instance may have a flight time of 75 minutes according to airline schedules. If we take the mean metro access/egress in Lisbon and Madrid as 20 and 15 minutes respectively, and we don't include waiting time at the airports, we get an interconnectivity ratio of about 31%. With an overnight bus trip lasting 9 hours, the interconnectivity ratio for the equivalent bus journey would be under 10%. This ratio can be defined in a variety of ways, such as including waiting time, which for flight could be significant.

Access is the first step in the user experience of an inter-city transport service, yet generally inter-city operators often have very little influence on it. It is normally strongly affected by public authority decisions such as terminal and stop location or urban bus service routing. A rerouted urban bus service can increase the walking (access) time of a user by several minutes and make an intermodal trip no longer attractive. The only intercity operator that has any significant influence might be a curb-side intercity bus operator who decides his stop location where he can easily attract many passengers and who often requires not much more than a publicly-built urban bus stop. (Pels et al. 2003) however showed that travellers choose their departure airport as well as access mode together as the decisions are inter-related. Not all terminals provide the same access modes, or travel times and costs. The overall door-to-door journey is the choice being made; not only the airport-to-airport trip, and access as well as egress have a role in that journey. This is supported by the use of access time in a variety of inter-city mode choice travel studies. Similarly, (Debrezion et al. 2009) found that station distance from the centre of postal code regions in the Netherlands was negatively correlated with station choice for rail travel, implying an effect of access time on station choice. They did note that 47% of surveyed travellers did not use the station nearest to their residence for rail travel however.

(Brons et al. 2009) estimated that a 5% increase in intercity rail service trips in the Netherlands could be obtained due to a 50% increase in public transport accessibility (service frequency) to stations. The cost of such a massive increase in service may not be worth the 5% increase predicted, but it does show that the relationship between public transport accessibility and usage is a real and measurable one.

Access time is estimated in various ways. Some authors use simple straight line distances to transport infrastructure ignoring the fact that actual service routes and travel times are often decided based on other factor such as population densities, congestion avoidance and cost minimization (Murray et al. 1998). Other, more involved methods look at actual measurements or schedules of trip times (Debrezion et al. 2009) or use survey respondent databases.

METHODOLOGY

To get access time distributions, we begin with a detailed network of the city of Lisbon, Portugal, identify the trips of interest, simulate those trips and measure the access times. We perform the same for egress times. Then we examine the effect of the access time variance on published mode choice models for the city, and present some conclusions. Below we discuss the modelling of the city's transport network including the data sources and assumptions made.

Lisbon City and Lisbon – Madrid Journeys

Lisbon is a city of 547,000 residents according to the latest Portuguese Census from 2011. The Portuguese capital covers an area of 83.8 square kms, and boasts a wide range of urban and regional transport options (metro, urban, regional, national and international bus, regional and national heavy rail services, ferries to nearby municipalities and a very urban international airport). We consider in this research trips made from residents in Lisbon to the nearby Spanish capital, Madrid (a straight line distance of 500km).

Lisbon-Madrid trips can use a range of options due to the relatively short separation between the two cities, and a large number of trips pass through a range of modes (we focus on the air trips from the Airport, the train trips from the Oriente Rail Station, and the bus trips from the Sete Rios bus terminus). The Lisbon airport for instance handled 1.2 million passengers to and from Madrid in 2011 or 8% of its total[1]. The driving distance between the two cities is on the order of 6 hours by private car or 9 by bus. There is an overnight rail service that takes about 9 hours and is marketed by the national rail operators of each country mainly to tourists. For several years, Portugal's leadership was considering investing in high-speed rail (HSR) which would connect its major cities and also Lisbon with Madrid. Although, economic issues have stopped the current effort to develop HSR in the country, there is still significant HSR research in Portugal for when economics return to the nation's favour. The layout of the city as well as its major intercity transport terminals are shown in Figure 1.

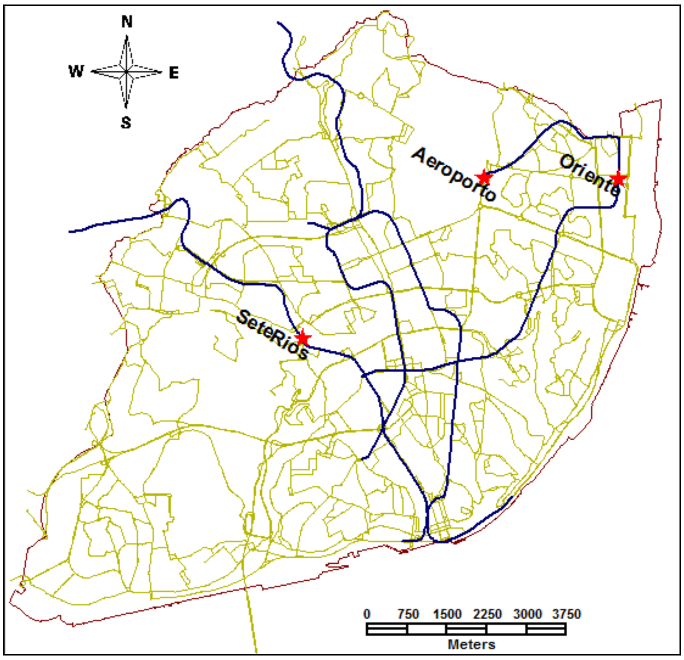

Figure 1 Diagram of Lisbon's Metro (blue) and Bus (green) networks with intercity transport terminals shown

[1] Source: www.inac.pt, the Portuguese National Civil Aviation Institute

Modelling Urban Transport in Lisbon

The metro and urban bus networks were chosen for simulation and analysis. Lisbon's 4 metro lines and over 100 bus lines are now managed by a single operator (as of 2012). Data on metro and bus schedules as well as routes and walkable streets were collected for the entire city. We used the metro's published maximum travel speed of 45km/h, an average bus commercial speed of 18km/h for rush hour traffic and 25km/h for interpeak traffic and used a walking speed of 3.96km/h (1.1m/s) for walking connectors.

The service schedules were represented in the model as average waiting time[2] assuming uniform traveller arrivals at the stop or station in question, and the average headways were calculated based on schedules separated into 3 focus periods:

- morning rush, 7am to 9am;
- afternoon interpeak, 12pm to 3pm and
- evening rush 5pm to 8pm.

Time spent by each vehicle (metro, bus) at each station or stop was estimated at 15s. As we are examining the access/egress from intercity travel terminals, we focussed on trips ending/starting at the 3 main of such terminals (illustrated in Figure 1):

- The Lisbon Portela International Airport
- The Oriente Rail Station
- The Sete Rios Bus Terminal

We model trips from 4403 blocks of the city (of 19,300 sq. m/1.93 ha average area), which cover the entire inhabitable area[3]. In GeoMedia Transportation Manager V6.1 we calculated the fastest routes from the city blocks towards the intercity terminals and vice versa using schedule data for each time period discussed above. The results are discussed below.

RESULTS

Distribution of Access Times

Shown in Figure 2 is the histogram and cumulative histogram of total access times from all city blocks to the Airport via metro and urban bus during the morning rush hour (7am-9am). The mean time was calculated at 44.8 minutes with a standard deviation of 14.3 minutes (giving a coefficient of variation of 31.9%) and a median of 43.2. The figure shows that 55% of city blocks had an airport access time of 45 minutes or less and using an access time of 30 minutes would only capture trips from about 15% of the habitable area of the city.

[2] The average waiting time is half of the average headway assuming uniform passenger arrivals at station or stop
[3] Note that in figure 1 that there is a large portion of the city with reduced service density due to the large forest (Parque Monsanto) in the South Western part of Lisbon.

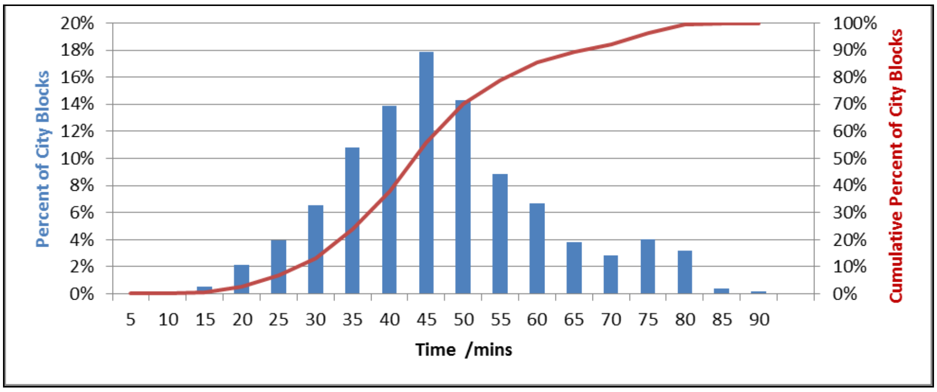

Figure 2 - Morning Rush Hour Travel Time plots to Airport showing histogram (left axis, blue) and cumulative histogram (right axis, red)

The distributions of other times of the day and other terminals were similarly shaped except for Sete Rios trips being more positively skewed as shown in Figure 3. This is likely due to the location of Sete Rios in the city. Being closer to the center of the city allows a reduced travel time, and this was also reflected in the average travel time being 33 minutes (versus about 45 for the Airport and Oriente which are both near the north eastern ends of the city).

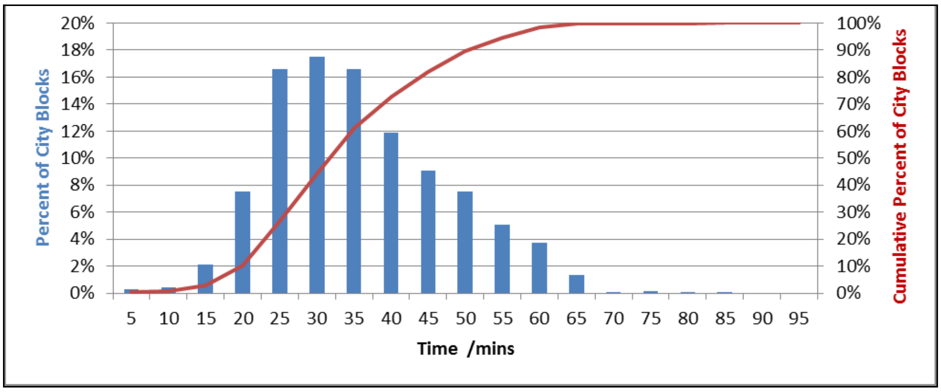

Figure 3 Histogram (left axis, blue) and cumulative histogram (right axis, red) of morning Rush Hour trips to Sete Rios bus terminal

Throughout the day, we can identify changes in the service for accessing the terminals. The frequencies of trains and buses change as well as the bus commercial speed. These changes however have opposing effects. During the interpeak (12h-15h) reduced frequency increases the waiting time for service, but on the buses, faster commercial speeds, reduces the in-vehicle travel time. The overall effects on each terminal access time are shown in Figure 4. There is a 6% decrease in the average access times to the Airport in the interpeak versus the morning, but only 2% and 1% for the Oriente and Sete Rios terminals respectively. The average wait time increased by 16%, 14% and 22% for the Airport, Oriente and SeteRios terminals respectively, with the in-vehicle time decreasing 8%, 2% and 9% respectively.

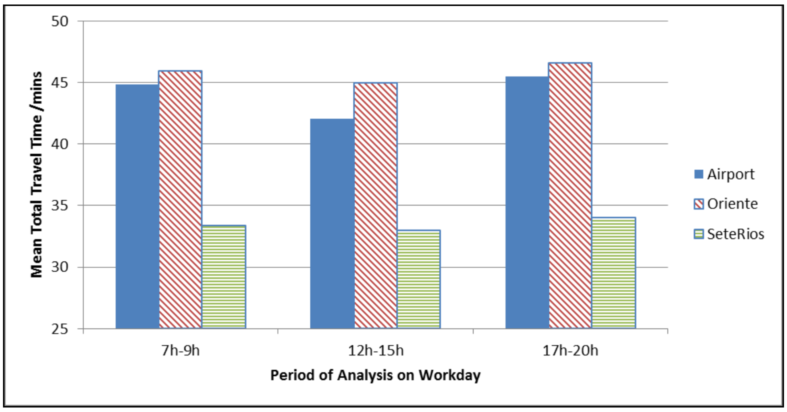

Figure 4 Comparison of mean access times across terminal and across time of day

Access Time versus Egress Time

Whereas the differences between access and egress may be initially ascribed to the traveller, specifically, the expected greater knowledge of access options versus egress options on an intercity trip, our analysis excludes the traveller yet still identifies differences. These differences are chiefly for travel to/from the airport and show mean egress time being 10% lower than access time. This is represented in Figure 5. The other city terminals showed only 1% decreases in travel time. This difference can be caused by uneven scheduling and routing of bus services across the city.

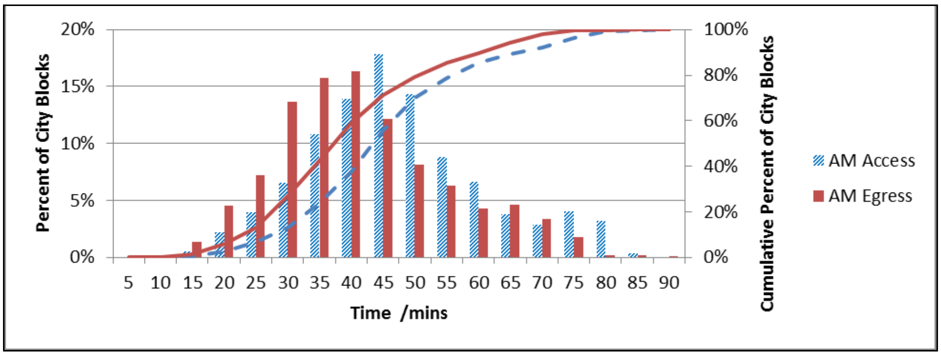

Figure 5 Histograms of Access and Egress time to/from Lisbon Airport.

Traveller Comfort: Walking and Transfers

While the overall travel time may vary across time of day and terminal used, the time spent walking as well as the number of transfers needed have a significant effect on the traveller and traveller mode choice. Some interurban studies have valued the walking time as almost twice the onerousness on the traveller[4] as the in-vehicle travel time (Wardman 2001), with urban values (metro-metro transfers) dropping as low as about half (Guo & Wilson 2011). For transfers, metro-metro transfers were valued at about 3.3 times the value of in-vehicle travel time, rising to 33 times for interurban transfers (rail-rail transfers). In our analysis, the distance walked to arrive at the bus/metro stops, to transfer between stops and to walk from

[4] By “onerousness”, we mean the coefficients of the discrete choice model developed. The coefficient for walking time was almost twice that of in-vehicle travel time.

stops to destination are all included, and shown in Table 1 for morning rush hour trips (the numbers for other times of the day are similar). The walking times were estimated from a walking speed assumption of 1.1m/s.

Table 1 – Average Walking Distances and Times for Intercity Travel Terminals for Fastest Public Transport Routes during Morning Rush Hour

	Access		**Egress**	
	Distance (m)	**Time (min)**	**Distance (m)**	**Time (min)**
Airport	988	15	651	10
Oriente	1,223	19	1,191	18
SeteRios	775	12	782	12

Table 1 indicates the large amount of time required to get to/from these terminals using public transport, and highlights the challenge that someone with luggage making an intercity trip must overcome if they use only scheduled public transportation for their Lisbon-based access/egress trip legs. Coupled with the fact that Lisbon is a rather hilly city, these numbers suggest why use of public transport for access/egress to intercity travel terminals may be undesirable for travellers.

On average the number of vehicle boardings is close to 2 for most scenarios (terminals and times of day) indicating that on average there is a single transfer per trip. The average number of boardings is however closer to 1 for Airport egress trips. These trips were also characterised with higher average vehicle distances indicating that the bus schedules and routes were more desirable for airport egress trips than airport access.

Fitting a Distribution to Lisbon Access Times

If we assume that the travel time by public transport (PT) for an individual trip is independent of all other PT trips (as we have implicitly in this analysis since we have ignored effects of human congestion on the metro and capacity limits on the bus network), then we can theoretically justify the use of a normal distribution to model the travel times obtained from the analysis. The normal distribution is a symmetric distribution, which is close to what we've noticed for the Airport (and Oriente) access times, but not so for the Sete Rios access times. We are interested in knowing how well a normal distribution can fit these data sets even with the skew shown. We will compare the normal to the Weibull distribution fitting results. For this distribution analysis, we will keep the univariate data in the 5-minute bins shown in the histograms, and acknowledge that results could differ for bins of different sizes.

Using distribution-fitting techniques in Matlab, we have compared Normal and Weibull distributions for each of the morning rush hour access time distributions. The results are presented in Table 2.

Table 2 – Results of Distribution Fitting Analysis for Morning Peak Access Times.

		Normal Distribution		Weibull Distribution	
		Parameters (mean, variance)	**Log Likelihood**	**Parameters (scale, shape)**	**Log Likelihood**
Access to	Airport	44.9; 204.49	-17,897	49.9; 3.36	-17,905
	Oriente	45.9, 213.16	-17,991	51.1; 3.40	-18,002
	SeteRios	33.3; 139.24	-17,070	37.3; 3.03	-17,037
Egress from	Airport	39.2; 187.69	-17,735	43.9; 3.05	-17,689
	Oriente	45.6; 204.49	-17,917	50.6; 3.43	-17,931
	SeteRios	33.1; 139.24	-17,074	37.0; 2.99	-17,037

Note: Highlighted in each row is the better distribution according to Log Likelihood.

As Table 2 indicates, the Weibull and Normal distributions are both matched for quality of fit to access and egress time data. The Weibull is slightly better for those distributions that were more skewed however. Nevertheless, we recommend the use of the Normal distribution for modelling access and egress times to each terminal for their familiarity and ease of use, since LL values obtained do not differ much (less than 0.3%). The access and egress distributions for Oriente are plotted with the best-fit normal distributions in Figure 6 (with mean and variance values of (45.9, 213.16) and (45.6, 204.49) for access and egress, respectively).

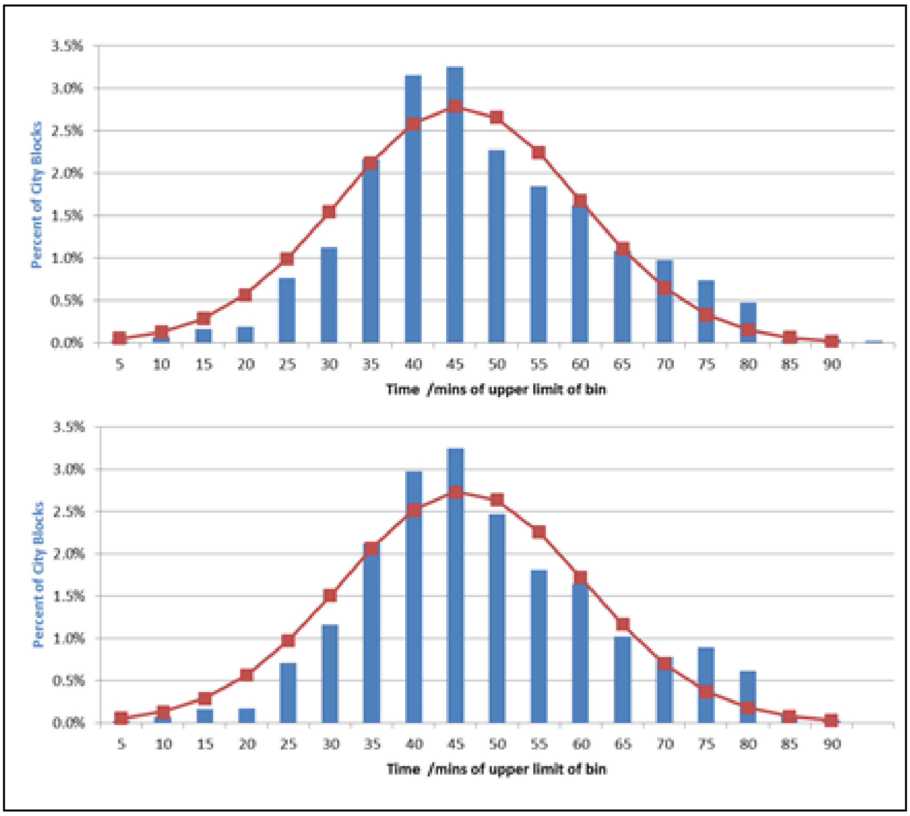

Figure 6 Histogram and best-fit Normal distributions for Morning Rush Hour Access (upper) and Egress (lower) for Oriente

Analysing the Effect of Access Time Variation on Intercity Mode Choice

With modelled distributions of access time, we can now examine how real access time variations can affect the choice of a particular mode in discrete choice models. For this we look at the stated preference (SP) research already performed for predicting the market share of the high-speed rail (HSR) system for the Portugal-Spain (i.e. Lisbon-Madrid) connection. The body responsible for HSR in Portugal, RAVE, commissioned a study which developed binomial models of HSR versus each of air, conventional rail, bus and car modes using the variables cost, journey time, service interval (frequency) and access time (Steer-Davies-Gleave 2006). Later, these models were re-specified in (Petrik et al. 2012) with different variables. Using the access distributions, we examine the changes to the probabilities of choosing HSR versus Air by fixing the other explanatory variables in the models at realistic values used by the authors of each paper, and then varying the difference between the access time of the HSR and the access time of each comparator mode. We set levels of the variables in Table 3. These levels will be referred to as the Base Case. Using the models specified, we examine the difference of the systemic component of the econometric utility of the choice of HSR versus Air (i.e. Utility of HSR – Utility of Air).

Table 3 – Base Case Variable Levels for estimation of Access Time Effects on Traveller Choice. Data Source: (Steer-Davies-Gleave 2006)

Explanatory Variable	Relative Value (HSR – Alternative)	Model Beta Coefficient	Contribution to Utility
Cost /€	80 – 100 = -20	-0.02404	0.4808
Journey Time[5] /min	130 – 120 = 10	-0.01415	-0.1415
Average Service Interval (1/frequency) / min	120 - 60 = 60	-0.005805	-0.3483
Subtotal (positive means HSR more desirable)			**-0.009**
Access Time /min	(see below)	-0.0208	(see below)

The access time distribution here is the distribution of the difference between the access time of the HSR (for which we will use Oriente Terminal, the current main rail station and slated location of HSR in Lisbon) and the access time of the airport. This distribution works out to be ~N(1.0, 417.7)[6]. After multiplying the distribution by the access time beta coefficient, we identify the access time contribution to the utility as being distributed ~N(-0.0208, 0.1807). Using these values the probability of getting a positive utility difference (for HSR versus air) based solely on access time distribution would be about 47%[7]. While this percent is not the percent of travellers that will choose HSR, it does mean that with the explanatory values of the variables selected in Table 3, the access time can have a significant effect on the choice between HSR and air.

Using the results of (Petrik et al. 2012), we will perform a similar analysis. These authors however specified a model which included socioeconomic variables indicating that an individual level analysis is required. We used the (69) individual records of the RAVE survey

[5] The journey time includes check-in and boarding time
[6] Recall that the distribution of the difference of two normal distributions with means m_1 and m_2 and variances s_1^2 and s_2^2 is ~$N(m_1 – m_2, s_1^2 + s_2^2)$. So the text shows the variance not standard deviation.
[7] Calculated from Normal Distribution tables here http://davidmlane.com/normal.html

referenced earlier for the travellers making Lisbon-Madrid routes. For details on the survey, the reader is invited to see (Steer-Davies-Gleave 2006; Petrik et al. 2012). The model beta coefficients are listed in Table 4.

Table 4 – Model Coefficients for HSR-Air Binomial Choice Model. Data Source: (Petrik et al. 2012)

Explanatory Variable	Model Beta Coefficient
Alternative Specific Constant (for HSR)	1.5872
Cost (€)	-2.4198
Journey Time[8] (min)	-3.0508
Average Service Interval (1/frequency) (min)	-0.0058
Age (years/100)	3.3520
Sex (Male=1, Female =0)	0.8277
Employment (Has job = 1, Otherwise = 0)	-2.3475
Income (Salary/100,000 €)	-1.2964
Trip Purpose (work, study = 1, otherwise = 0)	1.1026
Who Paid for Trip (work = 1, otherwise = 0)	-0.9086
Access Time (min)	-2.9562

Using the values in Table 4, the individual socioeconomic characteristics and the distributions and alternative characteristics defined earlier, we calculate that the average probability of travellers choosing HSR drops from 100% to 71% due to the increased access time when taken randomly from the distribution. We note though that the HSR-Air model was based on data from Lisbon-Porto travellers.

CONCLUSION

This paper aimed at quantifying the distribution of access times to intercity transport terminals in Lisbon. Using a model of metro and bus lines for the entire city, we were able to simulate shortest time routes from each city block to the terminals of interest. We acknowledge that the inclusion of car routing and choice information could strengthen the work, and see this as an extension. The distributions were analysed in a variety of ways, comparing access to egress times, comparing different intercity terminals, and examining the changes to walking connectors and transfers throughout the day. We were then able to mathematically represent the distributions of access and egress times, and found that they follow Normal curves with relatively good fit.

These mathematically modelled distributions were finally used to examine the effect of access time distributions on the discrete choice models (DCM) of intercity mode choice for Lisbon-Madrid trips. In particular we examined the effect on the systemic utility of travellers according to DCM models already estimated for Lisbon. The distribution of the systemic econometric utility of travellers as a function of access time was estimated.

[8] The journey time includes check-in and boarding time

This analysis could be expanded with the scaling of the access times according to population or population densities in each city block, including car travel and also by including all the other metropolitan areas of Lisbon.

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