Transactions on the Built Environment vol 64, © 2003 WIT Press, www.witpress.com, ISSN 1743-3509

To what extent does urban density influence the modal split? The Lisbon Metropolitan Area case study

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Abstract

The relationship between urban density and car use appears to have a growing importance as the urban areas sprawl and tend to be more diffuse. Considering this point of view, this paper analyses a recent mobility survey in the Lisbon Metropolitan Area (LMA).

The main objective addressed is to know to what extent does density influence the modal split in identical situations of public transport supply and of population socio-economic levels.

The car use weight was considered the dependent variable. Two approaches were developed: The first one considers the urban density, for each specific socio-economic level, as the only explicative variable.

The second approach uses a multivariate regression analysis, using as explicative variables of car use the density, the car availability, family income, the public transport supply and the public transport levels of comfort (measured by the number of transfers).

The results obtained, with both methods, are compared and discussed, in order to identify the real weight of density as an explicative variable of car use in LMA.

1 Introduction

This paper is organised in two main sections. The first one is a general overview of part of the extensive bibliography on this subject – the relation between density and modal split, namely with car use. The second part is the case study analysis.

The case study comprehends four different sections. In the first a brief geographical overview of Lisbon Metropolitan Area is made, followed by general description of the analysed survey. After an explanation of the methodology, afterwards a description regarding the variables construction is done.

Finally, the results are presented and conclusions are drawn.

2 Overview

It is well known that the relation between land use and transport is complex but undeniable [1]. It is commonly accepted that in dense cities there is lesser car use. This statement can be empirically perceived in a way that in a dense city one can easily access to several numbers of destinations by simply walking and in these cities transport systems well developed.

In fact, it is usually accepted that in denser areas the public transport is more economically effective, so all this concurs to the existence of a larger public transport offer in denser cities. On the other hand public transport is an important social equaliser [1], providing to those who don't have a car a higher degree of mobility and accessibility.

Car use is usually associated with lower densities, especially because the road infrastructure is a large space consumer and also due to the fact of the lesser transport capacity of roads, compared with the public transport (in terms of the number of passengers).

In the early nineties two important documents highlighted the correlation between land use patterns and transport: the investigation made by Peter Newman and Jeffrey Kenworthy [2] and the Green Paper on the Urban Environment, presented by the Commission of European Communities [3].

The Green Paper on the Urban environment [3] states that density and also the mixing of different urban functions are key elements in order to achieve a sustainable mobility, which means, among other things, a more intense use of public transport along with walking and cycling. Nevertheless, this was a normative document and not a direct result from a study.

One of the main findings of Newman and Kenworthy [2], was that a higher density reduced the number of kilometres travelled by car per capita. Although some authors dispute those conclusions [4] on the basis of the alleged bad quality of the collected data. Another recent international study [4] found, with a fairly good level of consensus, that residential density was inversely related with car use (Vehicle Kilometres Travelled per capita).

A review of several regional studies and models, recently made in the United States, found that higher densities near public transport infrastructures would reduce auto travel [4]. These conclusions are in direct concordance with the main findings made by Newman and Kenworthy [2].

Density is considered as more effective in reducing the levels of car use than the mixing of jobs and housing, particularly near public transport infrastructures.

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The SESAME research project [5] showed that in dense cities the modal split favours the public transport. This project also advanced that the offer of public transport was directly related with the density.

Regarding the relations between density and car share, in the SESAME Project [5] the following conclusions were drawn:

- Density is not included in the best fit model of car share;
- Density only has a strong negative correlation with the segment of drivers in car share;

3 Case study

3.1 Geographical overview

Lisbon Metropolitan Area, comprehends 17 municipalities, involving the city Lisbon (the capital of Portugal),. The Tagus River estuary, which crosses through the region, with a width ranging from 2 Km to 12 Km, is a considerable barrier by splitting this region in two.

In 1991 Lisbon Metropolitan Area had 2.540 inhabitants, representing 26% of Portugal's total population. Between 1991 and 2001 the total population of this region has increased in about 140 thousand inhabitants. The demographic growth rate of Lisbon Metropolitan area (between 1991 and 2001) was 0,65% higher than the country's growth rate. This area is also the richest region of Portugal and its most important economical driving region.

3.2 Survey

The mobility survey analysed was made seven years ago, between 1993 and 1994 [6]. The survey was made both by telephone and personal interviews. In every interview the social economical characteristics of every household member were asked, and it was randomly chosen one of them in order to know his mobility patterns. The universe comprehended all the residents in the Metropolitan Area of Lisbon with an age above ten years old (age of children above elementary school). For that survey, 30680 interviews were made, characterising 101 337 persons (with an average of about 3,3 persons per household).

3.3 Methodology

In order to know the influence of urban density on the car share in the weekday trips two different approaches were used. The first one considered the urban density as the sole dependent variable of car share. In this approach gender and socio-economic level were considered as segmentation variables.

The main objectives of this segmentation were to find if density induces different behaviour in each group. The groups considered were (also subdivided by gender):

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- Liberal professionals, and businessman (groups **a** – men and **b** - women) – generally with higher income levels, and consequently with higher levels of car availability;
- Employees (groups **c** – men and **d** - women) – the income levels varies a great deal, although the mobility patterns associated with this group have a vary important proportion of work related trips (going to work in the morning and come back home in the evening);
- Students (groups **e** – men and **f** - women) – they generally do not have their own income, relying on their families for money, car availability is generally low, mainly due to age constraints, and their mobility patterns are heavily associated with school activities;
- Retired and unemployed individuals, and agriculture workers (groups **g** – men and **h** - women) – the income levels in this group are generally lows and their mobility patterns are generally associated with a low rate of daily trips per person.

The second approach is based on a multivariate regression analysis, using as explicative variables of car use the density, the car availability, family income level, the public transport supply and the public transport levels of comfort (measured by the number of transfers).

The study was made considering only 10 of the suburban municipalities in the metropolitan region of Lisbon. It focuses, at civil parish level, on 36 zones that were at the time served by suburban trains. The lines considered are: Cascais Line – in yelow; Sintra Line– in green; Azambuja Line – in red, and Sado Line – in blue. Their geographical location is showed on the next figure.

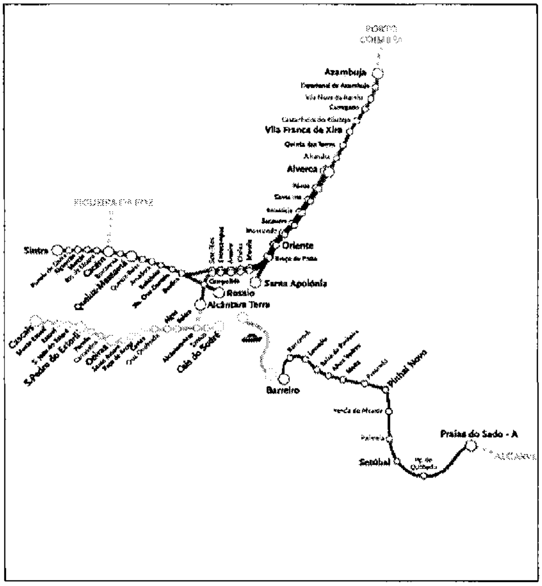

Figure 1: Suburban train lines in Lisbon Metropolitan Area

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3.3.1 Variables construction

In this section we will briefly discuss the variable construction, sources of information, estimation processes and possible errors. The most important variable: urban density, was considered in total number of persons/ha – inhabitants and workers. In the definition of urban areas the municipal urban plans were the main source of information. Since most of them date from the early nineties we expect a small error in the definition of boundaries for the urban areas. The categories of land uses considered were urban (mainly residential), tertiary and industrial uses.

The population estimate was made for 1993 considering an average yearly growth rate (between the two census years – 1991 an 2001). The estimation for the number of workers was made considering the number of trips with destiny in each zone related with the motive "going to work". The errors in this estimation could result from two different sources. The estimated error associated with the survey, and the error due to the fact that the survey didn't include interviews with the workers, so it is possible that there is people who doesn't live in the Lisbon metropolitan region, but works in it. We believe that this possible error don't affect significantly the results because the number of jobs generally represents less than 30% of the total population (inhabitants and workers). On the other hand it is commonly known that the number of workers that don't live in the Lisbon Metropolitan Area is small (possibly less than 5% of the total number of jobs).

Due to the fact that the survey didn't had any direct questions about income, this variable was considered in an indirect way. The chosen estimation was the percent of trips belonging to the groups **a** and **b** –generally associated with higher income levels.

The car availability was estimated considering the number of trips made by individuals who answered in the survey that they had a car or motorbike available for their own use.

The public transport supply was estimated considering only the train (it was practically impossible to consider the buses, due to the non-existence of a reliable source for that information). The variable considered was the number of circulations per weekday.

The comfort was also considered in an indirect way. The chosen estimation was the average number of transfers for public transport trips.

3.4 Results

For the first approach, the results obtained by the linear regression are presented in the next table.

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Table 1: Linear regression – results obtained

	Coefficients				R^2	Adjusted R^2	F	Significance F
	Intercept	t Stat	Density	t Stat				
Group a	0,8528	28,9646	-3,6E-05	-1,6184	0,0715	0,0442	2,6192	0,1148
Group b	0,5912	11,3241	2,7E-05	0,6962	0,0145	-0,0154	0,4847	0,4912
Group c	0,5949	21,1136	-4,4E-05	-2,0583	0,1108	0,0847	4,2368	0,0473
Group d	0,3817	12,8417	-1,8E-05	-0,8240	0,0196	-0,0093	0,6789	0,4157
Group e	0,2416	9,2800	-3,2E-05	-1,6500	0,0741	0,0469	2,7225	0,1082
Group f	0,2047	9,0743	-1,9E-05	-1,1493	0,0374	0,0091	1,3209	0,2585
Group g	0,3728	10,4887	-2,6E-05	-0,9549	0,0261	-0,0025	0,9118	0,3464
Group h	0,2326	8,8259	-1,9E-05	-0,9655	0,0267	-0,0019	0,9323	0,3411

Analysing the results obtained in the linear regressions one can see that density doesn't have an important explanatory power, and in some cases it is almost negligible. The F value is in some cases under 1, which clearly indicates that the non-explained variance is superior to the explained variance. Curiously those cases occur mostly in groups in which the gender is feminine – group **b**, **d**, and **h**, (only in group **h** the gender is masculine). We can conclude that, for the studied zones, women are less affected by density when they make their mode choice. This can be explained by the following facts:

- Women have generally less access to car;
- Women are usually conditioned by certain activities in which a car is very useful – taking children to school and shopping groceries;

This explanation is partly confirmed by the results obtained in group **f** (women students), which has more similar results to the male group with the same occupation. In both these groups the car availability is low (although it is very likely that can be higher for men). Student women generally don't have the same limitations, in terms of division of tasks within a household.

In the groups with low-income levels – groups **g** and **h**, it can be said that density doesn't explain their car share. It is probably the low-income levels that condition the most their decisions regarding mode choice.

As could be expected the group which present a higher percentage of explained variance is the group **c** – Employees (male). The main reasons for this are probably linked to the fact that:

- In this group there are less limitations in terms of car access, the husband is usually the one that drives, and actually owns the family car ;
- The type of trips made by this group in weekdays, are in the most part linked with work which are, generally, more adapted to the use of public transport.

In group **a** needs related to different patterns of mobility and social status influence modal choice. In group **e** (male students) is probably the access to the car that most influence modal choice.

So one can say that due to the fact that group **c** is the one with fewer constraints related with car access, and due to his mobility patterns it is the one

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which can make more rational decisions regarding the use of car depending on urban density.

These justifications are above all assumptions, backed by logic and by some bibliography, but with no data analysis to corroborate them. Nevertheless they are important hypothesis, which ought to be tested.

In the second approach, due to the fact that there were substantial differences of scale between independent variables all variables were standardised.

The first step taken was to analyse separately the relation between each independent variable and the dependent one. From that analysis it was perceived that the variables with a higher coefficient of determination with car share were car availability (R^2=0,7163) and income (R^2=0,3663). They were followed by density (R^2=0,1427). The coefficients of determination obtained for the last two independent variables were almost negligible (R^2=00387 for public transport supply and R^2=0,0351 for comfort).

The conclusion draught from these analyses is confirmed by the correlation analysis, in the same order of importance (in terms of ordination of the correlation coefficients absolute value).

Table 2: Correlation Matrix

	car share	*density*	*car availability*	*Income*	*Comfort*	*PT supply*
car share	1					
density	-0,37781	1				
car availability	0,84633	-0,41965	1			
Income	0,605248	-0,33698	0,587112647	1		
Comfort	-0,18747	-0,15801	-0,245221877	-0,19261	1	
PT supply	-0,19669	-0,34811	-0,22820841	-0,05454	0,245003	1

The results from the multivariate regression analysis give us slightly different conclusions. These results are shown below.

Table 3: Linear regression – results obtained

	Coefficients	**t Stat**	**R^2**	**Adjusted R^2**	**F**	**Significance F**
Intercept	2,3747E-16	2,57E-15	0,73575	0,691703	16,7054	6,878E-08
density	-0,015793	-0,12775				
car availability	0,740875	5,46765				
Income	0,169405	1,44018				
Comfort	0,032123	0,31446				
PT supply	-0,031745	-0,28382				

The regression results show a positive relation between comfort and car share (quite different from what was expected). They also show the small importance of density as explanatory variable, with less importance than comfort and public transport supply.

Considering the same explanatory variables, several combinations where considered. The obtained results are shown in the next table

Table 4: Parameters from the regressions with several combinations of variables

Combination of variables	R^2	Adjusted R^2	F
all variables	0,735745159	0,6917027	16,7053551
all variables, without density	0,735601406	0,7014855	21,5618049
car availability and income	0,734191208	0,7180816	45,5746963
car availability, income and density	0,734263694	0,7093509	29,473376
car availability, income and comfort	0,735035418	0,710195	29,5902861
car availability, income, density and comfort	0,735035602	0,7008466	21,4992126
car availability, income and PT supply	0,734487985	0,7095962	29,5072843
car availability, income, density and PT supply	0,734874109	0,7006643	21,4813963

As can be seen in the previous table the best results are obtained with the combination of car availability and income. Combinations of three variables (car availability and income plus another variable) also gives better results than the initial regression, all very similar between them but the combination that contains density has the worse results.

After these analyses the source data was checked again and a decision was made to disregard three zones. The main reason was that these zones were exceptional cases, which had an effect of biasing the results.

The first zone was Baixa da Banheira, the first illegal urban development ever built in Portugal. This zone has extremely high density values. Besides its population has a very low income level, which influences their mobility patterns. The other two zones are situated in Setubal municipality, which has a more tenuous and recent suburban relation with Lisbon. The civil parishes analysed in this city have an extreme high concentration of people with higher income. Afterwards, regressions were made for several combinations of variables, following the same procedure described earlier.

Table 5: Parameters from the regressions with several combinations of variables

Combination of variables	**R^2**	**Adjusted R^2**	**F**
all variables	0,688476033	0,63078641	11,93414
all variables, without density	0,678611298	0,632698626	14,78048
car availability and income	0,675578616	0,653950523	31,23616
car availability, income and density	0,686507726	0,65407749	21,16876
car availability, income and comfort	0,678611298	0,632698626	14,78048
car availability, income, density and comfort	0,686736425	0,641984486	15,3454
car availability, income and PT supply	0,675584195	0,64202394	20,13048
car availability, income, density and PT supply	0,68822885	0,643690115	15,45237

By analysing the results from the second linear regression it can be seen that density has increased is weight as an explanatory variable. Although car availability and income are still the most important variables, density has rosen to a third place. The combination of variables in which the highest value for adjusted R^2 is obtained, are car availability income and density.

Comparing the results from both models it is clear that the overall explanatory power of the second model (measured by R^2) is lower than the one found on the first model. Although, this phenomena may be caused by the reduction of the number of observations (due to the rejection of three civil parishes).

4 Conclusions

The first conclusion that can be drawn is that, in the suburban region of Lisbon Metropolitan Area, density is not the most important explanatory variable of car share. Car availability and income are far more important. In itself this fact is not quite surprising, since these two variables effectively condition car use (if someone doesn't have access to a car it is far more difficult to make car trips, in the same way income condition the possibility of buying, maintaining and driving a car).

The relative importance of the public transport supply and comfort in public transport trips varies considering the two models used in the second approach. If the three civil parishes referred before are excluded from the group of observed values, density has a higher importance than these two variables.

The comparison between the results obtained (in the second approach) with the ones found in the SESAME Project, shows that they go in the same direction, density is not an important explanatory variable of car share, although there is a negative correlation between the two of them.

Comparing the two approaches presented in this paper, they both go on the same general direction: although density is not an important explanatory variable of car share it's explanatory power varies throughout the different social segments.

This last conclusion tends to confirm the hypothesis about the relative importance of other variables to explain the variations of car share throughout the different social segments. Up to this point the main conclusion is that this is the start for a soon after study about the real explanatory weight of those variables through the different social segments (car availability, income and restrictions linked with mobility patterns).

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