

**USING STRUCTURAL EQUATIONS MODELLING TO UNRAVEL THE
INFLUENCE OF LAND USE PATTERNS ON TRAVEL BEHAVIOR OF URBAN
ADULT WORKERS OF PUGET SOUND REGION**

João de Abreu e Silva
CESUR - Centre of Urban and Regional Studies
IST, Technical University of Lisbon
Avenida Rovisco Pais, 1049-001 Lisboa, Portugal
Tel (+351) 21 841 83 94 Fax (+351) 21 840 98 84
joao.abreu@civil.ist.utl.pt

Konstadinos G. Goulias
Department of Geography
University of California at Santa Barbara
3611 Ellison Hall, Santa Barbara, CA 93106
Tel (805) 686-1225 Fax (805) 893-3146
goulias@geog.ucsb.edu

Paper submitted for presentation at the 88th Transportation Research Board Annual Meeting, Washington D.C. and publication in the Transportation Research Record

**Submitted August 1st 2008
5748 Words**

ABSTRACT

This paper addresses the relationship between travel behavior and land use patterns using a Structural Equations Modeling framework.

The proposed model structure in this paper is by design heavily influenced by a model developed for Lisbon (1) to allow comparisons. In that paper the existence of significant effects of land use patterns in travel behavior was found. The travel behavior variables included in the model are multidimensional and comprehend both short term, number of trips by mode and trip scheduling, and long term, home location, car and pass ownership, mobility decisions. The modeled land use variables measure the levels of urban intensity and density, diversity, both in terms of types of uses and the mix between jobs and inhabitants and the public transport supply levels,. The land use patterns are described both at the residence and employment zones..

In order to explicitly account for self selection bias the land use variables are explicitly modeled as functions of socioeconomic attributes of individuals and their households.

The Seattle findings are presented and then compared them to the Lisbon findings. Many commonalities between the two environments were found but also many important differences.

1. INTRODUCTION

Nowadays urban mobility is strongly supported by the massive use of automobiles, inducing important environmental, socioeconomic and territorial impacts, many of them perceived as strongly negative. This originated several proposals of policies designed to tackle these negative impacts. The three most important are: Policies advocating the diffusion and use of new technologies, policies advocating economic measures in order to change travel behavior, and policies advocating the use of land use changes to influence travel behavior and .

During the last 20 years the debate between advocates of the two latter policies has been rather intense (for some examples see 2, 3, 4, 5, 6, 7, 8). Consequently, the study of the relations between land use patterns and travel behavior was the object of important attention from researchers. Due to this continuous attention important theoretical and methodological innovations were made.

The first quantitative models built to test the existence of these relations were aggregated models, with important shortcomings. The first generation of studies was subjected to several criticisms (9, 10, 11), namely the fact that they had little behavioral basis. These criticisms, paved the way for the appearance of disaggregated and the application of models based on the utility theory (12, 11).

Within the framework of utility theory travel behavior is considered as a derived demand, (13). By this reasoning the land use patterns influence travel behavior by changing costs. This type of influence occurs either in long or short term decisions, as car ownership or mode or destination choice. Long term decisions influence short term decisions by restricting the alternatives available (14).

Other recent methodological advances expanded the framework of utility maximization in the activity based approach. In this case the land use patterns are determinants of opportunities and restrictions posed in the pursuit of activities (15).

However, the use of models based on the utility theory is plagued with difficulties. Using Logit or Probit models doesn't necessarily implicate itself a utility theory based model since; the model should reflect a theory based specification (11). Cervero (16) also points out that most of these models have been badly specified.

These innovations also highlighted other shortcomings of the empirical models developed in this area. One of them is the endogenous relations that occur between variables. Related with this phenomena there were also claims of self-selection, (17). This leads to the fact that at least there are some endogenous effects between land use variables and individual or family characteristics. A more radical hypothesis asserts that self-selection could be itself responsible for the differences in travel behavior found for residents in different urban environments. One solution to unravel all these relationships is to formulate many equations representing all these choices and allow them to be correlated in their observed and unobserved components. In this way causal inferences of mutual influence can be measured by estimated correlation among the variables in the equations.

Another important issue is the measurement of variables describing land use characteristics. One of the most widely used is urban density, although it could not be the most adequate variable, since it encompasses many diverse characteristics that

could not be easily replicated by simply changing density (9). Other land use variables more generally used include, mix of employees and residents, mix and diversity of land use categories, urban design measures, house characteristics, and accessibility variables. Related important issues are the multidimensionality of urban space, and the interconnections that exist between land use variables (18, 19). The former of these issues is due to the necessity of having at the same time an important number of land use variables that could encompass the multidimensionality of urban space, and to the need for a reduction in the number of variables employed to capture the multidimensionality of urban space. The interconnections and amplification effects that could exist between land use variables means that they could present negligible effects when analyzed one by one and significant effects when included in more comprehensive indexes (19).

These problems prompted the use of data reduction techniques such as factor or cluster analysis, which allow the maintenance of the levels of richness in the characterization of land use patterns (18).

One recent analytical innovation is key to this paper, is Structural Equations Modeling (SEM) (20, 21). SEM allows the parameterization of endogenous relations between variables, thus accounting for self-selection effects (17, 21). It also allows the modeling of a comprehensive framework of hierarchical relationships between long term decisions to medium or short term decisions. Relatively new estimation algorithms of Structural Equation Modeling allow the estimation of discrete and censored variables, thus allowing them to be used within the framework of utility theory (20).

All of these methodological innovations were incorporated in the model presented in this paper with a structure that replicates a previously developed model for the Lisbon Metropolitan Area (1) to compare the results obtained.

2. CASE STUDY AND MODEL DESCRIPTION

The present model used data from the Puget Sound Transportation Panel (PSTP). PSTP contains a large number of waves between 1989 and 2003 (22). The data used correspond to a sample taken from the ninth wave of this panel survey, which was in 2000. The choice of this wave was due to the availability of land use data of the same vintage (see also 23, 24). This sample with 1025 observations was made by selecting one adult worker in each of the households interviewed in this wave.

Table 1 contains a selection of individual and household characteristics of this sample.

TABLE 1 Sample travel behavior and socioeconomic characteristics

	Variables	Average	Standard Deviation
Endogenous travel behavior variables	Time spent between first last trips	10.55	3.04
	N° trips - non motorized	0.31	0.91
	N° trips - transit	0.31	0.82
	N° trips - car	3.76	2.52
	Transit pass	0.18	0.39
	Number of cars	2.11	0.79
	Log commuting distance	3.51	1.05
Socioeconomic exogenous variables	Age	46.76	10.84
	Gender (%)	0.51	0.50
	Low income (%)	0.09	0.29
	Medium income (%)	0.46	0.50
	High income (%)	0.33	0.47
	Household size	1.55	0.64
	Average age	46.11	10.46
	Household with 2 members (%)	0.41	0.49
	Number of teenagers	0.03	0.18

The proposed model structure analyses the relations between socioeconomic characteristics, land use patterns, relative residential and employment locations, car ownership and travel behavior. The proposed model structure is as follows.

- Land use patterns both in the residence and employment areas are influenced by the socioeconomic characteristics of the individuals and their households;
- Both land use patterns and socioeconomic variables influence travel behavior of employed individuals;
- This influence is assumed to be at least partly mediated by variables describing several travel behavior related decisions, going from long term decisions to shorter term ones;
- These variables include, the distance between employment and residence locations (commuting distance), car ownership and transit pass ownership, considered as being longer term decisions which influence shorter term decisions like the number of trips made daily by mode and the time spent between the first and last trips, corresponding to the height of Hägestrand prism in time geography;
- Land use variables are also allowed to be influenced by travel behavior variables, thus encompassing possible effects due to the fact that travel behavior is one of the visible outcomes of individual preferences and also the feedbacks due to the information that individuals have about optimal shorter term decisions (25)

The model's general structure is presented in the next figure.

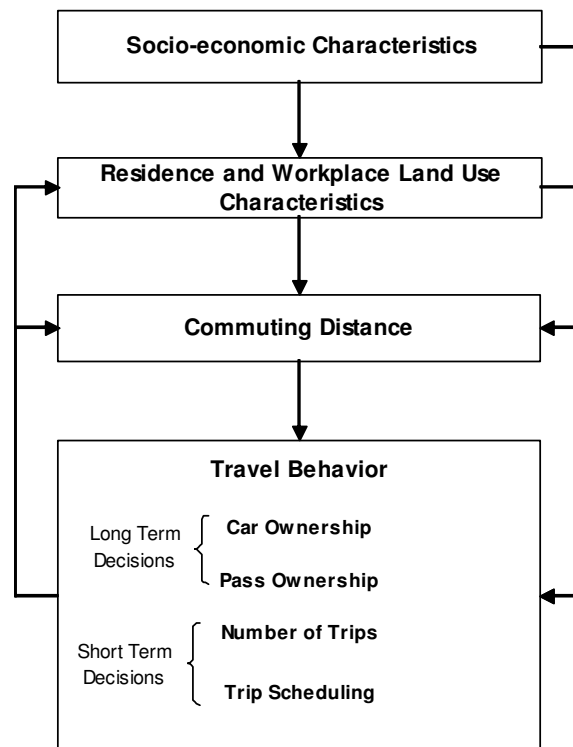


FIGURE 1 Model general structure

The socioeconomic variables used in the model include: gender, age, household total income (in three binary variables – low, medium and high income), household size, average age of the household, households with only two individuals and the number of teenagers in the household.

The created land use variables considered both the TAZ and a grid cell of 750x750 m around the place of residence and employment of each individual, respectively labeled home and work.

The land use variables included a global population density (considering both inhabitants and employees), a built floor space density, and the density of arterial intersections in each grid cell. The distance of each TAZ to Seattle Regional Centre was also included, and an entropy indicator was built using the built floor space of each type of use: residential, commercial and services, industry and government/public services. This indicator measures the diversity balance between several categories of land uses, and it was first used by Cervero and Frank and Pivo (26).

Transit supply variables were also created, including the availability of bus services (number of stops) during the morning peak and midday in each grid cell.

All of these variables were reduced to 5 factors characterizing both the residence and employment locations (capturing 77% of variation). With the exception of one factor there was a clear distinction between factors describing land uses in the residence and employment area.

The factors and their defining variables together with their scores are presented in the next table.

TABLE 2 Land Use factors and their defining factor loadings

Land use factors	Most Important Variables	Loadings
Employment in a central and denser area	Population density work	0.947
	Building density work	0.966
	Intersections density work	0.915
	Distance form CBD work	-0.586
Residence in a central and denser area	Population density home	0.933
	Building density home	0.917
	Intersections density home	0.706
	Distance form CBD home	-0.561
Bus supply in the employment area	Bus availability AM work	0.997
	Bus availability midday work	0.997
Bus supply in the residence area	Bus availability AM home	0.898
	Bus availability midday home	0.904
Mix	Entropy home	0.830
	Entropy work	0.490

Clearly the first two factors present high scores in variables describing the intensity and centrality of land uses. They are named employment and residence in central and denser areas respectively. The third and fourth factors are clearly connected with transit supply both at the residence and employment areas. They are named, bus supply in the employment and residence areas. The fifth and last factor measures the levels of mixed uses and their balance both at the residence and employment areas, it is named mix. They capture the most important dimensions of the home and work location choices and are used as five dependent variables in the model.

3. STRUCTURAL EQUATION MODELLING

SEM represents an evolution and a combination of two types of statistical methods, factor analysis and simultaneous equations models (27). In SEM variables could be either exogenous or endogenous (20, 21). These characteristics allow SEM to handle indirect and multiple relationships. Due to these characteristics SEM is particularly adequate as a tool to model the complex relationships between travel behavior and land use patterns.

A structural equation system with observed variables only, as the one presented in this paper (no measurement submodels) can be expressed as:

$$y = \mathbf{B}y + \mathbf{\Gamma}x + \zeta$$

Where

y is the vector of p endogenous variables;

x is a vector of q exogenous variables;

ζ is a vector of p disturbances with variance-covariance matrix Ψ ;

\mathbf{B} is (p by p) matrix containing the coefficients for the equations relating the endogenous variables;

$\mathbf{\Gamma}$ is a (p by q) matrix containing the regression coefficients for the equations relating endogenous and exogenous variables.

The model-replicated combined variance-covariance matrix of the observed (p) endogenous and (q) exogenous variables, arranged so that the endogenous variables are first, is given by the partitioned $(p+q)$ by $(p+q)$ matrix (27, 20).

$$\Sigma(\theta) = \begin{bmatrix} (\mathbf{I} - \mathbf{B})^{-1}(\Gamma\Phi\Gamma' + \Psi)[(\mathbf{I} - \mathbf{B})^{-1}]' & (\mathbf{I} - \mathbf{B})^{-1}\Gamma\Phi \\ \Phi\Gamma'[(\mathbf{I} - \mathbf{B})^{-1}] & \Phi \end{bmatrix}$$

Estimation of SEM models is performed by using the covariance analysis method – method of moments (20). The objective function is to minimize the differences between the sample variance-covariance matrix, S , and the model-replicated matrix $\Sigma(\theta)$.

The methods used for model estimation are normal theory maximum likelihood – ML, generalized least squares – GLS and weighted least squares – WLS . (20) (21)

WLS, the method used to estimate the model presented in this paper was specifically developed to deal with discrete and censored variables. Its genesis occurred with a multivariate probit developed by Muthen (28) Later this method was generalized (29) to accommodate structural equations with a mix of discrete, censored and continuous variables (30).

WLS minimizes the following fit function (31)

$$F(\theta) = (s - \sigma)' W^{-1} (s - \sigma)$$

Where

s' is the vector of the elements in the lower half, including the diagonal of the covariance matrix S ;

σ' is the vector of corresponding elements of $\Sigma(\theta)$, reproduced from the model parameters θ ; W^{-1} is the positive definite weight matrix of order u by u , where $u = (P+q)(P+q+1)/2$. These weights are estimates of the fourth-order moments (the variances of the covariances).

The direct effects in the SEM model are given by the parameters of the \mathbf{B} and Γ matrices and can be interpreted in the same way as regression coefficients (27). For an identified SEM model the total effects of the exogenous variables on the endogenous variables are given by $(\mathbf{I} - \mathbf{B})^{-1}\Gamma$ and the total effects of the endogenous variables on one another are given by $(\mathbf{I} - \mathbf{B})^{-1} - \mathbf{I}$ (20), they are deducted from the general model expression solved in order to y (27). The indirect effects are given by the differences between the total and direct effects.

4. ESTIMATION RESULTS DISCUSSION

The model estimation results are presented in the following way first the direct effects between exogenous and endogenous variables (matrix gamma), then the direct effects between endogenous variables (matrix beta). The total effects between land use variables and the other endogenous variables are presented next.

The estimated model shows a good fit. The value of chi squared statistic is 100.15, with 104 degrees of freedom. The ratio between these two values means that the differences between the population covariance matrix and the model implied

covariance matrix are small. An acceptable goodness of fit is obtained when this ratio is smaller than 2 and very good fit when it is close to 1 (32, 33). Also the standard Bayesian criteria (AIC and CAIC) indicate that this model is superior either to the independence or the saturated models.

TABLE 3 Gamma matrix direct effects between endogenous and exogenous variables

	Age	Gender (1 if man)	Low income	Medium income	High income	Household size	Average age	Household with 2	N° teens
Time spent between first and last trips		0.107	-0.040	0.076	0.106	-0.087	-0.182		
		<i>4.115</i>	<i>-3.926</i>	<i>5.043</i>	<i>5.695</i>	<i>-2.404</i>	<i>-3.674</i>		
N° trips non motorized	-0.162			-0.039	-0.037	-0.207		0.167	0.176
	<i>-2.685</i>			<i>-5.373</i>	<i>-3.992</i>	<i>-6.307</i>		<i>5.819</i>	<i>6.532</i>
N° trips transit	0.218	-0.044	0.013		-0.077		-0.199		
	<i>3.854</i>	<i>-2.878</i>	<i>2.276</i>		<i>-8.669</i>		<i>-9.036</i>		
Transit pass								-0.066	
								<i>-2.675</i>	
N° cars		0.113	-0.036		0.180	0.370			
		<i>3.221</i>	<i>-2.345</i>		<i>7.372</i>	<i>14.607</i>			
Log commuting distance	0.758	0.260		-0.037					-0.067
	<i>6.924</i>	<i>10.683</i>		<i>-2.561</i>					<i>-3.085</i>
Employment in a central and denser area	-0.188	-0.133	-0.067	0.093	0.144	-0.225	-0.197	0.053	
	<i>-2.566</i>	<i>-6.044</i>	<i>-7.387</i>	<i>8.239</i>	<i>11.593</i>	<i>-6.481</i>	<i>-3.328</i>	<i>2.132</i>	
Residence in a central and denser area		0.041		0.082		-0.459		0.260	0.257
		<i>2.110</i>		<i>7.152</i>		<i>-14.788</i>		<i>8.870</i>	<i>9.080</i>
Bus supply in the employment area		-0.038	0.033			-0.023		-0.018	
		<i>-23.759</i>	<i>46.627</i>			<i>-31.363</i>		<i>-13.287</i>	
Bus supply in the residence area				0.020	-0.052				
				<i>2.443</i>	<i>-5.726</i>				
Mix	0.085					0.087			
	<i>2.627</i>					<i>8.079</i>			

Note: t-statistics are presented in italic

The direct effects as presented in the gamma matrix are in general in accordance with what would be expected. Men tend to spend more time outside home. Similarly, people with higher levels of income also spend more time outside home. People belonging to older and larger households tend to spend more time at home.

Younger people tend to make more trips by non motorized modes and older people tend to make more transit trips, also being a man reduces the probability of making transit trips. A higher level of income also reduces the probability of making trips by transit and non motorized modes. Being a member of an older household reduces the number of trips by transit. People belonging to larger households also tend to make fewer trips using non motorized modes and households with only two members have a higher probability to make more trips by these modes.

There are no significant direct effects between socioeconomic variables and the number of trips made by car, which means that all the effects from the socioeconomic variables on the number of trips by car are mediated through other endogenous variables.

People in households with two members have a lower probability of having a transit pass.

Households with higher levels of income have a higher probability of having more cars, and also, also bigger households tend to have more cars. Gender also affects the number of cars in the household, since the presence of women in labor market is not as high as the men, although this difference could be considered small.

Being an older man increases the commuting distance, this can be explained by the fact that in American cities the suburbanization and sprawling phenomena are more intense and have occurred for a longer time than in Europe in general and Lisbon in particular. The effects of income show that neither higher or lower levels of income influence directly the commuting distance.

The model results show that land use variables are influenced by the socioeconomic variables, thus revealing the existence of self-selection effects.

The results show that younger women tend to work more in denser and central areas. Also people with medium and higher levels of income and belonging to smaller and younger households tend to work in this type of areas.

Men belonging to smaller households and with medium income levels tend to reside in more dense and central areas.

Women with lower income levels and belonging to smaller households tend to work more frequently in areas better served by bus.

The direct effects of socioeconomic variables in the levels of transit supply in the residence area are mainly those of income. Higher levels of income have a negative impact and medium levels of income have a positive one.

In Mix, only age and the household size have a significant impact, being both positive.

These results show that in a general way younger and richer people tend to work in more central areas, which also belong to smaller households. In addition, people living in more central areas tend to belong to smaller households. This is what one would expect as a description of urbanites.

These results show that people with generally lower levels of car availability either by gender or income tend to locate their residence and search for employment in areas better served by public transport.

TABLE 4 Matrix beta direct effects among endogenous variables

	Transit pass	N° cars	Log commuting distance	Employment in a central and denser area	Residence in a central and denser area	Bus supply in the employment area	Bus supply in the residence area	Mix
Time spent between first and last trips	0.093		0.224					
	<i>4.310</i>		<i>2.451</i>					
N° trips non motorized	0.293							
	<i>8.055</i>							
N° trips transit	0.519			0.172	-0.082			
	<i>10.049</i>			<i>3.938</i>	<i>-3.532</i>			
N° trips car	-0.385			0.175		-0.019		
	<i>-14.377</i>			<i>3.788</i>		<i>-4.579</i>		
Transit pass		-0.295	0.129	0.382	0.248	-0.034		
		<i>-9.481</i>	<i>7.154</i>	<i>10.051</i>	<i>10.705</i>	<i>-14.465</i>		
N° cars				-0.095		-0.017		-0.073
				<i>-3.995</i>		<i>-6.109</i>		<i>-3.345</i>
Log commuting distance		0.116		0.510		0.013	-0.070	
		<i>3.861</i>		<i>8.833</i>		<i>4.928</i>	<i>-4.234</i>	
Residence in a central and denser area			-0.254					
			<i>-9.823</i>					
Bus supply in the residence area		-0.044						
		<i>-3.971</i>						

Note: t-statistics are presented in italic

The direct effects between pairs of endogenous variables show in general the confirmation of the following hypotheses:

- Land use variables affect directly travel behavior;
- Generally the relations between travel behavior variables are consistent with the hypothesis that long term decisions condition shorter term ones;
- Land use variables are also directly influenced by travel behavior variables.

The time spent between the first and last trips is positively influenced by the commuting distance and by the possession of a transit pass. Having a transit pass also influences negatively the number of trips by car and positively all the others, meaning the existence of some levels of complementarity between transit and non motorized modes.

The number of trips using transit is also positively influenced by the land use factor employment in a denser and central area and negatively by the factor residence in a central and denser area, probably meaning that people residing in a place with a high score in this factor might use non motorized modes more than transit, presumably due to the distances involved between activity opportunities.

The number of trips by car is negatively influenced by the transit supply levels in the area of employment and positively by the factor employment in a denser and central area. Although this direct effect might appear as contrary to what might be

expected this could be at least partly a compensation effect due to the fact that this factor influences positively the probability of having a transit pass. Nevertheless the number of cars in the household is influenced by the income levels as is also the land use factor employment in a central and denser area. This could mean that although density and centrality could act as a deterrent to car ownership levels, the levels of income combined with the fact that public transport in Seattle is mainly built around a bus network (although for some commuters ferry is also a possibility but for the suburbs) could act as an impediment to a more widespread use of public transport by people working in central locations.

The ownership of a transit pass is negatively influenced by the number of cars in the household, and the levels of bus supply in the employment area. This variable is positively influenced by the commuting distance and by the residence and employment in central and denser areas.

The number of cars in the household is negatively influenced by the land use factors employment in a denser and central area, bus supply in the employment area and mix.

The commuting distance is positively influenced by the number of cars in the household, by the employment in a denser and central area and by the bus supply in the employment area. These effects are consistent with the hypothesis of a more intense suburbanization of the population being the employment more centralized.

Two land use factors are directly affected by travel behavior variables. One is the residence in a denser and central area, which is negatively influenced by the commuting distance, and the other is the bus supply in the residence area which is negatively influenced by the number of cars in the household. People who prefer to live closer to their workplace tend to choose more central and denser locations and people who prefer to own less cars tend to locate their residence in a place better supplied with public transport.

The total effects between endogenous variables are presented in the next table.

TABLE 5 Total effects among endogenous variables

	Transit Pass	N° cars	Log commuting distance	Employment in a central and denser area	Residence in a central and denser area	Bus supply in the employment area	Bus supply in the residence area	Mix
Time spent between first and last trips	0.093 <i>4.310</i>	0.000 <i>0.002</i>	0.230 <i>2.545</i>	0.153 <i>3.413</i>	0.023 <i>4.011</i>	0.000 <i>-0.141</i>	-0.016 <i>-2.218</i>	0.000 <i>-0.002</i>
N° trips non motorized	0.293 <i>8.055</i>	-0.084 <i>-6.214</i>	0.019 <i>3.720</i>	0.130 <i>6.177</i>	0.073 <i>6.435</i>	-0.008 <i>-7.081</i>	-0.001 <i>-2.839</i>	0.006 <i>2.980</i>
N° trips transit	0.519 <i>10.049</i>	-0.146 <i>-7.166</i>	0.055 <i>4.917</i>	0.412 <i>11.075</i>	0.046 <i>1.917</i>	-0.014 <i>-8.420</i>	-0.004 <i>-3.216</i>	0.011 <i>3.052</i>
N° trips car	-0.385 <i>-14.377</i>	0.111 <i>8.667</i>	-0.026 <i>-3.974</i>	0.005 <i>0.117</i>	-0.096 <i>-9.005</i>	-0.008 <i>-2.057</i>	0.002 <i>2.893</i>	-0.008 <i>-3.167</i>
Transit pass		-0.287 <i>-9.325</i>	0.066 <i>3.996</i>	0.443 <i>13.143</i>	0.248 <i>10.705</i>	-0.028 <i>-14.093</i>	-0.005 <i>-2.905</i>	0.021 <i>3.181</i>
N° cars				-0.095 <i>-3.995</i>		-0.017 <i>-6.109</i>		-0.073 <i>-3.345</i>
Log commuting distance		0.120 <i>3.968</i>		0.498 <i>8.627</i>		0.011 <i>4.407</i>	-0.070 <i>-4.234</i>	-0.009 <i>-2.540</i>
Residence in a central and denser area		-0.030 <i>-3.498</i>	-0.254 <i>-9.823</i>	-0.127 <i>-6.641</i>		-0.003 <i>-3.992</i>	0.018 <i>3.830</i>	0.002 <i>2.402</i>
Bus supply in the residence area		-0.044 <i>-3.971</i>		0.004 <i>2.941</i>		0.001 <i>3.455</i>		0.003 <i>2.553</i>

Note: t-statistics are presented in italic

The total effects from the land use factors to the travel behavior variables show the existence of significant influences of land use patterns on travel behavior. It is possible to see that land use patterns affect negatively the levels of car ownership, thus people working in more central, denser and mixed areas and with higher levels of transit availability tend to own fewer cars.

The effects of land use patterns on the probability of owning a transit pass are more complex. People living and working in more central, denser and mixed areas tend to have a higher probability of owning a transit pass. On the contrary the levels of bus supply have negative total effects, although with a much lower level of magnitude.

The total effects of land use factors on the number of trips show that density and centrality both at residence and employment areas increases the number of trips in transit and in slow modes. The effects on the number of trips by car are negative in the case of land factor residence in a denser and central area and not significantly different from zero in the case of the land use factor employment in a denser and central area. The variable mix influences negatively the number of trips by car and positively the number of trips by other modes. The levels of bus supply both at residence and employment locations tend to influence negatively the number of trips by every mode, with the exception of bus supply in the residence area which has a positive effect on the number of trips by car.

The effects of land use patterns on the time spent between the first and last trip go also in two directions, the residence and employment in denser and central areas

influences positively this trip scheduling variable and the levels of bus supply in the residence areas influence it negatively.

5. COMPARISON WITH THE LISBON MODEL AND CONCLUSIONS

One of the main objectives for building this model was to compare its results with a similar model built for the Lisbon Metropolitan Area (1). This comparison is presented mainly in terms of models assumptions global structure and results since the variables used in both models are not the same due to different data availability in the two areas studied.

The global structure was similar in both models with the small difference that the Lisbon Model also included the number of kilometers travelled by mode.

Other more important differences in both models were related with the number and breadth of land use variables which in the Lisbon model was vaster.. Other differences are related with the fact that in the Lisbon Model land use variables were mainly built at the zone level.

The results obtained in both models point to similar global conclusions. People with different socioeconomic characteristics and income levels tend to work and live in places of different urban environments. Also land use patterns in the areas of employment or residence are influenced by travel behavior variables which could be explained by the fact that travel behavior is among other things the visible result of personal preferences and lifestyles.

But the main point might be that in both models land use variables affect travel behavior in a significant way, thus giving weight to the argument of using land use measures as an another available and effective policy tool to change travel behavior.

More precisely both models show that the effects of land use are in great part passed thru variables describing long term decisions like commuting distance, car ownership and pass ownership.

But in here are differences between both models. In the Lisbon Model the car ownership is a function of pass ownership, but in Seattle is the other way around.

In the Lisbon Model the number of trips by mode is a function of car ownership and transit pass ownership and also they are a function of one another, an evidence of competition between modes. In the present model the number of trips by mode has only direct effects from transit pass ownership. There is no evidence of direct competition between modes. In terms of the total effect from transit pass and car ownership they tend to have the same signal.

The direction of total effects from commuting distance on the number of trips by mode is different in both models. In Lisbon the commuting distance affects positively the number of trips by car and transit and negatively the number of trips by non-motorized modes. In Seattle the results are different. The commuting distance affects positively the number of trips by transit and non-motorized modes, and negatively the number of trips by car.

Regarding the total effects of land use, although the results cannot be directly compared, it can be concluded that the results tend to generally point to the same conclusions, summarized in the following way:

- Living and working in central, denser and mixed areas tends to have a positive effect on the number of trips by non-motorized modes, and increasing the chances of owning a transit pass;
- Living in denser, central and mixed areas tends to reduce the number of car trips and the car ownership levels in the household;
- Working in central and denser areas tends to increase the commuting distance, which is a sign of the polarizing power that the centre of both metropolitan regions have, attracting people living in suburban and exurban areas.

Regarding this last effect it can also be seen that in the Seattle Model the total effects of car ownership on commuting distance are positive, contrary to what was found in Lisbon. This can be explained by the fact the public transport network and particularly the regional rail network in Lisbon is much more developed than the one in Seattle which relies mainly on a bus network with ferries mainly serving a few specific locations. Thus for people living in the suburbs and working in the centre of Lisbon public transportation is a more convenient option when compared to Seattle. This fact points to the importance of public transport supply levels together with land use patterns.

Regarding socioeconomic variables both models stress the impact that income has on travel behavior. Both models show that higher levels of income tend to have a positive effect on the commuting distance and on the car ownership levels. The total effects of income on transit pass ownership are different. In Lisbon there is a negative relationship with income and in Seattle that relationship is positive but not significant.

As a final conclusion it can be stated that the results presented in this model are strong evidence in favor of using land use regulation and land use change as a tool to change travel behavior. It should also be added that the impact of these policies will be different depending on local circumstances. It is still not known, however, if the commonalities and differences between the two metropolitan areas here are due to local peculiarities of generally valid relationships. This motivates the expansion of this study to other locations and the repetition of the analysis using variables measured at the same scale and with the same content.

Acknowledgements

The authors would like to thank Seo Youn Yoon a Ph.D. student at the University of California Santa Barbara for her contribution in the data gathering to this study. The Puget Sound Regional Council is also acknowledged for providing the data.

REFERENCES

- (1) Abreu e Silva, João, Golob, Thomas F. and Goulias, Kostadin G.. The effects of land use characteristics on residence location and travel behavior of urban adult workers. In *Transportation Research Record: Journal of the Transportation Research Board* N° 1977, Transportation Research Board of the National Academies, Washington, D.C., 2006, pp 121-131.
- (2) Newman, Peter and Kenworthy, Jeffrey. *Cities and automobile dependence, an International Sourcebook*. Gower Technical, Aldershot, 1989.
- (3) Giuliano, Genevieve. *New Directions for Understanding Transportation and Land Use, Environment and Planning A*, vol 21, 1989, pp 145-159,.
- (4) Giuliano, Genevieve. *The Weakening Transportation-Land Use Connection*, *Access*, n° 6, 1995, pp 3-11.
- (5) Newman, Peter, Kenworthy, Jeffrey and Vintila, Peter. Can we overcome automobile dependence? *Physical Planning in an age of urban cynicism*. *Cities*, vol. 12, n° 1, 1995, pp 53-65.
- (6) Neuman, Michael. *The Compact City Fallacy*. *Journal of Planning Education and Research*, 25, 2005, pp 11-25.
- (7) Gomez-Ibañez, José A.. *A Global View of Automobile Dependence*. *Journal of the American Planning Association*, Summer 1991, 1991, pp 376-379.
- (8) Gordon, Peter and Richardson, Harry W.. *Are Compact Cities a Desirable Planning Goal?*, in *Environment Land Use and Urban Policy*, David Banister, Kenneth Button e Peter Nijkamp (eds.), Edward Elgar, Cheltenham, 1999.
- (9) Boarnet, Marlon G. and Crane, Randall. *The influence of land use on travel behavior: specification and estimation strategies*. *Transport Research Part A*, 35, 2001, pp 823-845
- (10) Crane, Randall. *The Influence of Urban Form on Travel: An Interpretative Review*. *Journal of Planning Literature*, vol. 15, n° 1, 2000, pp 3-23.
- (11) Handy, Susan. *Methodologies for exploring the link between urban form and travel behavior*, *Transportation Research Part D*, vol. 1, n° 2, 1996, pp 151-156.
- (12) Cervero, Robert. *Built environments and mode choice: toward a normative framework*. *Transportation Research Part D*, n° 7, 2002, pp 265-284.
- (13) Van Wee, Bert. *Land Use and transport: research and policy challenges*, *Journal of Transport Geography*, 10, 2002, pp 259-271.
- (14) Miller, Eric J.. *Land Use Transportation Modeling*. In *Transportation Systems Planning, Methods and Applications*. Kostadin G. Goulias (ed), CRC Press, Boca Raton, 2003.
- (15) Handy, Susan. *Critical Assessment of the Literature on the Relationship among Transportation, Land Use and Physical Activity*, prepared for the Transportation Research Board and the Institute of Medicine Committee on Physical Activity, Health, Transportation and Land Use, 2004, <http://trb.org>, accessed in November 2004.

(16) Cervero, Robert (2003), *The Built Environment and Travel: Evidence from the United States*, *European Journal of Transport and Infrastructure Research*, 3, n° 2, pp 119-137.

(17) Bagley, Michael N. and Mokhtarian, Patricia. *The impact of residential neighborhood type on travel behavior: A structural equations modeling approach*. *The Annals of Regional Science*, n° 36, 2002, pp 279-297.

(18) Krizek, Kevin J.. *Planning, Household Travel, and Household Lifestyles*. In *Transportation Systems Planning, Methods and Applications*, Kostadinou G. Goulias (ed), CRC Press, Boca Raton, 2003.

(19) Stead, Dominic and Marshall, Stephen. *The Relationships between Urban Form and Travel Patterns. An International Review and Evaluation*, *European Journal of Transport and Infrastructure Research*, 1, n° 2, 2001, pp 113-141.

(20) Golob Thomas F.. *Structural equations modeling for travel behavior research*, *Transportation Research, Part B*, Vol 37, n° 1, 2003, pp 1-25.

(21) Golob, Thomas F.. *Structural equation modeling*, in *Transportation Systems Planning. Methods and Applications*, K.G. Goulias (ed.), CRC Press, Boca Raton, 2003.

(22) Goulias K.G., N. Kilgren, and T. Kim. *A decade of longitudinal travel behavior observation in the Puget Sound region: sample composition, summary statistics, and a selection of first order findings*. Presented at the 10th International Conference on Travel Behavior Research, *Moving through nets: The physical and social dimensions of travel*, Lucerne, 2003.

(23) Goulias K.G., L. Blain, N. Kilgren, T. Michalowski, and E. Murakami. *Catching the Next Big Wave: Are the Observed Behavioral Dynamics of the Baby Boomers Forcing us to Rethink Regional Travel Demand Models? Final Report Submitted to the Federal Highway Administration and the Puget Sound Regional Council*, Santa Barbara, CA, 2006.

(24) Goulias K. G., L. Blain, N. Kilgren, T. Michalowski, and E. Murakami (2007) *Catching the Next Big Wave: Are the Observed Behavioral Dynamics of the Baby Boomers Forcing us to Rethink Regional Travel Demand Models?* In *Transportation Research Record: Journal of the Transportation Research Board* N° 2014, Transportation Research Board of the National Academies, Washington, D.C., 2007, pp 67-75.

(25) Domencich, Thomas A. and McFadden, Daniel. *Urban Travel Demand. A behavioral analysis*. North-Holland, Amsterdam, 1975.

(26) Kockelman, Kara Maria. *Travel Behavior as a function of accessibility, land use mixing, and land use balance: Evidence from the San Francisco Bay Area*. University of California, Berkeley, Master Thesis, 1996, www.ce.utexas.edu, accessed in April 2005.

(27) Kaplan, David. *Structural Equation Modeling. Foundations and Extensions*. Sage Publications, Thousand Oaks, 2000.

(28) Muthén, Bengt. *A Structural Probit Model with Latent Variables*. *Journal of the American Statistical Association*, vol. 74, n° 368, 1979, pp 807-811.

(29) Muthén, Bengt. A general structural equation model with dichotomous, ordered categorical, and continuous latent variable indicators. *Psychometrika*, vol. 49, n° 1, 1984, pp 115-132.

(30) Golob, Thomas F. and Regan, Amelia. Trucking industry adoption of information technology a multivariate discrete choice model, *Transportation Research Part C*, vol 10, 2002, pp 205-228.

(31) Jöreskog, Karl and Sörbom, Dag. LISREL® 8: User's Reference Guide. SSI Scientific Software International, Lincolnwood, 2001.

(32) Jöreskog, Karl and Sörbom, Dag. LISREL® 8: Structural Equation Modeling with the SIMPLIS Command Language. SSI Scientific Software International, Lincolnwood, 1993.

(33) Schermelleh-Engel, Karin, Moosbrugger, Helfried and Müller, Hans. Evaluating the Fit of Structural Equation Models: Tests of Significance and Descriptive Goodness-of-Fit Measures, *Methods of Psychological Research Online* 2003, vol. 8, n° 2, pp 1-22, University of Koblenz-Landau, www.mpr-online.de, accessed in June 2005.