# URBAN FORM AND TRAVEL PATTERNS
# AN APPLICATION TO THE METROPOLITAN AREA OF BORDEAUX

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## ABSTRACT

The influence of urban form on travel patterns is of growing interest among researchers. It has been notably argued that high density, mixed land use settlements reduce automobile use and distances travelled, hence energy consumption per capita. A precise characterization of urban form calls analysis at an infra-urban level. To analyse the interaction between land use and mobility, we propose a conceptual framework linking mobility patterns, urban form and economic and/or demographic characteristics in a « triangular relationship ». This study aims at determining the factors of urban daily travel in the metropolitan area of Bordeaux (France), by using OLS regressions for usual transportation variables and a multinomial logit model for modal shares.

The results confirm a strong influence of both residential and firm density on mobility patterns. Mixed land use patterns doesn't seem to influence mobility. Some economic and demographic characteristics have an influence on travel patterns, and it is unavoidable to take them in account. The strong interdependence between variables, and the difficulty to determine the direction of the causal relationships shows the strong degree of complexity of the problem. In the context of land use policies aiming at influencing mobility behaviours, this complexity must be accounted for to give these measures a full efficiency.

***Keywords*** : urban sprawl, urban form, density, compact city, land use – mobility interaction

***JEL classification*** : R12, R14, R41

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## RESUME

Dans le cadre du développement urbain durable, l'influence de la forme urbaine sur la mobilité prend un relief particulier. Les fortes densités et la mixité dans l'usage des sols réduiraient l'usage de l'automobile et les distances parcourues, diminuant ainsi la consommation énergétique individuelle. La caractérisation précise de la forme urbaine appelle une analyse au niveau intra-urbain. Pour étudier l'interaction entre l'usage du sol et la mobilité, nous proposons un cadre conceptuel reliant les modalités de déplacement, la forme urbaine et les caractéristiques économiques et/ou démographiques des individus, cadre appelé « interaction triangulaire ». Cet article vise à déterminer les facteurs de la mobilité urbaine quotidienne dans l'aire métropolitaine de Bordeaux (France), en utilisant des régressions par les MCO pour les variables habituelles de mobilité et un modèle logit multinomial pour les parts modales.

Les résultats confirment l'influence des densités sur les comportements de mobilité, mais ne nous permettent pas de conclure quant à l'influence de la mixité. La prise en compte d'indicateurs économiques et démographiques, dont l'influence sur la mobilité est avérée, conduit l'analyse à une indétermination logique. La forte interdépendance des variables et la difficulté à déterminer le sens de la relation causale procurent un fort degré de complexité au problème. Dans le contexte de politiques d'usage du sol visant à influencer les comportements de mobilité, cette complexité doit être prise en compte afin de donner une pleine efficacité à ces mesures.



***Mots-clés*** : étalement urbain, forme urbaine, densité, ville compacte, interaction mobilité-usage du sol

***JEL classification*** : R12, R14, R41

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> « *Les déplacements résultent de l'agencement urbain (…). L'inverse est aussi vrai, c'est-à-dire que l'agencement urbain résulte des « conditions » de la mobilité (…). Nous sommes dans un système interactif où le plus permanent – le construit – et le plus éphémère – la mobilité – se modèlent en permanence l'un l'autre, suivant un processus évolutif à la fois global (tout interagit sur tout) et continu (inscrit dans le durée). Cette réciprocité (…) est constitutive du fait urbain lui-même ».*
>
> *« Trips result from urban layout (…). The opposite is true too, that is urban layout result from the « conditions » of mobility (…). We are in an interactive system where what is the most permanent – the buildings – and what is the most ephemeral – the mobility – shape permanently each other, following an evolutive process which is overall (everything interacts on everything) and continuous (it comes within the scope of duration). This reciprocity (…) builds up the concept of city. »* (translation made by the author)
>
> M. WIEL, *Ville et Automobile*, 2001

## INTRODUCTION

Sustainable development is a normative framework which has justified to bring under control the negative externalities of economic growth, such as pollutions due to transport (Hart, 2002). This concern has led to question the role of the automobile in trips, as it is the most polluting mode. To date various policies have been implemented to reduce automobile use, ranging from coercitive to incitative interventions.

As the theorem of the locality states, cities appear as an efficient scale to promote sustainability policies (Camagni, Capello & Nijkamp, 1998, 109-110). Amongst these policies, the planning of urban growth has received particular attention. Indeed, urban sprawl and car use are interrelated : on the one hand, the democratization of the automobile has brought about suburbanization, by increasing speed and allowing the city to spread (LeRoy & Sonstelie, 1983) ; on the other hand, the concept of *automobile dependence* (Dupuy, 1999) points out the necessity of owning an automobile in recently urbanized, low density areas (Newman, Kenworthy & Vintila, 1995).

The model of the « compact city » aims at thwarting the cities' tendency to spread out (Jenks *et al.*, 1996). Compacification measures (such as urban containment) are seen as an efficient way to reduce automobile use, and hence pollution, in cities. The compact city has been underlying planning policies of numerous countries in Western Europe (Netherlands – van der Walk, 2002 ; Great Britain – Breheny, 1995 ; France, Law on a rational use of energy (LAURE) in 1996 and SRU law in 1999[1]). As shown by the case of London, numerous european cities have adopted special measures to struggle against automobile use. It includes a strong commitment in land planning (*2001 Plus*, 2002) ; in Bordeaux for example, the PDU[2] aims at « having an effect on the evolution of urban morphology [so that] automobile use and its foreseeable growth could be limited (C.U.B, 2000, 31, *translation made by the author*).

The underlying issue is more generally the exploration of the link between transportation and land use. If town planning is an appropriate tool to reduce the use of automobile in cities, then we must know by which means urban form affects travel patterns[3]. Urban form is the way people use urban land : it is « the spatial location of the urban components seems like pawns which could form a shape on a chessboard but their meaning could only lie in the interrelation existing between them » (Wiel, 2001, p.22, *translation made by the author*). Its outward sign is the spatial distribution of people and functions in the urban area. The way it is generally measured includes densities, degree of land use mix, etc.

The purpose of this paper is to bring a contribution to the debate on the interaction between urban form and travel behaviour. It is based on an study of daily travel in the metropolitan area of Bordeaux, France.

[1] Solidarity and Urban Renewal law, which includes a specific zoning aiming at restricting urban sprawl.
[2] *Plan de déplacements urbains* (urban travels planning guidance), a town planning document.
[3] By « travel pattern » is meant the way people travel daily in the city.

The analysis of the determinants of travel patterns usually combines two main sets of factors : urban form, and economic and demographic characteristics. By applying this conceptual framework to data on Bordeaux, this study gives results concerning the influence of urban form and individuals' characteristics on mobility. Nevertheless, some complex interactions between travel patterns, land use and economic and/or demographic characteristics prove to be logical indecisions, making difficult a search of the factors of daily travel.

The structure of this paper is as follow : the first section gathers information from past research findings dealing with the land use-mobility linkages. This short survey allows to build a conceptual framework and a methodology which is applied to data on Bordeaux. In the second section main results are presented.

# 1. The interaction between urban form and mobility

## 1.1. The advantages of density

### *1.1.1. Past research findings*

The link between sprawl and automobile use is illustrated by the Newman and Kenworthy's curve (Newman & Kenworthy, 1989). They used a global comparative study of thirty-two cities to show a reverse relationship between urban density and gasoline use per capita. As sprawl appears as a decrease of urban densities (Barcelo, 1993 ; Ewing, 1997) or as a flattening of the density gradient (Mills, 1972 ; Peguy, 2000), it is generally concluded that it is a « dispendious form » of urban growth (Downs, 1994).

The Newman and Kenworthy's curve has been confirmed by some studies during the 1990's : P. Naess (1996) shows a positive relationship between floorspace per capita and gasoline use per capita in twenty-two norvegian cities ; updating his seminal work, J.R.

Kenworthy with F. B. Laube (1999) show an overconsumption of gasoline in low-density cities.

Moreover, the link between density and energy use per capita seems to be valid at an intra-urban scale. On the basis of a rough division of the New York region, P. Newman and J. Kenworthy (1989) find obvious differences in gasoline consumption with density. In Great Britain, M. Breheny (1995) finds differences in gasoline consumption according to the size of city. V. Fouchier (1997) brings to the fore the influence of different kinds of densities[4] on daily energy consumption per capita in the cities of *Ile-de-France* (the region surrounding Paris), and J.-P. Nicolas *et alii* (2001) obtain similar conclusions in the metropolitan region of Lyon (France), noticing important differences in polluting emissions between the traditional center, the inner city and the outer city.

#### *1.1.2. Theoretical justifications*

These empirical relationships have to be justified on a theoretical basis. The underlying idea is that high density settlements represent a « hostile milieu » (with the words of A. J. Scott) for the automobile. It appears that high densities allow :

- Shorter trips (Fouchier, 1997 ; Levinson & Kumar, 1997)[5], as there are more destinations available at a given distance of the origin of the trip ;
- A more efficient transit (Emangard, 1994 for an analysis of the greater French cities ; Kenworthy & Laube, 1999 for a global cost comparison) ;
- An easier modal split towards « soft » ways of travelling like transit and/or walking (Burton, 2000 ; Frank & Pivo, 1994).

[4] He underlines the importance to take into account not only residential density, but also job density. He proposes a synthetic indicator of land occupation : the « human density » is simply the sum of residential and jobs densities (Fouchier, 1997)

[5] As Le Corbusier wrote in 1925 : « the higher urban density is, the shorter distance to cover is » (Le Corbusier, 1994, *translation made by the author*).

These justifications are complemented by a historical analysis of the shaping of cities in relation to transportation conditions. The main idea is that the greater speed and freedom of the automobile (at low cost) has profundly modified the urban form, emphasizing urban sprawl.

The link between urban form and transportation technology lies upon the stability of the travel durations over times in cities, the so-called « Zahavi law ». Indeed, studies have shown that the average commuting time is remarkably stable for about a century (Zahavi & Ryan, 1980) and lasts about half an hour (Levinson & Kumar, 1994 ; Purvis, 1994 ; Fouchier, 1997). This hypothesis is used as a basis to determine the shape of the cities according to the dominant transportation mode (Dupuy, 1995 ; Newman & Kenworthy, 1998 ; Wiel, 1999, 2002, 46 ; Vijayan, 2002, 7). Three types of cities are considered :

**The Walking City** : traditional walking city is scarcely larger than 5 kilometers. It is very compact and features mixed uses of land. It usually constitutes the historical center of old cities. It inspires realizations such as « urban villages » which tend to re-create the conditions of the walking cities (OCDE, 1994).

**The Transit City** : the transit technology (first horse-drawn, then steam and electric) allows city to spread as far as twenty to thirty kilometers away from the traditional center. The transit city has a « finger plan » as it extends along radial rail lines. This form inspires the *Transit-Oriented Development* patterns (Laliberté, 2002) and the *network polycentric model* (Camagni & Gibelli, 1997), which try to organize further urban development around transit nodes to facilitate transit use, especially for long distances.

The **Automobile City** : the automobile made it possible for the city not only to spread as far as fifty kilometers from the center, but also to extend itself in all directions, filling in available spaces between mass transit lines. The urbanization has become « isotropic » (Tabourin, 1995). Low density settlements are made possible ; furthermore, principles of the

Modern Movement (CIAM, 1933) establish zoning patterns, a separation between the different urban activities.

Today's cities are a juxtaposition of these three types (Wiel, 1999). In this descriptive scheme, the emergence of the automobile as the dominant transportation mode has shaped an « car city », which in turn has created an « automobile dependence », compelling people to use their cars because of its low density and zoning patterns. The consequences in terms of gasoline consumption are obvious (Newman & Kenworthy, 1998, 33, table 2.1).

Nevertheless, the link between urban density and energy consumption has been questioned. Critics have been raised about the validity of the very relationship between urban density and energy consumption (e.g. Gordon & Richardson, 1997) as well as about the feasability of compaction measures (Breheny, 1997 ; Gordon & Richardson, 1989 ; Southworth, 2001). These critics underly the necessity to go further than an argument on advantages and drawbacks of high densities, which has long been disputed in the history of urban planning (Choay, 1965).

The underlying question is how urban form influences travel behaviour. What is at stake is to characterize more precisely urban form, which implies to reduce the scale of analysis. But other factors influence urban mobility ; taking them in account leads to formulate a conceptual framework for researching into the causes of specific travel patterns.

## 1.2. A search for the determinants of urban mobility

### *1.2.1. The characterization of urban form and its link with urban mobility*

The exploration of the link between travel and urban form is the subject of more than fifty recent empirical studies (Ewing & Cervero, 2001 for a survey), which shows a great interest in this field amongst urban researchers. They differ in the methodology used, ranging from aggregate approaches to analysis of individual data (Handy, 1996 for a methodological survey).

The necessity to get over the opposition between high and low density has led to characterize urban form more precisely. New variables are introduced, such as :

1) The degree of land use mix between dwellings and workplaces.

It has been suggested that zoning generates « tunnel effects » which increase trip lengths (OCDE, 1994). *A contrario*, mixed land use patterns should bring residential location closer to the workplaces (Wiel, 2001). There is no real consensus about what is land use mix :

- For L. D. Frank and G. Pivo (1994), it is the variety of activities within a given area. They use an entropy index to measure it. This index has a significant influence on work trips (negative for car use, and positive for walk and bicycle use), but not on non-work trips.
- For R. Camagni *et alii* (2002), land use mix is the jobs-housing balance. In the province of Milano, it proves to be negatively related to the « mobility impact », which measures the environmental impact of daily travels.

2) Number and type of jobs.

The aim is to distinguish retail jobs from service or manufacturing jobs, as it is generally assumed they don't have the same influence on travel behaviour. Yet M. G. Boarnett and S. Sarmiento (1998) find no significant relationship between retail density or service density and number of non-work automobile trips. Nevertheless, it seems that this kind of analysis is quite rare, and results have still to be found.

The interaction between land use and mobility is biased by different kinds of « trip generators », most notably employment subcenters. In their study of the San Francisco Bay

Area, R. Cervero and K.-L. Wu (1998) find that the largest increase in VMT (vehicle-miles travelled) occured in the fastest growing and most remote subcenters.

3) Various urban design features.

- Local street configuration : K. J. Krizek includes street connectivity in the calculation of an index of neighbourhood accessibility (NA). He notices that in the Puget Sound metropolitan area, NA affects negatively the change in VMT, the change in PMT (persons-miles travelled) and the number of tours.
- Parking facilities : in a study of the travel behaviour of employees of six companies in Greater Oslo, P. Naess and S. L. Sandberg (1996) find an increase in energy use per capita with distance to downtown Oslo. It could be explained by parking conditions both at the origin and the destination of the trip, which influence modal choice.
- The type of housing : as in the seminal research of the RERC on the costs of sprawl (RERC, 1974), we can suppose differences in mobility patterns according to the type of housing ; R. Camagni *et alii* (2002) find two out of ten patterns of urban expansion (that is, extension/linear and infilling/extension) to have a negative influence on the environmental impact of urban mobility.

These studies show that - more than the critics on the validity of global comparisons of cities, which state the logical impossibility to compare cities from different countries (Gordon & Richardson, 1989 ; Gomez-Ibañez, 1991) - the need for a more precise characterization of the urban form has led to a reduction of the pertinent scale of analysis (for example, it seems difficult to measure the degree of land use mix at a metropolitan scale). It is generally assumed that « within a relatively homogenous area (…), the local differences in mobility patterns can, at least to a lesser extent, be attributed to the form in which urban growth has occured » (Camagni *et al*., 2002, 206). Thus the interaction between urban form and travel is generally analyzed at the infra-urban scale.

The New Urbanism movement tends to be inspired by these results to design neigbourhoods that reduce automobile use and improve the quality of life. This can be reached by planning « compact, pedestrian-friendly and mixed-use neighbourhoods », with « interconnected street network », and « concentrations of civic, institutionnal, and commercial activities (…) embedded in neighbourhoods and districts » (C.N.U, 2001). As such, New Urbanism is in the continuity of european urban planning principles which have founded the ideal of the « compact city ».

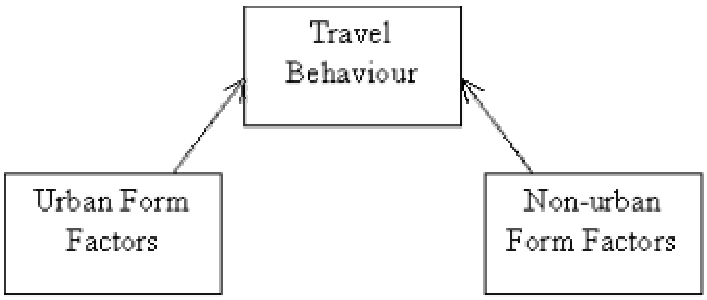
The exploration of the link between mobility and urban form has been enhanced not only by characterizing the urban form more precisely at an infra-urban level, but also by accounting for socio-economic characteristics that may have an influence on travel behaviour.

#### *1.2.2. Taking in account individuals' characteristics : the formulation of a conceptual framework to understand the determinants of daily travel*

Individual economic and demographic characteristics have long been recognized as influencing travel behaviour. Despite the democratization of the automobile in Western Countries, income is still a key factor in being able to afford an automobile and in its use (Jullien, 2002 ; Dieleman *et al*., 2002). Moreover, differences in automobile use (and, more generally, in travel patterns) according to gender, level of education, age, etc. have been noticed many times (e.g. Kauffman *et* al., 2001).

Studies about the link between urban form and mobility have to take these influences in account. Thus economic and demographic variables are « statistically controled », which means they are simply added to the model (Boarnett & Crane, 2001 ; Boarnett & Sarmiento, 1998 ; Frank & Pivo, 1994) or, to avoid multicolinearity problems, tested separately (Dieleman *et al*., 2002 ; Krizek, 2003). The underlying conceptual framework has been proposed by L. D. Frank and G. Pivo (1994 – *figure 1*) : here, the « non-urban form factors » consist of economic and demographic characteristics, individual preferences, etc.

**Figure 1. The conceptual framework : relationships between travel behaviour and factors that affect it**




*Source* : Frank & Pivo, 1994

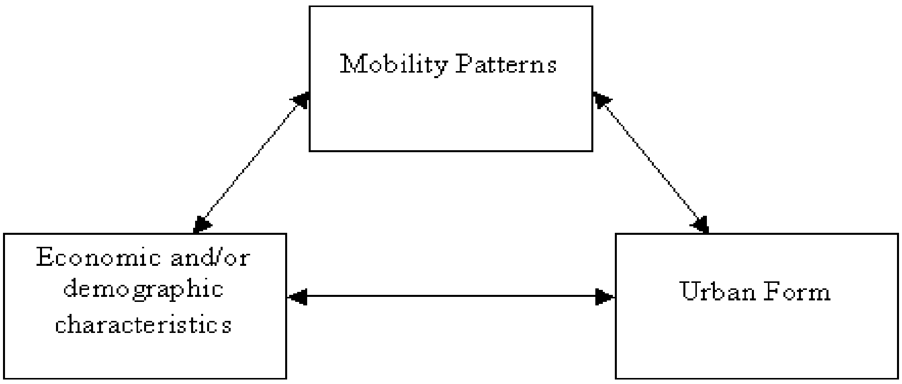
It seems true that economic and demographic variables are important to explain mobility patterns : income of course, but also the size of the household (the number of children has a positive influence on the number of tours in Puget Sound (Krizek, 2003) or on non-work automobile trip frequency in San Diego (Boarnett & Crane, 2001)), the level of education (in Netherlands, M. L. Dieleman *et alii* (2002) show that the highest education is, the lowest car use is), or the gender (for M. G. Boarnett and S. Sarmiento (1998), the proportion of women in the population has a positive influence on the number of non-work automobile trips).

But an important issue is the interaction between urban form and economic and demographic variables. We can't override the fact that the location in the metroplitan area is determined by economic (such as income) or demographic (such as household size) characteristics of the inhabitants, which interacts with individual preferences. So, there will arise a problem of interpretation : even if we accept a relationship between urban form and mobility, how can we know that the underlying causes of this relationship are not based on economic and/or demographic characteristics ? As R. Ewing and R. Cervero (2001) write,

> *« an unresolved issue is whether the impact of density on travel patterns is due to density itself or other variables with which density covaries (central location, good transit service, etc.). [S.] Handy puts this issue this way : 'many studies focus on density, but is it density that matters ? No, probably not. Probably what matters is what goes along with density' ».*

Thus mobility patterns at an infra-urban level are the result of both urban form factors and economic and/or demographic factors, just as economic and/or demographic characteristics interacts with urban form. These complex interactions form a « triangular relationship », as in the following scheme (*figure 2*) :

**Figure 2. The "triangular relationship", an interaction between mobility patterns, urban form and econmic and/or demographic characteristics**




This conceptual framework is of good help to understand urban daily mobility. We investigated this issue within the context of the metropolitan area of Bordeaux (France), a middle-size city of about 800,000 inhabitants. An originality of this work is that, in addition to testing usual factors of travel patterns (the two oblique arrows in figure 2), we try to take in account « what goes along with density » by testing interactions between urban form and economic and/or demographic characteristics (the horizontal arrow in figure 2).

## 2. Determining the motives of mobility in the metropolitan area of Bordeaux

### 2.1. Data and methodology

The *Household Travel Study* (HTS) is a survey about the metropolitan area of Bordeaux aiming at gathering very detailed pieces of information on inhabitants' travel habits. It was conducted in 1998 by the Regional Direction of the INSEE (French Statistics' Office), and concerned 4,869 households.

The area of study is the metropolitan area of Bordeaux, which represents 170,547 ha for 95 *communes* (an equivalent to the county) and has 801,309 inhabitants (343,406 households) and 266,013 jobs (50,279 firms). The studied area was divided in 69 zones of various sizes[6].

We divided the variables in transportation ones, economics and demographics ones, and land use ones to obtain three sets of variables, detailed in the table in annex. In order to determine the factors of urban mobility patterns, different models were tested.

1. The four key **transportation variables** are : trip frequencies (rates of trip making) ; trip lengths (in distance) ; modal split ; and individual number of kilometers travelled per capita, which is a product of the first three[7]. We added car ownership to this set, and per household variables (for trip frequencies and car ownership only), because the

[6] For technical constraints (that is, availability of data), the number of observations was reduced to 66 zones.

[7] They are the four main variables models habitually seek to explain (Ewing & Cervero, 2001). We made also a distinction between the purposes of the trip. Commuting is more regular and modal shift is easier ; at the contrary, many commentators have underlined an increase of the multi-purpose travels, notably for non-commuting purpose (shopping, leisure, etc.) : these trips prompt to automobile use (Gordon & Richardson, 1997).

comparison between per capita and per household variables may allow us to take in account the influence of the size of the household.

2. The **land use variables** were divided in two « land use models » :

    - A general « urban form model », which includes density, mix of uses index, and the jobs' distribution index. Population and firm densities were tested. Following L. D. Frank and G. Pivo (1994), the regressions use *residential* density (RESDENS) for kilometrage made *from* the trip origin zone, and *firm* density (FIRMDENS) for the kilometrage made *towards* the trip destination zone. To measure the degree of land use mix, we calculated a khi-index (KHITOT, which corresponds to the Gary and Pivo's approach mentioned above) and the jobs/housing ratio (JHBAL, which is conform to the Camagni *et alii*'s approach mentioned above). We added a « functional mix index » (FUNCMIX) calculated on the ground of the jobs-housing ratio (see ANNEX for detailed calculation). We distinguished two types of jobs : retail (proximity) and service/manufacturing (others), on the ground of their ability to induce trips, and calculated a khi-index (KHIPROX and KHIOTHER) to evaluate their distribution in a given zone compared to the overall distribution.
    - A « housing type model », which includes the proportion of the four types of housing in total housing (detached isolated houses, clustered houses, low-rise buildings and high-rise buildings), and an indicator of crowding (PEOPROOM, the average number of people per room).

3. The **economic and demographic variables** formed three models. To avoid multicollinearity problems (frequent in cross-section data), three separate models of economic and demographic characteristics were tested[8] :

- a « lifecycle model » : it combines the age (AGE, in years), the level of income (INCOME, in kF), and the level of education (COLLEDUC, proportion of high-educated people) ;
- a « type of population model » : it combines rates of unemployed and retired people (respectively UNEMPL and RETIRED), minors (MINOR), students (STUDENT) and women (SEX) in the total population ;
- a « size model » : it includes household size (HHSIZE, people per household), firm size (JOBFIRM, number of employees per firm), the total population in the zone (POP) and the floorspace per capita (SURFPEOP, in $m^2$).

According to the problematic stated above, we seek to determine the factors of daily travel patterns. The methodology consists in testing separately the two land use models and the three economic and demographic characteristics models. The technique we used is the OLS regression[9]. When the dependent variable is the set of modal shares, as modal shares are the result of a choice, the appropriate technique is a multinomial logit model (De Palma & Thisse, 1987). Such a model rests on the hypothesis of a perfect substituability among travel modes - as if sometimes they are not : for example, in areas where there is no transit supply, or from a given distance threshold (Salomon, 2001).

These regressions are given in tables 1 to 4.

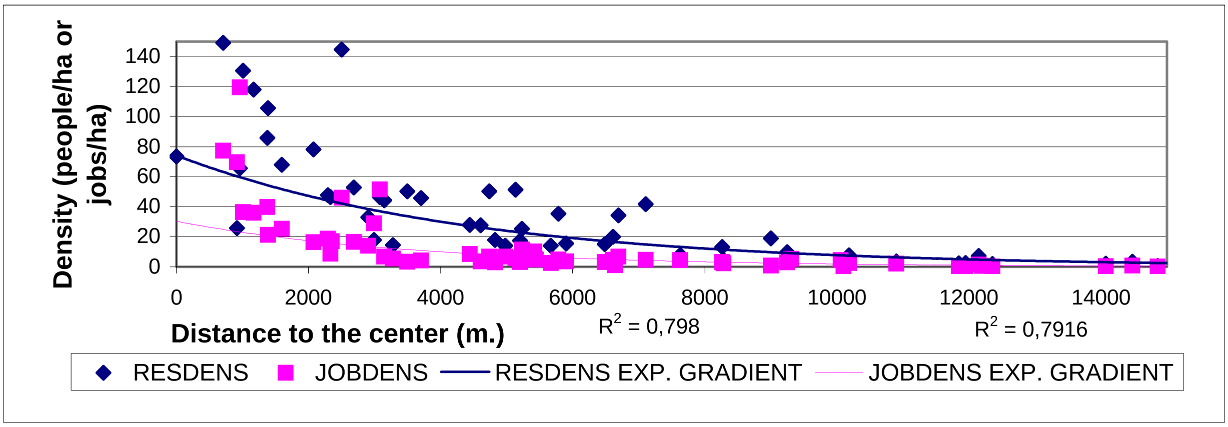
An important issue of this work is to take in account the interaction between the location in a specific urban form and the economic and demographic characteristics, as it

[8] These models were built on the ground of the non significativity (at the 5% level) of the Pearson correlation coefficients.
[9] We used the White correction to avoid problems of heteroscedasticity (see Greene, 1999, 547-549).

constitutes an « unresolved issue » in this field (see citation above). We made an OLS regression on the regressors, linking the two models of urban form and the three models of individuals' characteristics (*table 5*). These results will help us to comment and to put into context our main results on the factors of urban daily mobility.

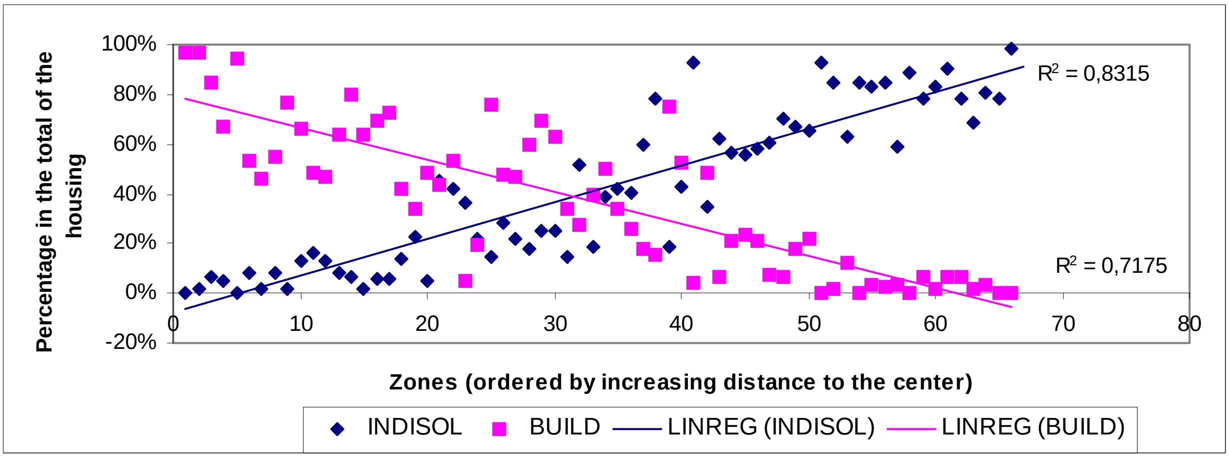
Some **preliminary observations** may help to understand the structure of land use in the metropolitan area of Bordeaux. We figured the exponential form of the density gradients for both jobs and people (*figure 2*), and the distribution of two different types of housing according to the distance to the center (*figure 3*) : isolated detached houses (INDISOL) and flats in low- or high-rise buildings (BUILD). These graphs shows the strong power of explanation of the distance to the center (see Gaussier & Puissant, 2001). Like most of european cities of this size, Bordeaux has still a monocentric structure : densities decrease almost uninterruptedly with distance to the center ; furthermore, as in the « three types of cities » model, the structure of the building stock is obviously linked to the distance to the center : as distance increases, the share of detached homes in the total of the housing increases and the share of buildings decreases. In further development we may be led to oppose low/high-density as well as center/periphery areas or detached homes/buildings.

**Figure 3. Density gradients (exponential form) in Bordeaux**




*Source* : HTS, 1998, treated by the author

**Figure 4. Types of housing according to distance to the center**




*Source* : HTS, 1998, treated by the author

## 2.2. Results : the motives of mobility

### *2.2.1. The interaction between urban form and mobility*

The **land use model** allows us to **confirm the traditional role of density in travel patterns**. Residential density as well as firm density have a significant negative influence on kilometrage per capita, trip length and car ownership (*table 1*), and a positive influence on the use of walking and transit compared to automobile use (*table 2*)[10]. Here, the influence of density tends to confirm previous results, that is, high density settlement is associated with shorter trip length, lower automobile ownership and use, and a modal shift towards « soft modes ».

Differences in land use characteristics don't explain differences in **individual trip frequencies** (see the weakness of the $R^2$, *table 1*). This is in line with what was expected, as trip frequencies are an indicator of the demand for travel, which theoretically doesn't depend

[10] Multinomial models require a reference dependent variable : here, the modal share of the car. Moreover, the coefficients have no meaning, only their sign is significant (Thomas, 2000). At last, the weakness of the pseudo-$R^2$ is linked to the high number of observations and doesn't mean the model has a weak explanatory power.

on urban form or accessibility but rather on economic and demographic characteristics (Quinet, 1998 ; Ewing & Cervero, 2001).

We must notice that the **degree of land use mix** (MIXFUNC), whatever the definition we adopted, as well as the khi indexes for the distribution of jobs (KHIPROX and KHIOTHER), have no influence on travel variables[11].

Regressions don't show any outstanding difference between the two purposes of the trips, which is contrary to what was expected. Travel behaviour may depend on the location in a specific urban form more than on the purpose of the trip, that is the influence of urban form is roughly the same whatever the purpose of the trip is.

The **jobs-housing ratio** (JHBAL) has a significant positive influence on kilometrage per capita for work trips - which is contrary to previous results (Camagni *et al*., 2002) - and a negative influence on car ownership (*table 1*). This influence is neither due to an increase in trip length, nor to a modal sharing in favour of the car (*tables 1* and *2*). On the contrary, walking and transit are more common in areas with high jobs-housing ratios (*table 2*).

This result must be linked to the significance of **KHIJOB**, which measures the degree of economic specialization of a zone. Table 1 shows a significant positive relationship between the economic specialization and the kilometrage per capita for work trips. That is, the more jobs are numerous compared to inhabitants in a given area, and the more this area is economically specialized, the higher kilometrage per capita for work trips is. This type of zones corresponds to the developing employment subcenters situated around the *rocade*[12] (Gaschet, 2001). One could suppose that this situation implies longer trips, but neither JHBAL nor KHIJOB are significant for trip length variables. So we are obliged to suppose a kind of « structural effect », which simply makes kilometrage per capita higher because of the

[11] That's why they weren't included in the result tables.
[12] Name of an expressway surrounding a metropolitan area.

scarcity of the population in these employment subcenters. This hypothesis is supported by the sign of the population variable in tables 3 and 4 (when significant)[13].

The **housing type model** shows a strong positive influence of the isolated detached houses (the reference category) on trip length as well as on car ownership (because of the negative influence of all other types of housing – *table 1*), and on the shares of transit and walking (*table 2*). Interpreting this relationship needs careful attention to what is hidden behind the type of housing : it seems difficult to justify that the percentage of isolated detached houses has an influence *by itself* on travel behaviour and car ownership. In fact, we can notice a significant effect of the type of housing on density : the highest densities are, the highest percentage of high and low buildings in total housing is[14], and the most numerous retail firms compared to other ones are[15] (*table 5*). At the contrary, isolated detached homes are the most numerous in low density, outlying areas. Then we find the results of figure 3. These results tend to confirm usual statements concerning automobile dependence : low density, residential areas mainly composed of isolated detached houses strongly encourages to own an automobile - and to use it (Newman, Kenworthy & Vintila, 1995). What's more, the outer location of these areas can explain the positive influence of isolated detached houses on trip length.

[13] As a consequence, one must be very carefully in interpretating complex relationships of this kind.
[14] One will note that HIBUILD is not significant for firm density, which may be astonishing. This is due to the French housing politics of the 1960's and 1970's : housing crisis has imposed to build numerous *Grands Ensembles* (subsidized high buildings) essentially dedicated to a residential function at the outskirts of greatest cities (Bidou, 1994).
[15] Which can be understood from a « market area » reasoning : all given, the higher density is, the most profitable retail firms are.

**Table 1. OLS Regression for the urban form - mobility interaction**

| | FIRST PURPOSE | | | SECOND PURPOSE | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PKMTO | PKMTD | TRIPLENG | PKMTO | PKMTD | TRIPLENG | TRIPFQ | HTRIPFQ | CAROWN | HCAROWN |
| Intercept | **3.777** | **2.881** | **9.735** | **11.522** | **10.689** | **7.101** | **3.746** | **9.529** | **0.715** | **1.465** |
| | **(5.459)** | **(5.687)** | **(14.105)** | **(9.517)** | **(11.622)** | **(14.050)** | **(33.212)** | **(29.749)** | **(33.025)** | **(24.519)** |
| RESDENS | **-0.039** | - | **-0.035** | **-0.070** | - | **-0.032** | 0.002 | **-0.025** | **-0.002** | **-0.006** |
| | **(-5.329)** | | **(-4.315)** | **(-5.127)** | | **(-4.965)** | (1.969) | **(-5.031)** | **(-6.309)** | **(-7.876)** |
| FIRMDENS | - | **-0.217** | - | - | **-0.317** | - | - | - | - | - |
| | | **(-6.383)** | | | **(-2.552)** | | | | | |
| JHBAL | **1.212** | **1.607** | -0.201 | **2.208** | **3.054** | -0.109 | **0.068** | -0.068 | **-0.022** | **-0.062** |
| | **(3.541)** | **(9.417)** | (-1.854) | **(3.441)** | **(6.572)** | (-1.298) | **(2.588)** | (-1.035) | **(-3.345)** | **(-3.824)** |
| KHIJOB | **6.692** | **6.168** | 2.665 | 4.238 | 1.222 | **3.625** | -0.541 | -0.172 | 0.076 | 0.254 |
| | **(3.438)** | **(3.263)** | (1.136) | (1.239) | (0.333) | **(2.259)** | (-1.311) | (-0.152) | (1.151) | (1.322) |
| Adjusted $R^2$ | 0.645 | 0.660 | 0.209 | 0.532 | 0.476 | 0.256 | 0.063 | 0.288 | 0.414 | 0.530 |
| *N* | *66* | *66* | *66* | *66* | *66* | *66* | *66* | *66* | *66* | *66* |
| Intercept | -17.132 | - | -1.654 | -8.986 | - | 0.933 | **6.370** | **9.729** | **1.536** | **2.475** |
| | (-1.061) | | (-0.422) | (-0.392) | | (0.318) | **(6.668)** | **(3.293)** | **(10.820)** | **(7.973)** |
| INDISOL | Reference Category | | | Reference Category | | | Reference Category | | | |
| INDCLUS | -0.794 | - | **-5.731** | -7.711 | - | **-4.562** | -0.104 | -1.962 | **-0.172** | **-0.635** |
| | (-0.241) | | **(-3.689)** | (-0.911) | | **(-3.675)** | (-0.248) | (-1.446) | **(-2.386)** | **(-3.976)** |
| LOWBUILD | -0.911 | - | **-4.108** | 3.867 | - | **-3.531** | **1.131** | **-4.366** | **-0.431** | **-1.394** |
| | (-0.307) | | **(-3.539)** | (0.483) | | **(-3.592)** | **(4.557)** | **(-5.501)** | **(-7.823)** | **(-11.506)** |
| HIBUILD | **-5.499** | - | **-6.374** | **-12.571** | - | **-5.984** | -0.164 | **-3.760** | **-0.308** | **-0.963** |
| | **(-3.511)** | | **(-4.939)** | **(-4.471)** | | **(-5.655)** | (-0.701) | **(-5.440)** | **(-7.602)** | **(-11.208)** |
| PEOPROOM | 39.202 | - | **22.144** | 41.826 | - | **13.950** | **-4.296** | 1.143 | **-1.147** | **-1.084** |
| | (1.518) | | **(3.559)** | (1.194) | | **(2.957)** | **(-2.961)** | (0.254) | **(-5.235)** | **(-2.258)** |
| Adjusted $R^2$ | 0.132 | | 0.439 | 0.436 | | 0.436 | 0.173 | 0.411 | 0.741 | 0.826 |
| *N* | *66* | | *66* | *66* | | *66* | *66* | *66* | *66* | *66* |

*Note : coefficients in bold are significant at a 5% level*

**Table 2. Multinomial logit model of modal choice for the urban form – mobility interaction**

| | CARSHAR | | TRANSIT | | WALK | | BICYCLE | | OTHER | |
|---|---|---|---|---|---|---|---|---|---|---|
| Intercept | **-1.334** | **-1.341** | **-2.580** | **-2.304** | **-1.733** | **-1.340** | **-2.684** | **-2.599** | **-2.776** | **-2.839** |
| | **(-12.363)** | **(-13.002)** | **(-18.107)** | **(-16.706)** | **(-17.528)** | **(-13.957)** | **(-14.580)** | **(-14.666)** | **(-11.282)** | **(-12.166)** |
| RESDENS | $-0.765^{E}$-3 | - | **0.014** | - | **0.017** | - | **0.065** | - | **-0.014** | - |
| | (-0.508) | | **(9.545)** | | **(15.819)** | | **(3.014)** | | **(-3.002)** | |
| FIRMDENS | - | -0.002 | - | **0.095** | - | **0.118** | - | **0.064** | - | **-0.163** |
| | | (-0.129) | | **(8.458)** | | **(13.398)** | | **(3.979)** | | **(-2.582)** |
| JHBAL | 0.026 | 0.016 | **0.134** | -0.012 | **0.181** | -0.014 | **0.096** | 0.053 | -0.132 | -0.046 |
| | (0.842) | (0.569) | **(3.718)** | (-0.323) | **(7.267)** | (-0.505) | **(1.979)** | (1.131) | (-1.467) | (-0.663) |
| KHIJOB | 0.234 | 0.234 | -0.247 | 0.336 | -0.474 | 0.044 | -0.561 | -0.539 | 0.839 | 0.509 |
| | (0.639) | (0.645) | (-0.520) | (0.700) | (-1.428) | (0.131) | (-0.870) | (-0.814) | (1.032) | (0.651) |
| Pseudo-$R^2$ | 0.04 | 0.03 | 0.04 | 0.03 | 0.04 | 0.03 | 0.04 | 0.03 | 0.04 | 0.03 |
| *N* | *4329* | *4329* | *4329* | *4329* | *4329* | *4329* | *4329* | *4329* | *4329* | *4329* |

| | CARSHAR | TRANSIT | WALK | BICYCLE | OTHER |
|---|---|---|---|---|---|
| Intercept | **-1.282** | **-3.463** | **-2.545** | **-2.816** | **-2.299** |
| | **(-11.430)** | **(-16.183)** | **(-17.956)** | **(-13.818)** | **(-11.063)** |
| INDISOL | Reference Category | | | | |
| INDCLUS | 0.085 | **1.975** | **1.800** | 0.570 | -0.868 |
| | (0.241) | **(4.059)** | **(5.404)** | (0.961) | (-1.066) |
| LOWBUILD | 0.152 | **2.899** | **3.829** | **1.490** | -2.379 |
| | (0.380) | **(6.828)** | **(13.230)** | **(2.533)** | (-1.871) |
| HIBUILD | -0.077 | **2.286** | **2.068** | -0.083 | **-1.603** |
| | (-0.299) | **(6.496)** | **(8.488)** | (-0.183) | **(-2.414)** |
| Pseudo-$R^2$ | 0.042 | 0.042 | 0.042 | 0.042 | 0.042 |
| *N* | *4329* | *4329* | *4329* | *4329* | *4329* |

*Note : coefficients in bold are significant at a 5% level*

One may notice the negative influence of the share of high-rise building flats on kilometrage per capita, whatever the purpose of the trip is (*table 1*). These are central areas, or planned areas with an excellent transit supply : as average household income and level of car ownership are low, planners have wanted these areas to be well-desserved. The effect of the percentage of low-rise buildings on individual kilometrage may be significant as well, as this type of housing is frequent in central areas, but these are areas with higher trip frequencies, which counterbalances the expected effect of shorter distances travelled and/or a modal shift at the expense of the car.

#### *2.2.2. The interaction between mobility and economic and demographic characteristics*

The **« lifecycle model »** shows an insignificant effect of income on trip frequencies and kilometrage per capita. However, income has a strong positive influence on car ownership, which was expected ; this influence is strengthened by the results of the « type of population model », as low income populations (unemployed and students) proved significantly related to car ownership (*table 3*). Results in table 4 go along with this, as modal shares of transit and walking depend negatively on income.

Thus income seems to be related to travel behaviour in favour of car ownership and use. One could interpret this result suggesting that « rising incomes may be the root cause of much of the growth in auto dependence » (Gomez-Ibañez, 1991, 377). The author cares about a distinction between « direct effects [of high incomes] on auto use » (people buy more mobility as income rises) and « indirect effects on density » (people buy more space as income rises). The direct effect seems obvious in view of above results ; the indirect effect is confirmed by table 5, in which income is negatively related to density, and positively related to isolated detached housing. P. Newman *et al*. (1995) are convinced of the erroneous aspect of such a statement (« the link between wealth and urban form may be more complex than conventional argument has suggested », 54), but their demonstration lies anew on a global comparison (that is, Zurich and Los Angeles), not on infra-urban analysis.

In the case of Bordeaux, the influence of income on travel patterns interacts with the influence of urban form. Income has a significant effect on automobile use ; income is higher in low density areas ; automobile use is higher in low density areas. It is difficult to establish what is the cause and what is the effect. The only conclusion that can be drawn is that high income, location in low density areas and automobile use go together.

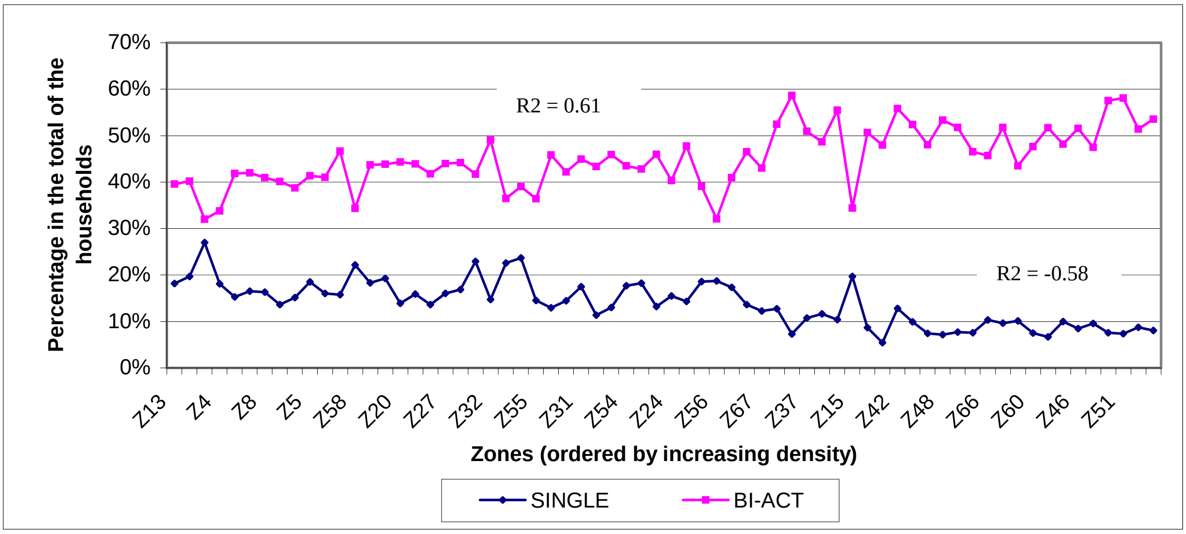
The **« type of population model »** shows a significant negative influence of the **share of women in the population** on kilometrage per capita. It is a kind of paradox, as higher percentage of women is associated with higher trip frequencies (*table 3*). The explanation lies in shorter trips (*table 3*) as well as on higher share of walking (*table 4*) – that is, closening the origin and the destination of the trip allows modal shift.

Various interpretations of these results are available, none of them prevailing :

- Higher trip frequencies may be due to a greater number of purposes, like shopping and school service. As a consequence, women attach a greater value to the location of the home and seek to settle closer to their usual destinations ;
- A kind of aversion to the use of automobile ;
- An interaction with urban form : the heads of the family for single-parent households are mainly women. This may explain that SEX variable is significant for *individual* trip frequencies and not for *household* trip frequencies. Single-parent households are often poorer than other ones (DJIDER & RAVEL, 2004) and hence may not have access to car ownership. Furthermore, the head of the family has to manage with domestic and non-domestic activities. As a consequence, single-parent households may locate in central, well-desserved parts of the city

in order to shorten distances travelled and to have a wider modal choice. This statement is confirmed by the proportion of single-parent households according to density (*figure 4*).

**Figure 5. Percentage of single-parent and bi-active households**
**(zones ordered by increasing density)**




*Source* : HTS, 1998, treated by the author

This last explanation leads to wonder if there are any differences in mobility according to the type of population.

The unemployment rate proves itself significantly related to « soft modes » use compared to car use, while the percentage of retired people and of students is significantly related to transit use compared to car use (*table 4*). Such results are no surprise, as these kinds of population have to a lesser extent access to automobile ownership (*table 3*) and may shift towards other modes.

**Table 3. OLS regressions for the interaction between mobility and economic and demographic characteristics**

| | PKMTO1 | PKMTO2 | TRIPLENG | TRIPFQ | HTRIPFQ | CAROWN | HCAROWN |
|---|---|---|---|---|---|---|---|
| Intercept | **50.552** | 19.138 | **18.114** | **4.477** | **9.991** | **0.359** | **0.681** |
| | **(2.017)** | (1.956) | **(5.386)** | **(8.466)** | **(7.565)** | **(4.098)** | **(3.227)** |
| INCOME | 0.019 | 0.025 | **0.017** | 0.0007 | **0.034** | **0.003** | **0.008** |
| | (1.717) | (1.054) | **(2.524)** | (0.568) | **(9.895)** | **(13.337)** | **(16.005)** |
| AGE | -0.433 | -0.198 | **-0.161** | **-0.031** | **-0.135** | -0.002 | -0.009 |
| | (-1.987) | (-0.746) | **(-2.150)** | **(-2.097)** | **(-3.635)** | (-0.868) | (-1.710) |
| COLLEDUC | **-16.270** | -9.384 | **-12.124** | **1.698** | **-6.821** | **-0.266** | **-1.442** |
| | **(-2.171)** | (-0.717) | **(-5.969)** | **(3.518)** | **(-5.805)** | **(-3.053)** | **(-8.808)** |
| Adjusted $R^2$ | 0.177 | 0.011 | 0.234 | 0.160 | 0.621 | 0.705 | 0.790 |
| *N* | *66* | *66* | *66* | *66* | *66* | *66* | *66* |
| Intercept | **41.742** | **117.391** | **41.582** | 1.819 | **9.583** | **1.062** | **4.533** |
| | **(3.153)** | **(5.282)** | **(6.244)** | (1.298) | **(2.869)** | **(3.998)** | **(6.940)** |
| UNEMPL | -0.259 | 13.703 | -9.911 | 0.460 | -7.784 | **-2.493** | **-5.115** |
| | (-0.022) | (0.482) | (-1.722) | (0.219) | (-1.361) | **(-9.896)** | **(-8.489)** |
| RETIRED | 0.742 | -5.459 | -2.769 | **-2.294** | **-7.245** | **-0.637** | **-1.298** |
| | (0.095) | (-0.260) | (-0.615) | **(-2.124)** | **(-2.713)** | **(-3.338)** | **(-2.648)** |
| MINOR | 34.206 | -0.013 | 3.364 | -0.691 | **13.593** | -0.179 | 0.257 |
| | (1.874) | (0.0005) | (0.759) | (-0.427) | **(3.429)** | (-0.633) | (0.375) |
| STUDENT | 16.235 | -5.646 | -2.905 | -0.697 | **-6.624** | **-0.843** | **-2.151** |
| | (1.572) | (-0.364) | (-0.950) | (-0.079) | **(-3.237)** | **(-5.509)** | **(-5.363)** |
| SEX | **-91.173** | **-214.780** | **-70.624** | **5.364** | -2.119 | -0.059 | **-4.928** |
| | **(-2.663)** | **(-4.525)** | **(-5.619)** | **(2.099)** | (-0.352) | (-0.119) | **(-3.991)** |
| Adjusted $R^2$ | 0.344 | 0.319 | 0.471 | 0.111 | 0.605 | 0.715 | 0.788 |
| *N* | *66* | *66* | *66* | *66* | *66* | *66* | *66* |
| Intercept | 0.079 | -6.319 | 3.572 | **2.263** | **-4.016** | **-0.581** | **-1.908** |
| | (0.013) | (-0.572) | (0.901) | **(2.878)** | **(-2.251)** | **(-4.512)** | **(-7.444)** |
| HHSIZE | **3.243** | **5.133** | **3.243** | -0.174 | **3.210** | **0.212** | **0.739** |
| | **(2.193)** | **(3.016)** | **(6.344)** | (-1.703) | **(13.360)** | **(11.426)** | **(21.853)** |
| FIRMSIZE | 0.292 | 0.378 | **-0.155** | 0.017 | 0.034 | 0.001 | -0.002 |
| | (1.741) | (1.332) | **(-2.763)** | (1.650) | (1.373) | (0.536) | (-0.456) |
| POP | **-0.185E-3** | **-0.529E-3** | **-0.958E-4** | 0.265E-6 | 0.135E-4 | **0.616E-5** | **0.104E-4** |
| | **(-2.095)** | **(-3.260)** | **(-2.160)** | (0.027) | (0.602) | **(4.045)** | **(3.107)** |
| SURFPEOP | -0.031 | 0.323 | -0.007 | **0.049** | **0.123** | **0.017** | **0.034** |
| | (-0.244) | (1.119) | (-0.084) | **(2.973)** | **(3.209)** | **(5.983)** | **(5.564)** |
| Adjusted $R^2$ | 0.272 | 0.254 | 0.293 | 0.133 | 0.672 | 0.697 | 0.854 |
| *N* | *66* | *66* | *66* | *66* | *66* | *66* | *66* |

*Note : coefficients in bold are significant at a 5% level*

**Table 4. Multinomial logit model of modal choice for the relation between mobility and economic and demographic characteristics**

| | CARSHAR | TRANSIT | WALK | BICYCLE | OTHER |
|---|---|---|---|---|---|
| Intercept | -0.902 | -1.372 | 0.188 | -1.541 | **-5.058** |
| | (-1.567) | (-1.900) | (0.384) | (-1.643) | **(-3.565)** |
| INCOME | -0.476E-3 | **-0.019** | **-0.016** | -0.002 | **0.012** |
| | (-0.348) | **(-9.670)** | **(-12.136)** | (-0.824) | **(3.572)** |
| AGE | -0.666E-2 | **0.044** | 0.003 | -0.030 | 0.025 |
| | (-0.438) | **(2.162)** | (0.244) | (-1.186) | (0.712) |
| COLLEDUC | -0.194 | **2.272** | **4.621** | **2.233** | **-4.002** |
| | (-0.366) | **(3.608)** | **(11.052)** | **(2.715)** | **(-2.762)** |
| Pseudo-$R^2$ | 0.038 | 0.038 | 0.038 | 0.038 | 0.038 |
| *N* | *4329* | *4329* | *4329* | *4329* | *4329* |
| Intercept | -0.209 | **-6.622** | **-9.121** | -2.393 | 7.524 |
| | (-0.119) | **(-2.868)** | **(-5.765)** | (-0.791) | (1.754) |
| UNEMPL | 0.978 | **16.319** | **15.159** | -0.639 | -8.748 |
| | (0.522) | **(7.936)** | **(10.374)** | (-0.204) | (-1.724) |
| RETIRED | 0.424 | **3.727** | -0.345 | -2.496 | 0.800 |
| | (0.394) | **(2.608)** | (-0.344) | (-1.348) | (0.336) |
| MINOR | 0.368 | -1.582 | **-3.049** | -3.642 | -0.088 |
| | (0.240) | (-0.797) | **(-2.216)** | (-1.399) | (-0.026) |
| STUDENT | 0.421 | **3.595** | 1.558 | -0.868 | -2.355 |
| | (0.391) | **(2.639)** | (1.644) | (-0.492) | (-0.834) |
| SEX | -2.496 | 5.299 | **14.698** | 2.416 | **-19.469** |
| | (-0.730) | (1.194) | **(4.827)** | (0.415) | **(-2.329)** |
| Pseudo-$R^2$ | 0.043 | 0.043 | 0.043 | 0.043 | 0.043 |
| *N* | *4329* | *4329* | *4329* | *4329* | *4329* |
| Intercept | -0.068 | **5.826** | **2.901** | **-2.907** | **-5.682** |
| | (-0.945) | **(6.064)** | **(4.638)** | **(-2.383)** | **(-3.460)** |
| HHSIZE | -0.015 | **-1.489** | **-1.434** | -0.347 | **1.067** |
| | (-0.129) | **(-9.777)** | **(-13.981)** | (-1.822) | **(3.926)** |
| FIRMSIZE | 0.013 | 0.019 | 0.003 | 0.028 | -0.066 |
| | (0.921) | (1.063) | (0.243) | (1.206) | (-1.662) |
| POP | -0.104E-4 | **-0.257E-4** | **-0.346E-4** | -0.174E-4 | -0.355E-4 |
| | (-1.121) | **(-2.096)** | **(-4.155)** | (-1.112) | (-1.585) |
| SURFPEOP | -0.013 | **-0.112** | 0.002 | 0.036 | 0.021 |
| | (-0.824) | **(-5.085)** | (-0.166) | (1.383) | (0.590) |
| Pseudo-$R^2$ | 0.037 | 0.037 | 0.037 | 0.037 | 0.037 |
| *N* | *4329* | *4329* | *4329* | *4329* | *4329* |

*Note : coefficients in bold are significant at a 5% level*

**Table 5. The urban form – economic and demographic interaction (OLS regression)**

| | RESDENS | FIRMDENS | JHBAL | PROXRATE | INDISOL |
|---|---|---|---|---|---|
| Intercept | **91.684** | **17.329** | 5.019 | **0.772** | 0.171 |
| | **(2.175)** | **(2.440)** | (1.246) | **(3.009)** | (0.853) |
| INCOME | **-0.528** | **-0.0646** | -0.001 | **-0.002** | **0.006** |
| | **(-4.717)** | **(-4.306)** | (-0.253) | **(-3.867)** | **(10.208)** |
| AGE | -0.657 | **-0.339** | -0.095 | 0.004 | -0.009 |
| | (-0.57) | **(-2.07)** | (-0.895) | (0.442) | (-1.641) |
| COLLEDUC | **210.143** | **39.159** | 0.638 | **0.860** | **-1.503** |
| | **(6.513)** | **(4.418)** | (0.197) | **(3.956)** | **(-8.271)** |
| Adjusted $R^2$ | 0.494 | 0.541 | 0.015 | 0.242 | 0.663 |
| *N* | *66* | *66* | *66* | *66* | *66* |
| Intercept | **-499.108** | -2.899 | 5.459 | **-2.911** | **3.373** |
| | **(-3.259)** | (-0.207) | (0.995) | **(-2.671)** | **(6.134)** |
| UNEMPL | **275.220** | **73.067** | 12.043 | 0.601 | **-4.004** |
| | **(2.032)** | **(3.141)** | (1.395) | (1.068) | **(-6.276)** |
| RETIRED | -105.055 | **-41.611** | -3.250 | -0.669 | -0.779 |
| | (-1.640) | **(-2.904)** | (-0.771) | (-1.768) | (-1.944) |
| MINOR | -135.972 | **-63.472** | 3.844 | -0.899 | 0.369 |
| | (-1.405) | **(-2.953)** | (0.315) | (-1.650) | (0.496) |
| STUDENT | 41.218 | -15.781 | -0.018 | -0.022 | **-1.022** |
| | (0.455) | (-1.384) | (-0.003) | (-0.061) | **(-2.324)** |
| SEX | **1074.355** | 47.501 | -9.124 | **7.473** | **-5.401** |
| | **(3.633)** | (1.743) | (-0.678) | **(3.598)** | **(-5.537)** |
| Adjusted $R^2$ | 0.597 | 0.610 | 0.002 | 0.505 | 0.637 |
| *N* | *66* | *66* | *66* | *66* | *66* |
| Intercept | **163.137** | 12.654 | -0.704 | **1.431** | **-1.647** |
| | **(2.703)** | (1.690) | (-0.461) | **(5.327)** | **(-4.449)** |
| HHSIZE | **-59.011** | **-7.701** | 0.234 | **-0.298** | **0.576** |
| | **(-6.300)** | **(-4.055)** | (0.392) | **(-6.162)** | **(12.682)** |
| FIRMSIZE | 0.388 | -0.085 | **0.260** | 0.002 | -0.011 |
| | (0.325) | (-0.750) | **(3.463)** | (0.207) | (-1.901) |
| POP | 0.599E-3 | **-0.315E-3** | **-0.124E-3** | 0.134E-5 | -0.186E-5 |
| | (0.829) | **(-2.536)** | **-2.884** | (0.355) | (-0.493) |
| SURFPEOP | 0.052 | 0.363 | 0.043 | -0.825E-3 | **0.021** |
| | (0.043) | (1.978) | 0.812 | (-0.141) | **(2.427)** |
| Adjusted $R^2$ | 0.456 | 0.469 | 0.422 | 0.297 | 0.689 |
| *N* | *66* | *66* | *66* | *66* | *66* |
| Intercept | 102.985 | 11.002 | -7.353 | **1.827** | |
| | (1.558) | (1.687) | (-0.947) | **(3.525)** | |
| INDISOL | | Reference Category | | | |
| INDCLUS | 28.301 | -4.597 | 1.586 | -0.108 | |
| | (1.366) | (-1.221) | (0.963) | (-0.894) | |
| LOWBUILD | **88.206** | **29.809** | 2.797 | **0.357** | |
| | **(2.691)** | **(3.820)** | (1.286) | **(1.999)** | |
| HIBUILD | **105.388** | 2.911 | -0.405 | **0.544** | |
| | **(4.773)** | (0.818) | (-0.581) | **(3.571)** | |
| PEOPROOM | -178.164 | -18.531 | 12.787 | **-2.002** | |
| | (-1.706) | (-1.811) | (1.033) | **(-2.496)** | |
| Adjusted $R^2$ | 0.533 | 0.586 | 0.039 | 0.400 | |
| *N* | *66* | *66* | *66* | *66* | |

*Note : coefficients in bold are significant at a 5% level*

The concept of *self-selection* can help us to interpret these results. It « questions the direction of the causal relationship between urban form and travel » (Krizek, 2003, 268). Urban form may determine travel patterns as much as travel patterns determine the location in a specific urban form. Choosing a specific environment to live would be partly due to individuals'preferences for a precise travel pattern : those who prefer walking, for example, may settle in dense, mixed-use locations because more destinations are available at walking distance[16]. We can generalize this statement by arguing that a wide selection of travel modes is an important criterion in the selection of the residential location : as suburban, low density settlements are supposed « car-dependent », having a modal choice implies to live in dense, well-desserved areas.

If the location in a specific urban form depends on individuals' preferences on travel patterns, then residential location is the result of a choice. But it can also be a constraint, due to economic and/or demographic characteristics : G. Dupuy (1995, 2002) has been underlying a tendency in populations who can't afford an automobile (like students or unemployed people) to concentrate in the denser parts of the metropolitan area, where a modal choice is possible to reach usual, dispersed destinations[17]. This location is constrained by the necessity to avoid automobile dependence.

The analysis of the data brings a weak confirmation of this hypothesis. The rate of unemployed people proves positively related to residential and firm densities, and negatively linked to the proportion of isolated detached houses (*table 5*), but the proportion of students or retired people is not significant[18]. This result matches up above commentaries on the influence of income on travel behaviour and land use.

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[16] This is consistent with the hypothesis of a « consumer city » where speed is one out of four « vital amenities » (Glaeser *et al*., 2000).

[17] What is called the « gregarious effect » (Dupuy, 2002).

[18] The percentage of students is not significant with urban form variables, as this population is mainly concentrated in the center of the city and around the campus, which is located at the outskirt of the metroplitan area (zone number 29, where STUDENT is at its higher level, 47%, but which is only the 34th densest zone).

The **« size model »** shows a strong influence of household size on travel patterns. The household size has a significant effect on *per household* trip frequency and *per household* car ownership (*table 3*), which seems standing to reason[19]. But what is really interesting is the significant positive relationship between household size and kilometrage per capita. Therefore, as this last variable is a composite one, it can be explained as follow :

- Higher automobile ownership : greater household size prompts to own an automobile, as the household's needs in travels are higher (*table 3*) ;
- Lower « soft modes » use compared to automobile use (*table 4*), which goes along with car ownership ;
- At an individual level, trip frequencies do not increase as household size increases, which is in keeping with the hypothesis made above that there is a stability of travel needs amongst individuals. However, trip lengths increase with household size. This relationship could be due to the location factor, as in the model of the three types of cities (see above), detached houses are much more numerous in peripheral zones.

Such a hypothesis of a location factor is confirmed by results in table 5. It seems obvious that large households settle in specific zones, with low residential and firm density, low rates of retail firms, and high rates of isolated detached houses. This description corresponds to low density, residential neighboorhoods, which are habitually described as « auto-dependent » urban form (Cervero, 1998 ; Newman & Kenworthy, 1998).

Thus the household size goes along with specific residential patterns and travel behaviours. Once again, we're faced with a kind of logical indecision which doesn't allow us to determine what is the cause and what is the effect. To find a relevant explanation to these

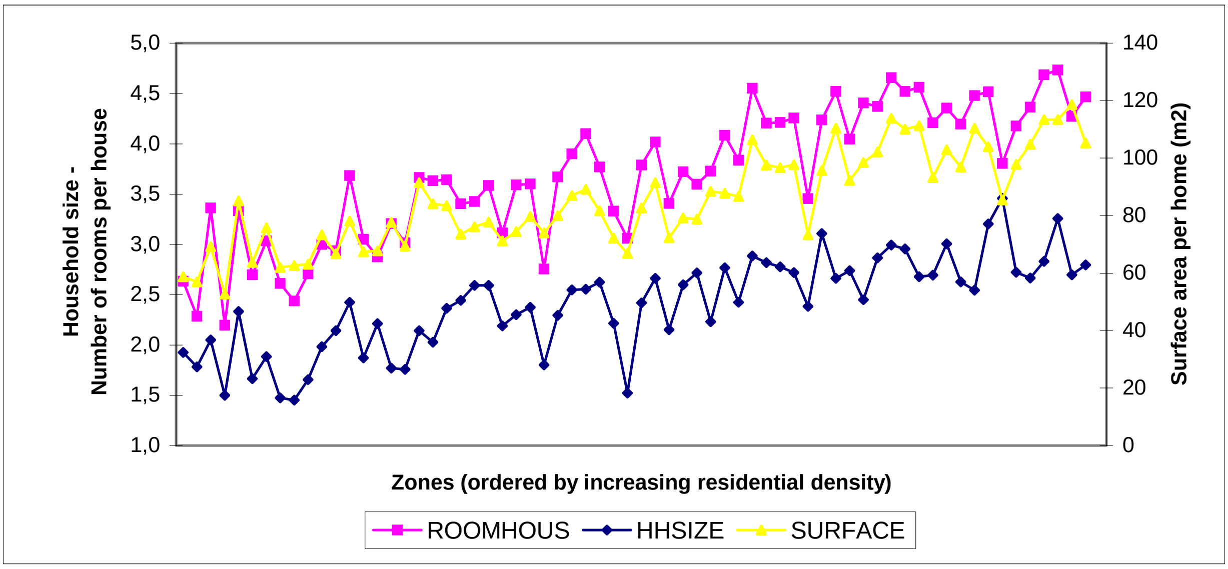
[19] Let's notice the significant negative relationship, in table 4, between small-size households (students and retired people) and per household trip frequency and car ownership, as well as the positive link between the proportion of minors and the trip frequency per household.

results requires exogenous elements that the researcher has to find thanks to his experience and knowledge of the situation. We bring out two points :

- An « amenities » explanation : the denser parts of the city are associated with pollution, low levels of security, etc. Which is bearable for certain adults (as negative amenities go along with positive ones) constitutes a repulsive environment for human children : parents with young children are strongly prompted to settle far from the center, near natural amenities. However, this type of explanation is very difficult to corroborate because of a lack of available data for Bordeaux.
- A « real estate availability » explanation : an increase in household size implies an increase in surface area needs. We have noticed the stability of the floorspace per capita in the whole metroplitan area (see *annex* : the standard error is less than 10% of the mean). As a consequence, an increase in household size implies an increase in the size of the flat.

Now small flats appear to be more prevalent in central, high-density zones, and large-size homes (such as detached ones) are much more numerous in peripheral, low-density ones. Thus, small-size households will locate in the first ones, as large-size households will settle in second ones (*figure 5*). So the distribution of the households according to their size (and the travel patterns that ensue) is due to the availability of housings fitted to their surface area needs.

**Figure 6. Household size, density and real estate conditions**




*Source* : HTS, 1998, treated by the author

One can't know if this state of affairs is imposed on or chosen by households. Do large-size household settle in low-density zones because of the abundance of large-size housings, or do large-size housings are numerous in low-density zones because large-size households settle there ? It would be chosen if the real estate market adapts to their demand and needs, which is the habitual hypothesis. It would be imposed on if households had to adapt to the real estate supply. R.F Muth (1969, 96-99) has underlined the consequences of the gap between the durability of housing, which is measured in centuries, and the necessity to adapt buildings to quick changes in housing demand. He points out that there is an upper limit to residential density in older parts of the city, as most of the buildings are protected from destruction because of their aestetic and historical value[20]. The problem is that there is no limit to the rise of the rent. It may lead to a growing disconnection between the rent gradient and the density gradient, yet they are theoretically linked (Mills, 1972, chap. V). But « durability affects primarily the exteriors of buildings » (Muth, 1969, 97), and a rise of the rent which is not accompanied by a rise of density leads to a multiplication of small-size, more rentable flats.

[20] This is the case in almost every great european city ; in Bordeaux, the 18th century buildings in the older part of the city are the pride of the inhabitants.

## CONCLUSION

The study of the key factors determining daily travel is generally treated as a twofold relationship, with economic and demographic characteristics and urban form considered as the two main factors of travel patterns. The analysis of 1998 transportation data of the metropolitan area of Bordeaux show that these factors have a strong influence on travel patterns. In particular, we are able to confirm the benefits of high density as far as automobile use is concerned, underlied by the model of compact city, which has inspired numerous planning policies in Europe. Despite the test of several indicators of land use mix, results doesn’t permit to rule on its influence on travel patterns.

Economic and demographic variables – such as income, household size or the proportion of women in the population – have also a strong power of explanation on numerous travel variables. But attempts to comment such results leads to a logical indecision, a kind of « egg-and-chicken » dilemma as R. F. Muth had already noticed in 1971 for the land use - mobility interaction. It seems difficult to extricate the causal relationships and to determine their direction. The only conclusion to draw is that « everything interacts with everything » (Wiel, 2001, 23).

These results allow to draw some teachings for policy purposes. Compacification measures aim at increasing density to thwart urban sprawl and influence daily mobility patterns. But an increase in density may not be suficient *by itself* to reduce automobile use, as economic and demographic characteristics interact with the distribution of densities. This kind of policies may be more efficient if they are reinforced by specific measures, for example real estate policies such as building large-size flats in the CBD to prompt families with children to go « back to the center »[21]. The study of the key factors of urban daily travel shows very complex relationships, and one must be warned not to simplify such phenomenons, notably for policy purposes.

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[21] As was done in the ZAC (concerted planning zone) of the Chartrons, in the historic center of Bordeaux, where city authorities have planned with real estate promoters to mix small and large-size flats in a set of new buildings.

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## ANNEX – MAIN VARIABLES

| | | Mean | Std. Deviation | Minimum | Maximum |
|---|---|---|---|---|---|
| Land-use variables | RESDENS | 32.298 | 39.18 | 0.69 | 150.83 |
| | Gross residential density (people/hectare) | | | | |
| | FIRMDENS | 3.15 | 6.30 | 0.03 | 39.47 |
| | Gross density of firms (firms/hectare) | | | | |
| | JHBAL | 1.39 | 1.94 | 0.13 | 9.25 |
| | Jobs-housing balance (jobs/people[22]) normalized[23] | | | | |
| | FUNCMIX | 0.56 | 0.25 | 0.08 | 0.98 |
| | Index of functional mix[24] | | | | |
| | KHIJOB | 0.29 | 0.15 | 0.08 | 0.87 |
| | Khi index for distribution of jobs[25] | | | | |
| | KHIPROX | 0.07 | 0.07 | 0.007 | 0.334 |
| | Khi index for distribution of retail jobs | | | | |
| | KHIOTHER | 0.22 | 0.12 | 0.06 | 0.66 |
| | Khi index for distribution of other jobs (mainly service and manufacturing) | | | | |
| | PROXRATE | 71% | 0.24 | 0.24 | 1.61 |
| | Ratio jobs of proximity/other jobs | | | | |
| | INDISOL | 42% | 0.31 | 0% | 98% |
| | Percentage of detached isolated houses in total housing | | | | |
| | INDCLUS | 22% | 0.15 | 2% | 58% |
| | Percentage of clustered houses in total housing | | | | |
| | LOWBUILD | 14% | 0.15 | 0% | 68% |
| | Percentage of low-rise building (less than 4 levels) flats in total housing | | | | |
| | HIBUILD | 22% | 0.20 | 0% | 83% |
| | Percentage of high-rise building (4 levels or more) flats in total housing | | | | |
| | PEOPROOM | 0.63 | 0.03 | 0.56 | 0.71 |
| | Average number of people per room | | | | |
| | PKMTO1 | 6.11 | 4.03 | 1.91 | 30.61 |
| | Kilometers travelled per capita from the origin zone for the first purpose[26] | | | | |
| | PKMTD1 | 6.19 | 4.11 | 1.52 | 29.38 |
| | Kilometers travelled per capita towards the destination zone for the first purpose | | | | |
| | PKMTO2 | 13.51 | 7.31 | 5.06 | 43.37 |
| | Kilometers travelled per capita from the origin zone for the second purpose | | | | |
| | PKMTD2 | 13.53 | 7.45 | 4.67 | 42.74 |

[22] Three type reference population were used : total population, working population, number of households.

[23] JHBAL is normalized, which means the value for a particular zone is divided by the value for the whole study area ; a value of JHBAL equal to one means that the zone has exactly the same ratio jobs/people as the whole study area.

[24] This index was built on the same ground as JHBAL (jobs/people) ; the default of JHBAL is that it only indicates the quantity of jobs compared to population. Functional mix is at its highest level for JHBAL=1 (equal proportion in the zone and in the whole area). For values superior to one, JHBAL increases whereas functional mixity decreases. That's why we inversed values superior to one to build FUNCMIX.

[25] The Khi Index is a specialization index. The higher it is, the most specialized the zone is, which means that the sectoral distribution of jobs is all the more far off the whole area's one (LAJUGIE, DELFAUD, LACOUR, 1985).

[26] Many studies have underlined the necessity to distinguish the purpose of the trips, on a basis of its frequency and repetitivity (e.g. DIELEMAN *ET AL*., 2001). Purpose 1 is commuting (work trips), and purpose 2 is other (non-work trips, mainly shopping and leisure ones).

| | | | | | |
|---|---|---|---|---|---|
| Mobility Variables | Kilometers travelled per capita towards the destination zone for the second purpose | | | | |
| | TRIPLENG | 9.11 | 2.78 | 4.76 | 18.72 |
| | Average trip length (km) | | | | |
| | TRIPFQ | 3.76 | 0.46 | 2.62 | 4.67 |
| | Average trip frequency (trips per person) | | | | |
| | HTRIPFQ | 8.58 | 1.75 | 5.34 | 13.32 |
| | Average trip frequency (trips per household) | | | | |
| | CAR | 51% | 0.13 | 19% | 70% |
| | Percentage of trips made by car (driver) | | | | |
| | CARSHAR | 15% | 0.04 | 5% | 22% |
| | Percentage of trips made by car (passenger) | | | | |
| | TRANSIT | 7% | 0.05 | 0% | 24% |
| | Percentage of trips made by transit | | | | |
| | WALK | 20% | 0.14 | 3% | 58% |
| | Percentage of trips made by walking | | | | |
| | BICYCLE | 4% | 0.02 | 0% | 10% |
| | Percentage of trips made by bicycling | | | | |
| | OTHER | 3% | 0.03 | 0.1% | 13% |
| | Percentage of trips made by other modes (mainly rail) | | | | |
| | CAROWN | 0.65 | 0.13 | 0.33 | 0.85 |
| | Car ownership (cars per person) | | | | |
| | HCAROWN | 1.24 | 0.37 | 0.44 | 1.91 |
| | Car ownership (cars per household) | | | | |
| Economic and demographic variables | INCOME | 147.46 | 38.29 | 65.66 | 213.22 |
| | Average income of the household (kF) | | | | |
| | AGE | 37.5 | 3.40 | 30.49 | 45.13 |
| | average age (years) | | | | |
| | COLLEDUC | 21% | 0.11 | 3% | 49% |
| | Percentage of high-educated population (two-years college) | | | | |
| | UNEMPL | 6% | 0.03 | 1% | 16% |
| | Unemployment rate (%) | | | | |
| | RETIRED | 23% | 0.07 | 8% | 45% |
| | Retirement rate (%) | | | | |
| | MINOR | 19% | 0.06 | 6% | 32% |
| | Percentage of the population under 18 | | | | |
| | STUDENT | 8% | 0.09 | 0% | 48% |
| | Percentage of students | | | | |
| | SEX | 52% | 0.02 | 49% | 58% |
| | Percentage of women in the population | | | | |
| | HHSIZE | 2.41 | 0.46 | 1.45 | 3.46 |
| | Household size (people/household) | | | | |
| | JOBFIRM | 5.45 | 3.86 | 1.35 | 20.35 |
| | Firm size (jobs/firm) | | | | |
| | POP | 12,141 | 5,250 | 2,067 | 24,278 |
| | Population | | | | |
| | SURFPEOP | 36.71 | 3.34 | 30.54 | 44.72 |
| | Floorspace per capita ($m^2$) | | | | |