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Irving Tapia Villarreal

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**Urban form, demography and daily mobility forecasts:
Comparative analysis France-Mexico**

by

Irving Tapia-Villarreal, B.S.C.E., M.S.E.

Dissertation

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L'Université de Paris 1 Panthéon-Sorbonne n'entend donner aucune approbation ni improbation aux opinions émises dans les thèses ; ces opinions doivent être considérées comme propres à leurs auteurs.

*Dedicado a mis padres y hermanos,
a mi compañera en esta aventura,
y a mis hijos que vienen en camino.*

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*« Tout comme l'avenir, ce n'est pas tout à la fois,
mais grain par grain que l'on goûte le passé. »*
Marcel Proust. Extrait d'À la recherche du temps perdu.

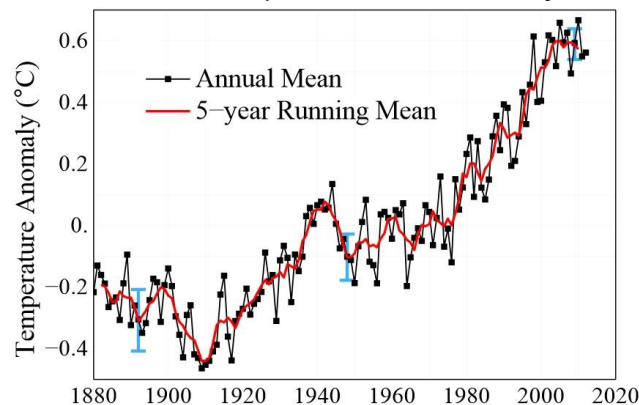
Chapter 1. INTRODUCTION

Chapter 1. Introduction

1.1 Background

Human-induced climate change has increased 0.8°C since the industrial revolution [1]. Indeed, a recent update of the global analysis reveals that Global temperature in 2012 was 0.56°C warmer than the 1950-1980 base period average [2]. It is commonly accepted by the scientific community that without any action aiming to reduce greenhouse gas emissions (GHG) global warming it is more likely to continue to rise by 4°C above the preindustrial levels by the year 2100 [3]. Under this scenario besides the threat to human safety and health, significant changes in the global environment are expected to be observed such as unprecedented heat waves leading to aridity and severe drought, increases in tropical cyclone intensity and rise in the sea level leading to major floods having a profound negative impact on both ecosystems and human systems [3, 4].

Figure 1.1. Historical Global Temperature trends (base year 1951-1980)



Source: http://www.columbia.edu/~mhs119/Temperature/dTs_60+132mons.pdf

In an effort to counteract global warming trends (Figure 1.1) the United Nations created in 1994 a Framework Convention on Climate Change (UNFCCC) ratified by most United Nations member states in order to achieve:

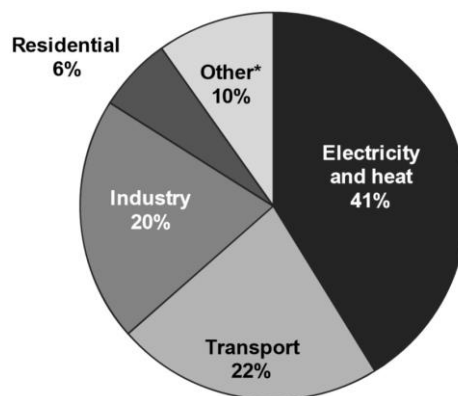
*"stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner"*¹.

¹ "Article 2". The United Nations Framework Convention on Climate Change. Retrieved 14 July 2013.

The UNFCCC was the most important step that led in 1997 to the Kyoto Protocol. This international environmental agreement came into effect on 2005 and sets binding specific greenhouse gas emission reduction targets for 37 industrialized countries. The goal was to cut down GHG emissions by the year 2000 to 1990 levels² and by at least 18% below 1990 levels by 2020³. Most industrialized countries had set targets to reduce GHG emissions to at least 60–80% below base year (1990) by 2050 [5, 6]. For instance, the European Union (EU) is committed to reduce GHG emissions to about 80-95% below 1990 levels by 2050 [7].

Carbon dioxide (CO₂) is regarded to be the main producer of the greenhouse effect and the most abundant anthropogenic of all GHG emissions, hence the interest in its potential mitigation since projections show consistent and continuous increase in the future [8](Figure 1.5).

Figure 1.2. World CO₂ emissions by sector in 2010



* Other includes commercial/public services, agriculture/forestry, fishing, energy industries other than electricity and heat generation, and other emissions not specified elsewhere.

Source: [9]

In 2010 the Transport sector was the second largest producer of CO₂ emissions (Figure 1.2) and was responsible for 22% of world's CO₂ emissions [9] and about 30% of OECD country members⁴ [10]. In fact, globally CO₂ emissions from the transport sector are growing at a faster rate than total emissions from all sectors [10].

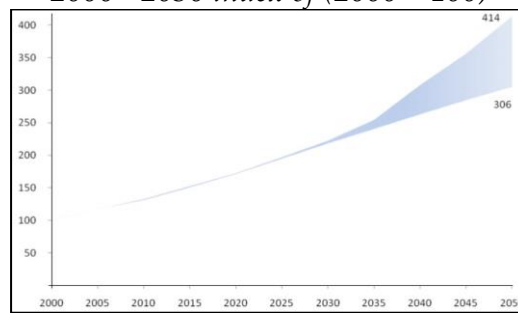
² First commitment period of the Kyoto Protocol adopted in Kyoto Japan on December 1997.

³ Second commitment period adopted in the "Doha Amendment to the Kyoto Protocol" in Doha, Qatar, on 8 December 2012.

⁴ The Organisation for Economic Co-operation and Development (OECD) member countries as of December 22, 2013 are Australia, Austria, Belgium, Canada Chile, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom and the United States.

The world's population is expected to reach 9.6 billion by 2050, this will lead global passenger mobility (passenger-kilometers travelled) to increase by a factor of 3 to 4 by 2050 with respect to 2000 [10-12] (Figure 1.3). Regarding future transport fuel trends, projections from the World Energy Outlook 2012 states that transport fuel demand will increase by 40% by 2035 announcing that global transport demand is unlikely to decrease in the near future [13]. Even with the use of new technologies and new energy sources in the future, on-road transport activity is expected to be a major contributor to global climate seeing that almost 75% of the world CO₂ emissions from transport in 2010 were due to road [13]. The growth in transportation energy demand is largely a result of increases projected for the non-OECD nations [14].

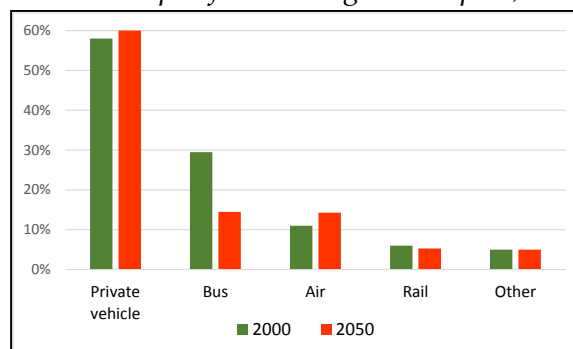
Figure 1.3. Index of world passenger transport activity (passenger-km), 2000 - 2050 index of (2000 = 100)



Source: [11]

Among transportation modes for passengers, Private Vehicles (cars and light trucks) are unquestionably the most pollutant of all [11] and their share at a Global level show that it is by far the dominant mode (Figure 1.4). Projections from the International Transport Forum show also that this share it is expected to rise worldwide by 2050 to the detriment of Public Transport mode⁵ [11, 15], despite the stagnation of car traffic in most industrialized countries since the 2000's.

Figure 1.4. World modal split for Passenger transport, 2000 and 2050 ⁶



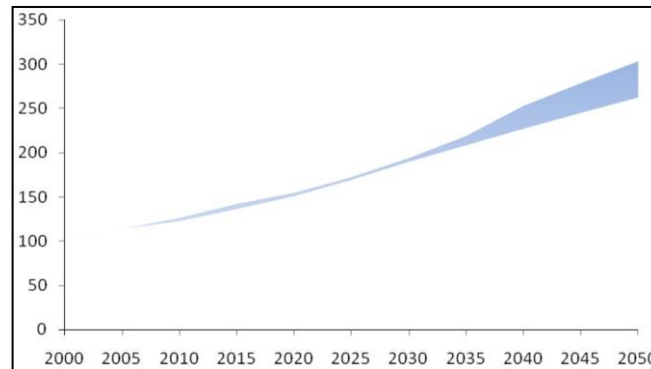
Source: [11]

⁵ Buses are expected to be substituted by private vehicles as incomes increase.

⁶ Halfway case between high and low scenarios (%).

Although fuel economy improvements⁷ were taken into account in the forecast from the International Transport Forum (Figure 1.5), and the expected growth rate is smaller than the growth rate of Global passenger transport activity (Figure 1.3), the World's CO₂ emissions from vehicles continue to increase by a factor of 2.8 by 2050, going in the opposite direction of the GHG emissions reduction targets established in the Kyoto protocol.

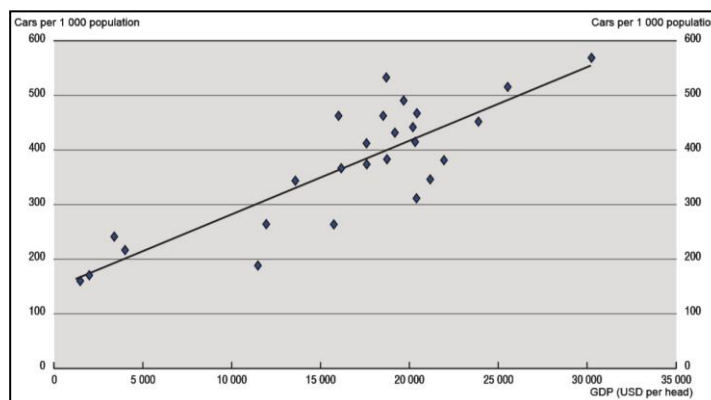
Figure 1.5. Index of World CO₂ emissions from transport vehicle, index (2000 = 100)



Source: [11]

To what extent this increasing trend (Figure 1.5) will be observed in different regions of the world? Will the countries that are currently more responsible of on-road CO₂ emissions be the same in the future? On one hand, it has long been observed in many studies [15-17] that income and travel demand are positively correlated, which seems to be no more the case in industrialized countries (Figure 1.6). More specifically there is a general linear correlation of car use and wealth [18].

Figure 1.6. Number of cars as a function of per capita GDP, 1994 data ⁸



Note: Cars=146+.0136 GDP.

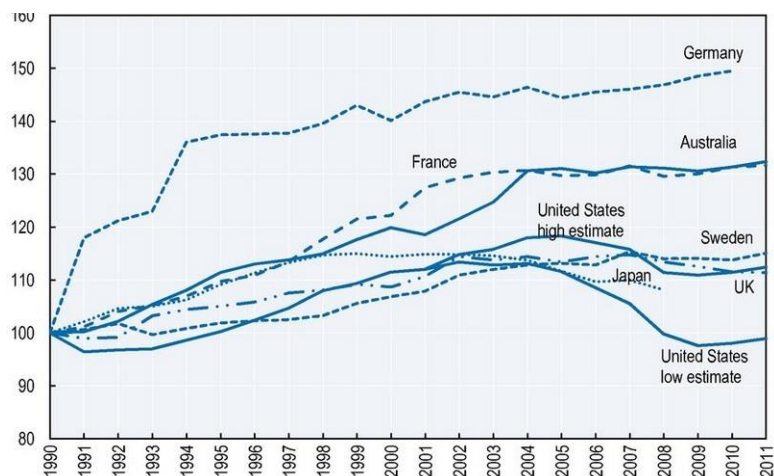
Source: [15] based on [19].

⁷ Implementation of public policies of penetration of hybrid and electric vehicles in the vehicle fleet.

⁸ Based on 1994 data from Australia, Canada, Japan, New Zealand, the United States and 21 European countries.

On the other hand, more recent studies also show this apparent relation is in fact robust [20] but it could have an apparent saturation point in wealthiest nations⁹ [11, 21, 22] This deceleration in travel demand in the last decade can be observed more clearly only in high-income economies (e.g. United States, United Kingdom, Germany, Sweden, France, Australia and Japan) where the growth of Passenger-Kilometres by private car has stopped or even decreased since 2003-2005 [23] (Figure 1.7).

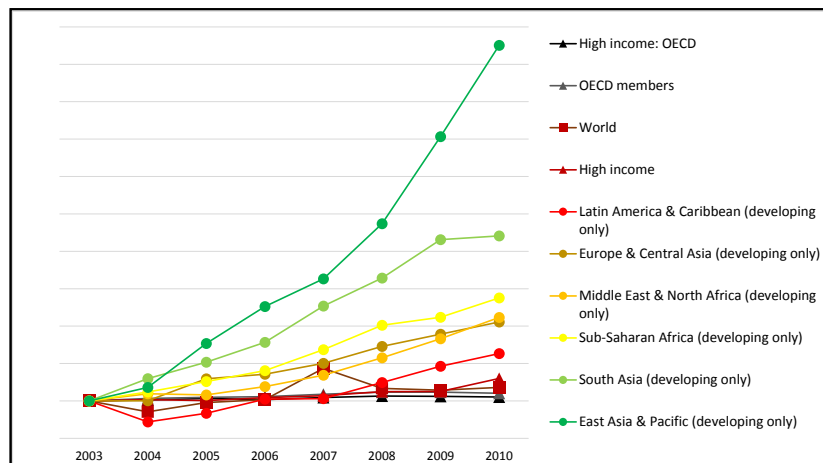
Figure 1.7. Index of Passenger-Kilometers by private car, Index of (1990=100)



Source: [23]

Are countries from different levels of development taking the same path? What can be said about vehicle ownership and vehicle use trends in developing countries? Is the developing world catching up with developed countries? If yes, can a time gap between development levels be estimated? And what are the driving forces –besides income- that interact in that process? How significant will be the influence of developing countries in the travel demand and CO₂ emissions in the future? Per capita vehicle ownership is obviously higher in developed countries [24], but what can be said about future trends in developing regions? Data from the World Bank show a clear distinction of growth rates of Private vehicle per 1000 people between developed and developing regions. While high income countries have been stable from 2003 to 2010, there is a major growth rate trend on all developing regions, going from 1.25 in Latin America and the Caribbean to 2.90 in East Asia and the Pacific, only in the short period of 2003-2010 (Figure 1.8). Since level of motorization at a household level is positively correlated to vehicle kilometers travelled [25], it seems that future increase of private vehicle use will be more important in developing world.

⁹ This saturation point it is also called "peak travel" for all modes and "peak car" when taking into account only private vehicle travel.

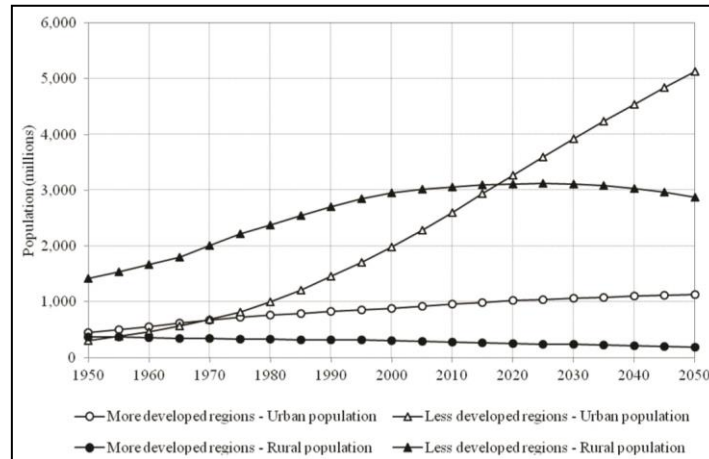
Figure 1.8. Index of Passenger cars (per 1,000 people) Index of (2003=100) ¹⁰

Source: [24]

In general, income increase over time, the levelling-off trends of richest countries (Figure 1.7) could suggest then a weakening of the link between travel demand and increasing incomes [16]. In very high-income economies the income effect on mobility will become smaller, therefore Private Vehicle travel demand will be then gradually a function of changes in the size and structure of the population [11] and changes on travel behaviour as well [25-32]. Hence, population growth forecasts and its spatial distribution within a territory plays a key role in travel demand forecasts, ergo the assessment of GHG emissions. It is well known that the majority of world's CO₂ emissions from transport are due to road, mostly concentrated in urban areas. According to United Nations 2011 revision [33]: *"the urban areas of the world are expected to absorb all the population growth expected over the next four decades while at the same time drawing in some of the rural population"*. It also states that among urban areas the population growth will increasingly be observed in cities of one million or more inhabitants [33]. Hence, on-road transport in urban areas with more than one million inhabitants have an important impact on global environment. Projections from The Population Division of the Department of Economic and Social Affairs at the United Nations predicts that 86% of developed countries and 64% of developing world will be urbanized by the year 2050 [33]. Levels of urbanization are closely correlated with national income [34]. Most population growth is expected to be concentrated in urban regions in the developing world [35, 36] (Figure 1.9). As a consequence, global travel demand trends will gradually be an outcome of urban mobility, and progressively from developing countries. Therefore urban mobility planning and management will be increasingly influential in order to reach not only regional but national environmental goals [23] and specific greenhouse gas emission reduction targets.

¹⁰ Passenger cars refer to road motor vehicles, other than two-wheelers, intended for the carriage of passengers and designed to seat no more than nine people (including the driver).

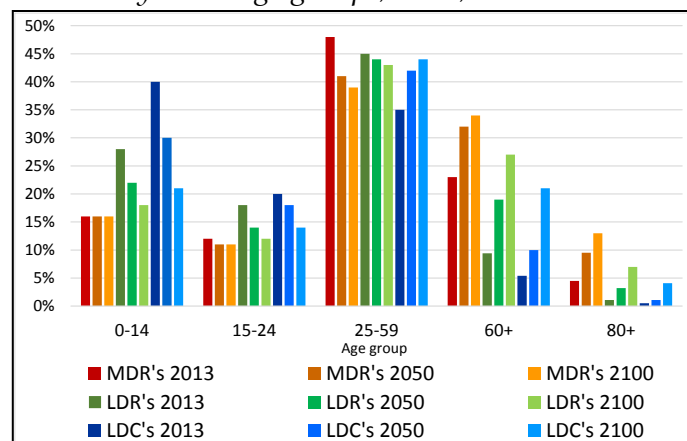
Figure 1.9. Urban and rural populations by development group, 1950-2050



Source: United Nations Department of Economic and Social Affairs/Population Division. World Urbanization Prospects: The 2011 Revision.

Population growth is expected also to be very different between developed and developing countries in terms of its age-pyramid composition. In fact, the last Revision from 2012 of the World Population Prospects from the United Nations states that increasing longevity, slow population growth and low fertility rates¹¹ had led to rapid population ageing¹² in developed countries. In 2012 the proportion of persons over 60 was significantly higher in the more developed regions and it will continue to increase from 23% in 2012 to 34% in 2100. On the other hand, population is still young in developing countries and population ageing is lower. In 2012, 9% of the population was aged 60 years or over, the percentage is expected to reach about 27% by 2100 [37] (Figure 1.10 and Table 1.1).

Figure 1.10. Distribution of the population of the world, development groups and major areas by broad age groups, 2013, 2050 and 2100¹³



MDR's=More developed regions; LDR's=Less developed regions; LDC=Least developed countries.

Source: [38].

¹¹ Most developed countries have had below-replacement fertility during last decades.

¹² Populations where the proportion of older cohorts increases while younger cohorts decreases.

¹³ Corresponds to the medium variant forecast scenario.

Table 1.1. Median age¹⁴ for the world, development groups and major areas, 1950, 1980, 2013, 2050 and 2100⁶

Development group or major area	Median age (years)				
	1950	1980	2013	2050	2100
World	23.5	22.6	29.2	36.1	41.2
More developed regions	28.5	31.9	40.5	44.5	46.3
Less developed regions	21.4	20.0	27.2	34.9	40.6
Least developed countries	19.3	17.6	19.7	26.4	35.9
Other less developed countries	21.6	20.3	28.7	37.6	42.8
Africa	19.2	17.6	19.4	24.7	34.9
Asia	22.0	21.0	29.7	39.8	45.4
Europe	28.9	32.7	40.9	45.7	46.8
Latin America and the Caribbean	19.9	19.8	28.3	40.6	48.1
Northern America	29.8	30.0	37.7	40.9	44.6
Oceania	27.9	26.4	32.6	37.0	44.1

Source: Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat (2013). World Population Prospects: The 2012 Revision. New York: United Nations.

NOTE: Only countries or areas with 90,000 persons or more in 2013 are considered.

What would be the impact of future age composition of the population on travel demand? Population ageing trends individually and collectively will have profound and significant social and economic implications on all aspects of human activity [19, 39, 40] including travel demand [11, 15, 19, 23, 25-32, 36, 41, 42]. To illustrate the impact of ageing on travel demand the OECD made an inquiry based on National Travel Surveys showing that in countries like Germany, Sweden, USA, Norway and Great Britain non-elderly people make about the double of number of trips per day and travel, in some cases, three times more kilometers compared to elderly people (Table 1.2).

Table 1.2. Number of trips and travel distance per day, elderly vs non elderly, for selected developed countries.

	Age, elderly	Age, non-elderly	Number of journeys per day		Distance per day (km)	
			Elderly	Non-elderly	Elderly	Non-elderly
Germany (1997)	75-79	18-59	1.9	3.4	8	22
Sweden (1994-96)	75-79	40-49	1.5	3.2	12	35
US men (1995)	75-79	18-64	3.5	4.6	38	83
US women (1995)	75-79	18-64	2.9	4.7	26	60
Norway (1997-98)	65+	35-44	1.9	3.5	16	35
Melbourne, Australia (1993-94)	80-84	18-59	2.4	3.0	–	–
Great Britain, men (1996-98)	75-79	25-49	2.2	3.3	15	50
Great Britain, women (1996-98)	75-79	25-49	1.6	3.5	12	32

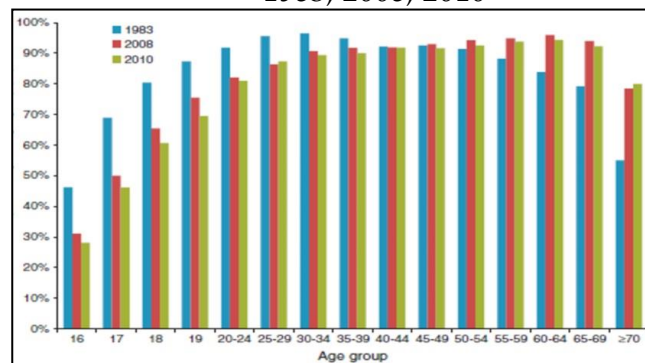
Source: [15]

The age of a person indicates the stage in which a person is placed in the life-cycle, which trace the essential stages of an individual through life from school to retirement. Indeed, age and life-cycle have been correlated with daily mobility which are explanatory factors for travel demand and mobility behavior.

¹⁴ The median age is an indicator of population ageing, it divides the population in two halves of equal size.

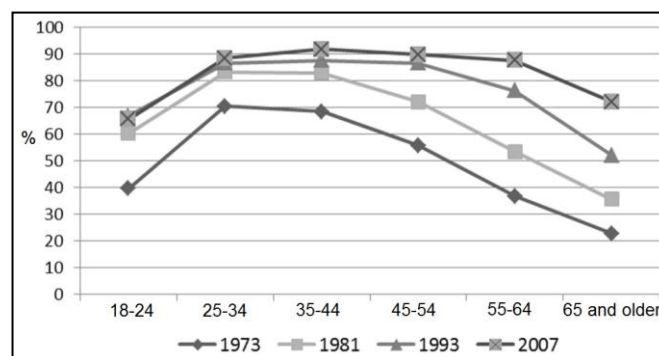
In fact, age-mobility relationship has been largely observed on transportation surveys [19, 25-32] and in some cases it is a strategic variable to explain travel behavior choices, almost as important as income [25, 26]. The relationship of daily mobility with respect to age might not be exactly the same between countries and cities, but in general we can observe a similar pattern in which retired people travel the least of all¹⁵, as well as younger kids. The people who travel the most are always those from the 30-50 years old bracket (Figures. 1.11, 1.12, 1.13, 1.14 and 1.22). For instance, the same pattern can be observed at an aggregate data level (e.g. annual and national level) from Driver License Holders¹⁶ rate by year in USA (Figure 1.11) and France (Figure 1.12). The same pattern seems to remain comparable at urban level (e.g. Melbourne and San Francisco) and also when broken down by total daily number of trips per person (Figures 1.13 and 1.14).

Figure 1.11. Evolution of Driver License Holders (in percentage) in USA, 1983, 2008, 2010



Source: [29]

Figure 1.12. Evolution of Driver License Holders (in percentage) in France, 1973, 1981, 1993, 2007

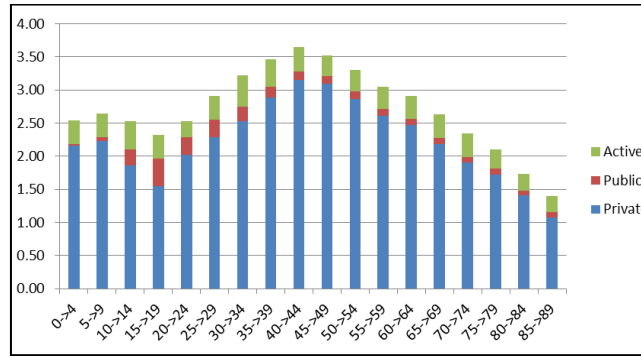


Source: [25] base on National Travel Surveys 1973, 1981, 1993 and 2007.

¹⁵ In general, oldest cohorts usually have not only the lowest travel activity, but also the largest share of people who did not travel on the surveyed day as well.

¹⁶ Driver License Holders is positively correlated to private vehicle use [22, 25].

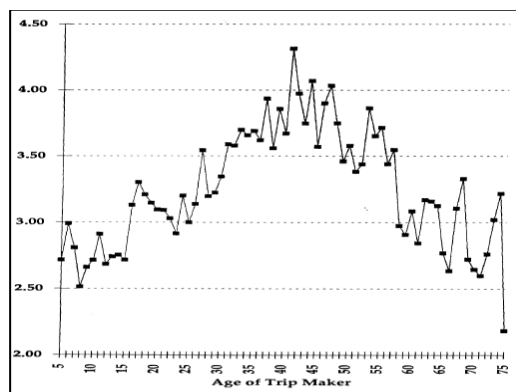
Figure 1.13. Average daily trips per person by age, Melbourne, Australia 2009.



Source: Victorian Integrated Survey of Travel and Activity (VISTA).

<http://www.transport.vic.gov.au/research/statistics/victorian-integrated-survey-of-travel-and-activity>

Figure 1.14. Average daily trips per person by age, San Francisco Bay Area, 1990



Source: <http://ntl.bts.gov/DOCS/SF.html>

Even though it has been shown that age can be a predictor of travel demand at one point in time, there is as well sufficient evidence that support the fact that age-dependent activity like travel demand vary from one generation to another. Actually, intergenerational lifestyles are not static but change dynamically between generations [25-32]. For instance, one of the phenomenon observed recently is the counterintuitive opposite trend in use of private vehicle between elder and non-elder people. On one hand, it has been observed in recent years that young adults of most of developed countries have becoming less likely to get a driving license [25, 29]. In fact the decline of driver's license rates for younger adults with respect to past generations can be explained by many factors (e.g. carpooling, high fuel costs, economic crisis, the use of internet/telecommuting, behaviors more prone to multimodality, etc.). On the other hand, quality of life for elder people in developed countries have been increasing over the last decades (among other factors such as the increase of mobility of women from all ages in apparently all developed countries, the extension of the retirement age limit in some countries, etc.) having important mobility consequences. This increase of private vehicle use in elder people has been observed in many countries.

For instance, the evolution of Driver License Holders in USA (Figure 1.11) and France (Figure 1.12) clearly show that elder people from the latest survey (2010 in USA and 2007 in France) keep and drive their vehicles significantly more than people at the same age from previous generations (surveys of 1983 in USA and 1973 in France).

Since age and cohort-effect are correlated to travel activity they are essential to the development of mobility and GHG emissions forecasts. But, Can a stabilization of the relation between travel behavior and age be possible in future years? It appears that intergenerational dynamics in terms of travel demand will continue to be observed in the future. In fact, projections from OECD of developed nations of different continents (i.e. USA, Japan, France, Australia, etc.) show important intergenerational increases in licensed drivers aged 65 and older between 2000 and 2030 (Table 1.3). Hence, the necessity to take into account not only age and cohort effects but also its future trajectory into travel demand forecasts [26, 27, 31, 32].

Table 1.3 *Driving license rates for people 65 and older for selected OECD⁴ member countries, 2000 and projected 2030*

	Percentage of licensed drivers aged 65+ in 2000	Percentage of licensed drivers aged 65+ in 2030	Percentage increase in licensed drivers aged 65+
Australia	12.6	22.1	75
Finland	14.9	26.7	79
France	16.1	25.8	60
Japan	17	27.4	61
Netherlands	13.7	26.5	93
New Zealand	11.6	18.3	58
Norway	15.3	23.5	53
Spain	16.8	26.1	55
Sweden	17.2	24.1	40
United Kingdom	15.7	23.5	49
United States	12.6	20	59

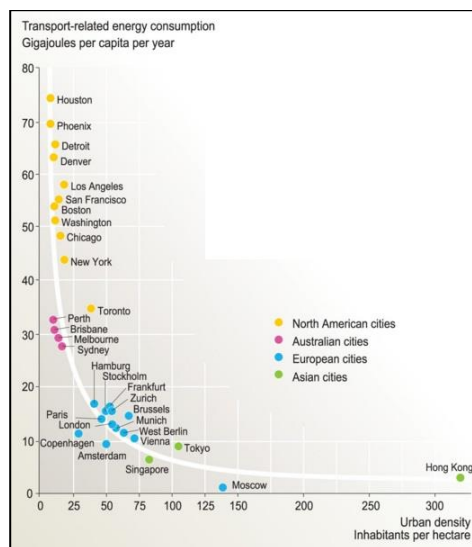
Source: [15]

Once controlling for income, age and cohort-effects, what are the driving forces that influence travel intensity and mode choice? It has been previously said that the future world's travel demand will be gradually a function of rate growth and age composition of the population. Additionally, data have shown that future population will live mostly in urban areas. However, cities have been growing and taking shape very differently from each other, thus they have very different urban form configurations [36, 43-45]. For example, the number of people living in a given urban area¹⁷ differs greatly between urbanized territories around the globe, influencing very differently the needs for urban travel of an individual and his/her transportation mode choices [22, 45-48]. A great deal of research has been conducted on the

¹⁷ e.g. hectare, acre, km², ft², Transportation Area Zone (TAZ), Census Block, etc.

relationship between urban characteristics and travel demand¹⁸ [36, 43-47, 49-56]. Density, which refers to the number of homes, people or jobs in a given area [48] is not the only, but probably the most important determinant of travel among urban characteristics¹⁹ [45]. The difficulty with this indicator is, that it is often difficult to identify non-built areas (fields, forests, parks, etc.) ; it is why the proportion of households living in collective buildings is a better explanatory factor of car ownership [57]. According to [34], urban density is the most significant measure of urban form for explaining urban transportation. A highly cited research on this subject is the world-wide comparison by [47]. Newman and Kenworthy show a strong negative correlation between average urban density and transport-related energy consumption per capita (Figure 1.15). For example, in a very densely populated city like Hong Kong (with 350 inhabitants per hectare), the energy consumption due to transport is about 2 Gigajoules/per/year, while in a sprawled city such as Houston (only 6 inhabitants per hectare) the consumption rises up to 75 Gigajoules/per/year.

Figure 1.15. Urban density and transport-related energy consumption



Source: [47]

A study of 32 major world cities developed by [52] shows that direct public policy instruments (e.g. provision of infrastructure for private vehicles and/or bus rapid transit, or the density of population and jobs) have more impact on transport than economic factors (e.g. petrol price and income). The conclusion based on observation

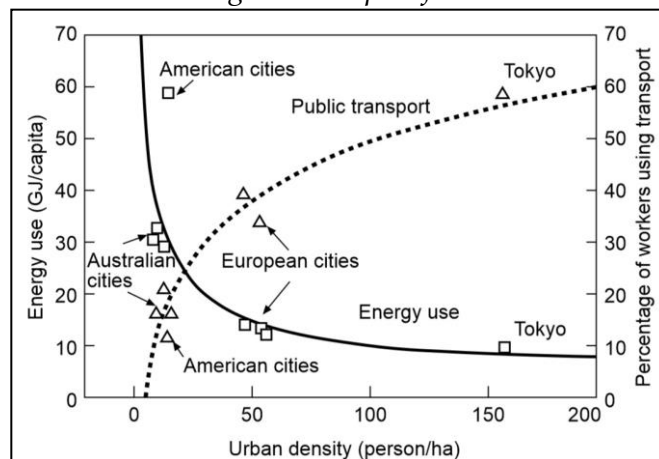
¹⁸ As daily transport intensity in terms of total number of trips and total distance by each transportation mode (e.g. car, bus, bicycle, walk, etc.).

¹⁹ Population density may be coupled with other key variables. As stated by Newman, P. [22]: “density is an intermediate variable that is often expressed by the others (i.e., dense settings commonly have mixed uses, short blocks, and central locations, all of which shorten trips and encourage walking)”.

from these 32 cities was that, in general, cities seem to reduce their dependence on private vehicles by increasing population densities [52]. This statement is consistent with results based on a major meta-analysis computed from 62 studies mainly from North American cities, in which one of the conclusion was that doubling urban population densities¹⁸ seems to reduce per capita Vehicle Miles Traveled (VMT) by about 25% [22].

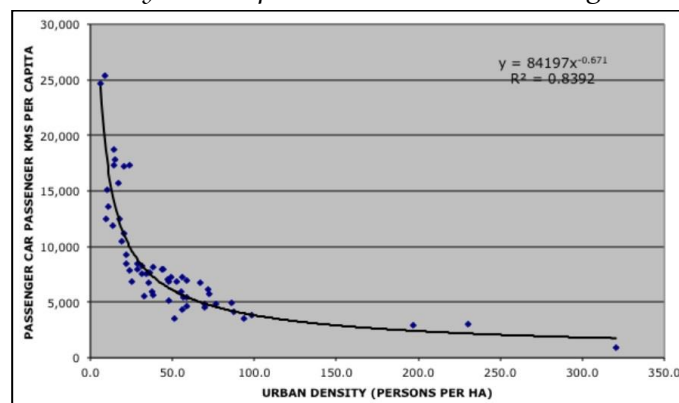
In fact, updates from Newman and Kenworthy [22, 46] reveal that density is highly correlated with modal choice. In general, denser cities around the globe tend to have greater use of alternative modes than sprawled cities. Indeed, high density cities exhibit an almost total predominance of public transport use and total transport-related energy consumption (GJ/capita) is negligible compared to low density cities (up to seven times less) (Figure 1.16). Furthermore, a comparison between urban density versus private vehicle use in 58 higher income cities exhibit rapid decline in private vehicle use with increasing population density (Figure 1.17).

Figure 1.16. Urban density, energy use and public transport for the journey to work in a global sample of cities



Source: [46]

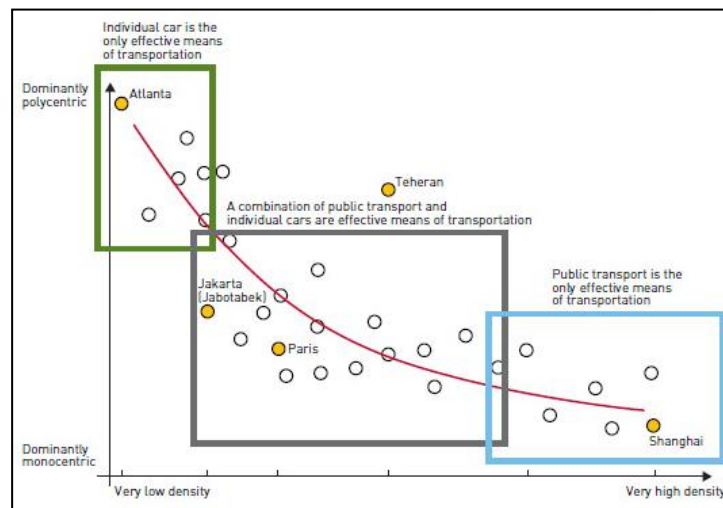
Figure 1.17. Urban density versus private car travel in 58 higher income cities, 1995



Source: [22]

Consistent with [22, 46, 48], and based on approximately 50 cities around the globe, [58, 59] show that in very low-density cities private vehicle tend to be the most effective means of transportation in terms of its modal share. On the contrary, in very high-density cities, Public Transport seems to be the most effective means of transportation (Figure 1.18).

Figure 1.18. Relationship between spatial structure, population density and the use of public transportation



Source: [58]

In general, the number of potential trip destinations tend to grow with each density gradient increase within an urban area, reducing travel distances and the need for private vehicle use [48]. In fact, travel demand patterns differ also across residential zones within an urban area. As stated by [48, 59], density can be measured at various scales: county, municipal, neighbourhood, census tract, etc. Thus, cities have different density gradients depending on the spatial distribution of people within each urban area. Indeed, several studies have highlighted also the influence of urban form at a smaller scale within a city (e.g. center²⁰, inner suburbs and outer suburbs) on travel intensity and transport behaviour [36, 43-45, 60]. It seems that the analysis of disaggregate gradients of density and not only the average is needed in order to better understand²¹ travel demand, transport choices and transport-related energy consumption in an urban area. As stated by [53] :

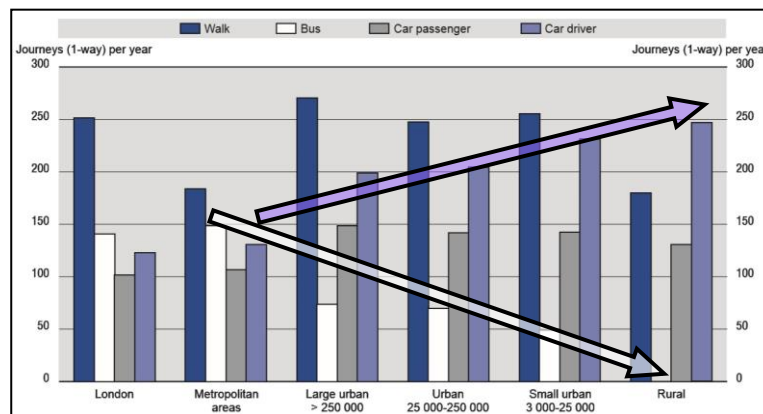
²⁰ Also called city-center, downtown or central business district (CBD).

²¹ Therefore to better assess (based on current activity), model and forecast future travel demand and transport-related energy consumption.

"While the general conclusions put forward by Newman and Kenworthy are not disputed, they have been criticised, in particular because the spatial distribution of activities and households is not analysed. The spatial structure of a city, in particular the relative location of homes, employment and amenities, also has an impact on the number and length of trips. An analysis of average density is not sufficient to explain transport-related energy consumption".

The National Transport Survey of 1997-1999 from Great Britain clearly illustrates how different gradients of density and urbanization affects travel patterns (Figure 1.19). While Public Transport mode show a rapid downstream trend from metropolitan to rural areas, Private Vehicle Driver mode experience exactly the opposite trend.

Figure 1.19. Trips made annually in Great Britain, 1997-1999 ²²



Source: [15]

As remarked by [34]:

“Low to medium density residential areas (urban sprawl) around urban centres are common in the developed world. Well developed infrastructure and the increasing use of the car have facilitated this trend. Urban sprawl has an especially damaging effect on the environment associated with the increase in use of private motorized transport”.

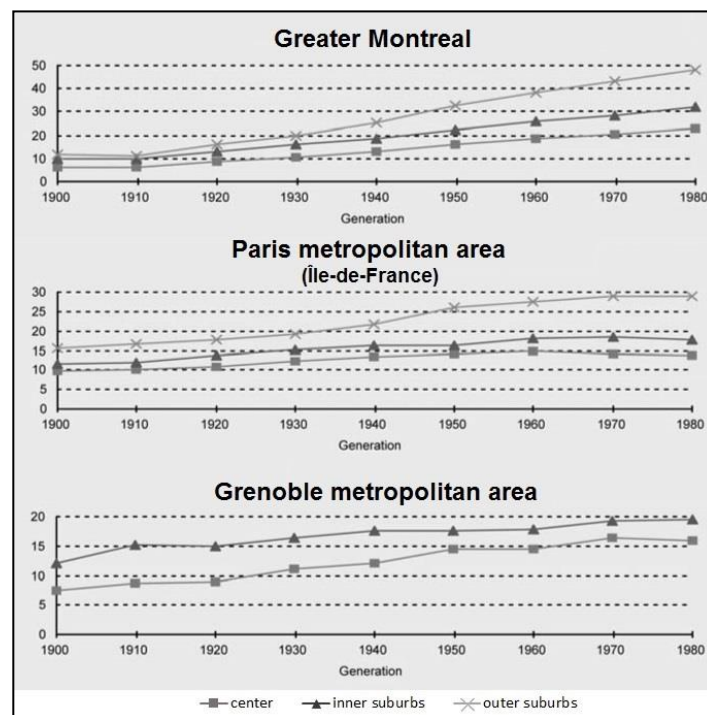
In relation to urban form and its impact on travel behavior, transportation surveys have shown that variables that explain travel demand actually change over time, meaning that these determinants are dynamic [25, 27, 31, 32, 36]. These dynamic evolutions have to be also accounted for when analyzing the urban form and transport relationship. Reviewing the work done by Newman and Kenworthy [48] remarked that:

²² by people aged 70 or more.

"One problem is that analyses of city density and car dependence are usually static. Plotting urban form and transport consumption at a particular point in time – the mid/late 20th century in the Newman and Kenworthy case – embodies particular patterns of technology, wealth, and behaviour. Consequently, their urban prescription is based implicitly on the 9 to 5 work day; single city centres that focus urban employment, exchange, and consumption; and the nuclear family with its distinctive housing and service demands. These are all urban artifacts that have been breaking down since the 1960s".

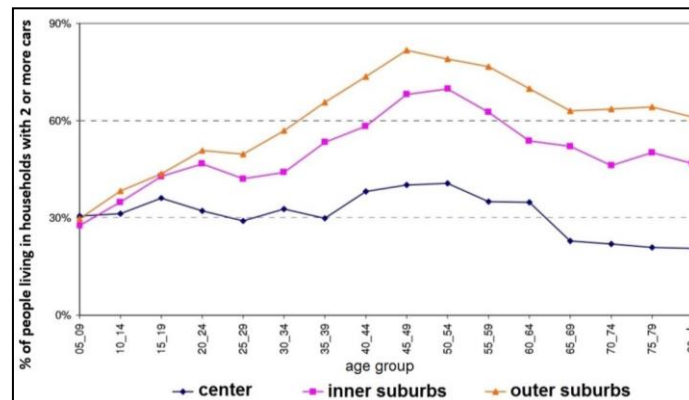
For instance, [36] show from very different metropolitan areas (Montreal, Paris and Grenoble) that the urban zone has a direct influence on total travel distance. As expected, those residing in the center of the metropolitan area travel significantly shorter distances than those residing in the suburbs. This is consistent to the case of Lille (Figure 1.21). Additionally, the growth rate of travel distance from 1900 to 1980 for Montreal, Paris and Grenoble is significantly bigger in the outer suburbs than in the city center (Figure 1.20). Hence, disaggregate approaches to the study of travel demand by residential zone are needed.

Figure 1.20. Travel Distance by zone of residence: center, inner suburbs, and outer suburbs. Generation gaps from 1900 to 1980, for mobility of 30-34 years-old bracket (units: km/day/per)



Source: [36]

Figure 1.21. Motorization (≥ 2 cars) by age group and by zone of residence for generation of 1966-1970, Lille



Source: [32]

Concerning residential mobility, the general trend worldwide has been urban sprawl [34]. Urbanized areas are usually described in terms of concentration of housing and employment buildings, but the expansion of faster transport modes in Europe and highway infrastructure in USA has allowed this sprawling trend followed by a relocation of office parks and the development of the newest generation of housing in outer suburbs. This has caused in many developed cities the concentration of population and employment in the inner and outer suburbs and the parallel decrease in the city center²³ [34]. Consequently, the interactions between these different urban zones (city center, inner suburbs and outer suburbs) have changed rapidly over the years [48]. Does the influence of urban form on transport behavior is comparable in contexts as diverse as the developed and developing countries? In the developing world urban sprawl is often caused by lack of urban planning, high cost of living in the city center and by the relocation of people to cheaper former rural areas, usually in very poor conditions. Nevertheless, urban sprawl in poor southern cities, is not very important due to low levels of car ownership and the difficulty to implement road and transport infrastructure in remote areas [36].

On the one hand, transport and urban planning policies can help cities ease their dependence on the automobile and reduce transport-related GHG emissions. On the other hand, determinants of car ownership (or the reasons for not use public transport) between developed and developing countries may vary significantly. Therefore managing the urban environment sustainably through urban planning policies will become one of the major challenges in both worlds in the future.

²³ “doughnut effect”

A crucial phase needed for the development of such policies is a comprehensive knowledge of the driving forces behind travel demand and travel behavior over time. The main question is therefore, for whom exactly are urban and transportation planners planning for? Literature have shown that the most important determinants of travel demand can change significantly year after year and could differ between levels of development. Hence, GHG emissions reduction strategies (e.g. public transport policy) in urban areas in developed and developing countries need to react to evolving travel demands differently and have to anticipate changes of demographics (e.g. age pyramid ageing), transport behaviors (e.g. intergenerational changes or cohort effects), urban form configurations (e.g. population density increase in city center vs suburbs), income and fuel prices (with evolving elasticities). Indeed, studying demography and urban form in opposed development countries is therefore important in order to identify the main factors of urban mobility and transport-related GHG emissions; and consequently, to promote sustainable mobility in the future.

Why a particular emphasis on developing countries? As said before, population growth will be mainly in southern countries; they are still young and motorization rates are expected to grow rapidly in comparison to developed countries which are old and are becoming less car-dependent, therefore developing countries will be gradually responsible for most of transport-related GHG emissions in the future.

Observing these clear differences between levels of development, one question has to be considered: Will southern urban areas with population over 1 million inhabitants reach the stage where northern urban areas with the same size are currently located in terms of urban mobility? If not, does each city takes a different path of evolution in terms of travel demand? In other words, can transport behavior in comparable cities in developed countries today could be a predictor of transport behavior in urban areas of the developing world?

More important, have travel behavior changes and population ageing in these urban areas been sufficient to slow down travel demand in the past in developed and developing countries?

Will the demographic changes (population ageing) and travel behavior changes (between age and cohorts) be sufficient to slow down urban travel demand in developed and developing countries in the future?

Lastly, have vehicle technological advances been sufficient to reduce transport-related GHG emissions? What is the delay between developed and developing countries in terms of vehicle technology implementation? And, what is the repercussion of this delay (if observed) on the environment?

If factors are identified, then they may be used by urban and transportation planners in order to promote sustainable public policies, by influencing (among the variables that can be modified) the controllable variables that have greater impact on travel demand in the future. Thus, developing cities could anticipate and adopt sustainable solutions implemented (or avoid "mistakes" made) by developed countries.

The main focus of this research effort is therefore to perform comprehensive analysis in urban areas (with population over 1 million inhabitants) from different development contexts in order to determine the main factors of travel demand taking into account socioeconomic, geographic and demographic variables. Additionally, to forecast daily mobility taking into account age and generation effects. Finally, to assess the impact of observed travel activity on GHG emissions.

1.2 General objectives of research

The objectives of the present research project are:

Make household travel surveys from two northern urban areas and two southern urban areas exploitable and homogeneous.

Identify for each case study, based on household travel surveys, the most significant determinants of travel demand and transport behavior and their evolution through time at an individual and disaggregate level in terms of zone of residence and socio-demographic characteristics.

Apply for each case study Travel Demand Forecast models taking into account age and cohort effects, decoupling the effects of changes in transport behavior and population structure.

Finally, to develop Greenhouse Gas (GHG) emissions assessments in order to follow the environmental impact of travel demand changes and vehicle technology implementation over time.

1.3 Literature review

Travel demand long-term forecasts by mode are essential for urban transportation planning [61]. Household travel surveys are the most commonly used statistical surveys to analyze daily mobility in an urban area and are also generally used worldwide by planners to develop these projections [32, 43]. However, these are Cross-sectional surveys, meaning that they provide only a snapshot of mobility at a single year [62]. Since Cross-sectional surveys are confined to a specific point in time, they have limitations for long term travel demand forecasting [26, 27, 61, 63-68]. As shown in section 1.1, population characteristics and behaviors are not static but change constantly over time. Hence, cross-sectional surveys reflect current travel behaviors only if a very recent survey is available. Since travel behavior tends to be different over time, efforts to predict future travel behavior based only on most recent Cross-sectional surveys seems to be inappropriate. For instance, [26, 31] and more recently [69] have found that long term income elasticities with respect to transport behavior cannot be drawn from cross-sectional analysis, hence cannot identify long-term dynamics of car ownership and car use. Long term travel demand modeling, based on time series datasets seems to be the most appropriate way to take into account the impact of changes in travel behavior in the forecast [70]. However, it is not conceivable to obtain constantly the data needed in transport studies due to high complexity and cost [27, 62].

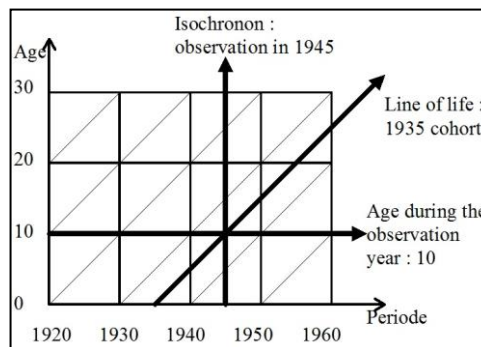
First steps of temporal transferability taking into account successive cross-sectional transport surveys from the same territory have been done since early 70's in the United States. In fact urban planners and researchers have had the intuition to compare systematically every transport survey from each other to see their evolution. They have mostly used linear regression models applied by zone from successive travel surveys [71-73]. However the results do not allow the development of accurate travel behavior forecasts. Although some models produce acceptable forecasts errors in zonal level²⁴, they also conclude that the coefficients of relationship (regression) change significantly and parameters are not always stable.

Years later, researchers began to create time series data from repeated cross-sectional surveys [74]. According to [75], pseudo-panel does not need any panel data, but simply a series of cross-sectional surveys to recreate the linear link between the three

²⁴ between 10 and 15% for best forecast.

dimensions (age, period and cohort). The « Lexis-Becker-Verweij-Pressat » diagram (Figure 1.22), which is the interaction between these three chronological dynamic variables, was described by [76].

Figure 1.22. Lexis-Becker-Verweij-Pressat diagram (Pressat style)

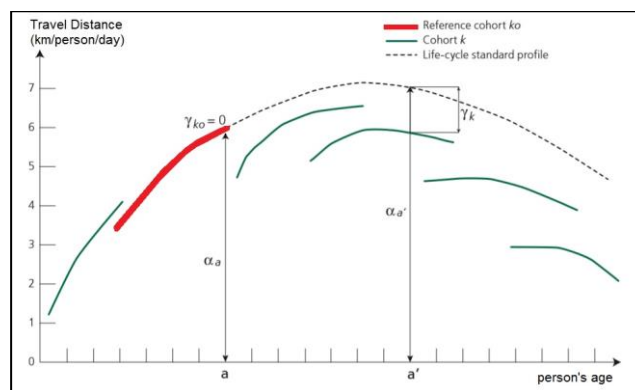


Source: [76]

Literature review revealed that forecasts based on pseudo-panels²⁵, rather than a static observation (cross-sectional), have been studied for travel demand, particularly in developed countries for cities like Montreal, Paris [36, 61, 67, 68, 77] and Lille [27, 32, 65]. Developing countries began to use this forecasting approach for cities such as Sao Paulo, Brazil [36, 78, 79] and Puebla, Mexico [36, 80, 81]. In fact, time (or period), age of an individual (life-cycle position), and year of birth or cohort are linked to specific travel behavior activity [61]. In other words, the samples from different cross-sectional surveys change from one year to another, but it is possible to follow cohorts of persons defined by their year of birth [31, 32]. To evaluate these effects (age, generation and period) on transport behavior, and to make long-term projections of mobility, researchers of the French National Institute for Transport and Safety Research (INRETS) [31, 63, 64, 66], developed a demographic approach to travel demand forecast (Figure 1.23). The construction of this dynamic model for transport demand was made in the 80's mainly based on work developed by [63, 64], first to make projections of car ownership in the long term [31, 66] and then in the 90's to make long-term mobility estimations [77]. [31, 66] [77] established that it was possible to use pseudo panel data sets to forecast travel demand with reliable results (Figure 1.23).

²⁵ Pseudo-panel data sets are created with comparable cross-section data collected repeatedly over time [74].

Figure 1.23. Life-cycle standard profile and travel activity



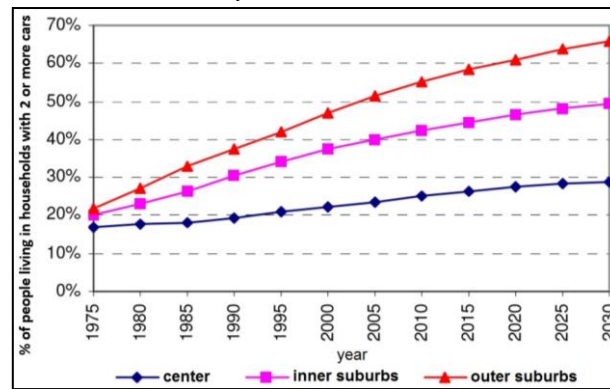
Source: based on Gallez, 1994, diagram 26a, p. 178.

In most cases, the regression parameters applied on different cities indicates that the Age-Cohort model estimates appropriately travel activity by the analysis criteria (e.g. gender, zone of residence, age, etc.) [31, 32]. In relation to forecast precision, [61] have found that the demographic approach for long term forecasting with an Age-Cohort model applied at Paris and Montreal gives generally good results with errors in the 10-15% range. When errors reach higher levels (in the range of 30-40%) are mainly when the size of the sample is very small. As stated by [68]:

“The Age-Cohort approach is a reliable methodology for long term projection of transport demand”.

In addition to age and cohorts effects previously mentioned, and in an effort to take into account urban form and transport behavior dynamics, researchers have applied Age-Cohort model in order to forecast travel demand by zone [26, 27, 31, 32, 36, 61, 68]. In general, they have shown that travel distance declines with density and this trend seems to continue in the future in many cities of developed countries. For instance, projection with Age-Cohort model of motorization rate by zone of residence in Lille, estimates that the largest share of non-motorized individuals should still reside in the city center while the fastest growth of multi-motorization (≥ 2 cars) will be observed in lower density suburbs [32] (Figure 1.24).

Figure 1.24. Motorization (≥ 2 cars) forecasts by zone of residence, Lille from 1975 to 2030



Source: [32]

Furthermore, the Age-Cohort model has been a convenient tool for analyzing global phenomena such as peak car and peak travel (mentioned in section 1.1). For instance, [65], have decoupled behaviors shifts from structural effects showing that population ageing in Lille explains only partially the saturation in daily mobility observed in the 2000's.

In relation to on-road GHG emissions inventory, literature review show that in Europe, one of the first efforts to estimate CO₂ emissions from Household Transportation Surveys was performed by the former French National Institute for Transport and Safety Research (INRETS) in the 1990's through the development of BEED methodology (Energy Environment Budgets from Travel) and its application on several French cities [82-85] and the French Environment and Energy Management Agency (ADEME) [86]. Afterwards, the emission factors for road transport at European level were harmonized through the MEET project (Methodologies to Estimate Emissions from Transport), an European Commission (DG VII) sponsored project within 4th Framework Program (1996-1998), [87, 88]. Which later became the COPERT methodology (Computer Programme to Calculate Emissions from Road Transport) [89]. COPERT has been developed for preparation of standardized, hence comparable road transport emission inventories in European Environment Agency (EEA) member countries [90]. The BEED methodology has permitted several French cities to develop harmonized transport-related GHG emissions inventories, disaggregated at an individual and household level, hence to highlight very successfully the explanatory socio-economic and geospatial variables of transport-related CO₂ emissions per person [83, 91-95].

Full descriptions of Age-Cohort Travel Demand model and BEED methodology are found in chapters 4 and 5 respectively.

Besides the work done by [78, 79] for the city of Sao Paulo and [80, 81] in Puebla, the significance for dynamic demographic approach for urban transport modelling have not previously received substantial treatment in the literature on urban areas from developing countries. Therefore, this study represents an unprecedented effort in Mexican urban areas to forecast transportation demand in the long-term with the Age-Cohort model approach developed by the French National Institute for Transport and Safety Research (INRETS). Additionally this project aims to assess energy expenditure and greenhouse gas (GHG) emissions from observed travel demand.

1.4 Outline of report

The present document has been structured in six chapters.

Chapter 1 (Introduction) provides a background and justification for the research.

Chapter 2 (Case studies and data sources). Outline the selection of case studies. Additionally, it describes Household Travel Survey database organization and the variable imputations needed to apply the econometric modelling analysis, the Age-Cohort Travel Demand Forecast model and the GHG emissions inventory methodology.

Chapter 3 (Daily mobility evolution) describes mobility evolution based on cross-sectional observations; includes a general overview of travel activity and a comprehensive econometric modelling section covering major travel determinants for each household transportation survey and their changes over the years.

Chapter 4 (Age-cohort mobility forecasts) describes the Age-Cohort Travel Demand Forecast model followed by its application to all case studies. Additionally, it contains an overview of forecasted transportation trends in Mexican and French cities.

Chapter 5 (Environmental assessment from daily mobility) describes the general BEED (Energy Environment Budgets from Travel) methodology and its applications on the case studies. By combining Household Travel Surveys and emissions factors, our aim is to measure the GHG emissions due to transport at global and individual level.

Chapter 6 (Conclusions) presents the overall contributions of the research, its limitations, general findings, as well as future research recommendations.

Chapter 2. CASE STUDIES AND DATA SOURCES

Chapter 2. Case studies and data sources

2.1 Background

This chapter outlines the selection criteria of case studies (Section 2.2). Additionally, it describes the data requirements (Section 2.3), data availability (Section 2.4) and variable imputations in case of item non-response and generation when the information has not been collected in the survey (Section 2.5) in order to apply both: the GHG emissions inventory methodology²⁶ and the Age-Cohort Travel Demand Forecast Model²⁷.

2.2 Case studies

The previous chapter has presented evidence on the impact of urban form, age and level of development of an urban area on travel behavior. One of the interests of this study is to identify the driving forces of travel behavior over time and their trends in different contexts in terms of level of development. In order to attain this objective two countries from different level of development are presented on this study: France from developed countries and Mexico from emerging nations. As said in the previous chapter, Household Travel Surveys are the most common surveys used to observe travel behavior in an urban area. The first step in order to attain the objectives of this research effort is then to make Household Travel Surveys from developed and developing countries exploitable and homogeneous in a sense that surveys have to be comparable. Therefore, the availability and accessibility of Household Travel Surveys played a major role in the selection of case studies at country and city levels, in particular in developing regions. It is important to emphasize that in order to apply the Age-Cohort Travel Demand Forecast Model, at least two points in time are required. In other words, the forecasting methodology presented in this study needs two or more Household Travel Surveys from the same urban area from different years collected at different points in time distant of at least ten years. France, like most industrialized nations, has been applying standardized Household Travel Surveys on major urban areas, at least since the 70's. The availability and accessibility of these surveys was an important factor for choosing this country. In addition, the Age-Cohort Travel

²⁶ Full description and application in Chapter 4.

²⁷ Full description and application in Chapter 5.

Demand Forecast Model has been previously applied mainly in French cities, hence the interest to choose this country in which the model has been already tested. France is a developed country member of the leading industrialized countries named G8 group, and it is the world's fifth-largest economy by nominal GDP [96]. In 2012, France was ranked n°24 worldwide by Gross Domestic Product (GDP) at Purchasing Power Parity (PPP) per capita²⁸ and n°22 by GDP (nominal) per capita²⁹ [97].

Moreover, in virtually all developing countries the study of daily mobility has been focused mainly in the capital cities and larger metropolitan areas. This is explained by the fact that governments try to resolve first the problems related to public transport which are observed mainly in larger conurbations [98]. The main problem with Travel Household Surveys in developing nations is their high cost, which has resulted in its application in a limited number of cities, the lack of updating and sometimes significant compatibility issues between each other (e.g. surveys from the same city from different years) and with other sources (e.g. surveys from different cities) [99].

In addition, even if Travel Surveys exists, it is often very difficult to have access to them, even from governmental authorities. For instance, Ortúzar [100] points out that in the absence of official statistics, the vast majority of large and medium urban areas in Latin America have conducted Household Travel Surveys through private consultants. This has derived to almost exclusive internal use of Surveys by local governments, limited distribution and therefore its difficult access [100].

In Mexico there is almost no research on the evolution of daily mobility within an urban area. This can be explained by the absence of time series transport-related datasets that could make them viable, as well as compatibility issues between existing Household Travel Surveys [98]. Hence, the interest to study the evolution of urban daily mobility in Mexican cities. Despite its level of development, some Mexican cities have managed to apply consecutive Household Travel Surveys through mixed or complementary funds from international organizations (e.g. World Bank, North American Development Bank, etc.).

²⁸ Gross domestic product (GDP) at purchasing power parity (PPP) per capita, the value of all final goods and services produced within a country in a given year, divided by the average (or mid-year) population for the same year [98].

²⁹ Gross Domestic Product (GDP) per capita at nominal values. This is the value of all final goods and services produced within a nation in a given year, converted at market exchange rates to current U.S. dollars, divided by the average (or mid-year) population for the same year [98].

In the present study the Travel Demand Forecast Model is applied to two urban areas from the same country, representing different travel behaviors within a same nation. As said previously, the forecasting model requires at least two surveys from each city at different points in time. This means that one important selection criteria for case studies is that at least two comparable surveys from two urban areas had to be available. Mexico meets those requirements, in particular with the cities of Juarez and Puebla³⁰.

Mexico, is one of the most important emerging economies, but its place in the GDP international rankings indicates that there is a significant gap between this nation and developed ones. In fact, as described in previous chapter, one interest of this study is actually to follow this gap between developed and developing countries in terms of travel behavior. In 2012, Mexico was ranked n°66 by Gross Domestic Product at Purchasing Power Parity (PPP) per capita³ [97].

In summary, the present study will focus on 4 case studies. Two in Mexico: Juarez and Puebla, representing two levels of motorization in an emergent economy. In addition 2 case studies from France: Lille, which can be compared to Juarez, two international border cities with a population in a range of 1 to 2 million inhabitants, and the Paris Region (Île-de-France, with 11 millions).

2.2.1 Juarez, Mexico.

The city of Juarez, which was founded in 1635 by Spanish explorers, is located in the north of Mexico (Figure 2.1), bordered to the north by the city of El Paso Texas in the United States. Juarez and El Paso meet to create North America's largest border community (Figure 2.2) with a combined population of 2.4 million people and is the most important site of the international commerce that links Mexico and USA. Indeed Juarez is still considered one of the most important hubs of the manufacturing industry in the United States-Mexico border despite the effects of the world economic crisis, violence and social problems in the city that began in 2008. Juarez is one of the premier manufacturing locations in Mexico alongside Tijuana and Monterrey.

³⁰ Every metropolitan area in Mexico such as Mexico, Guadalajara, Monterrey and Tijuana [99] have developed Household Travel Surveys, but in most cases there are no updating/consecutive surveys and sometimes with significant compatibility issues between each other which make their use not feasible for this study.

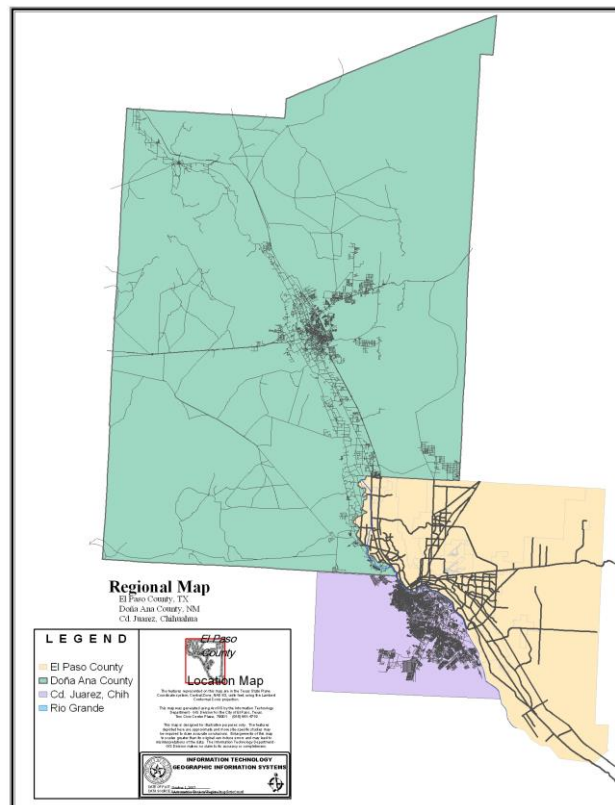
Overall, by 1996 Juarez had a population of 1.1 million and an estimated population of 1.2 million in 2006. Its strategic location (4 international crossings between US and Mexico), cheap labor and qualified employees were not the only reasons causing the manufacturing industry to choose Juarez as the location for their facilities, the Mexican government also contributed to this economic and employment boom by designing incentive programs that usually included low taxes and cheap land costs in order to make Juarez even more attractive to investors. Juarez has subsequently grown substantially in recent decades, not only in terms of population with the large influx of people rapidly moving into the city in search for job opportunities but in terms of urban sprawl as well. This was due to the preference of industries for sites located in the suburbs for logistic purposes, new housing developments trying to be closer to jobs and in general a lack of applied urban planning. In addition to this, and even if there are mobility surveys available created specifically to develop transport sustainability projects, the transportation infrastructure implemented in the last decades in Juarez were only highway construction and no efficient public transport system, which made Juarez a car-dependent city over time. Two comparable Household Travel Surveys are available: 1996 and 2006.

Figure 2.1. Geographical location of Juarez



Source: <http://es.justmaps.org/mapas/norteamerica/mexico/ciudadjuarez.asp>

Figure 2.2. Regional Map: El Paso Texas, Doña Ana New Mexico and Juarez Mexico



Source: <http://www.pdnmapa.org>

2.2.2 Puebla, Mexico.

The city of Puebla was founded by the Spaniards in 1531 and it is now the fourth largest urban area in Mexico with a population of approximately 1.6 million inhabitants. It is located southeast of Mexico City in the center of Mexico (Figure 2.3). Puebla is much less motorized than the city of Juarez and it is representative of a more traditional life-style. In fact, due to its historical and cultural value the city was named a World Heritage Site by UNESCO in 1987. Puebla is one of the first planned Mexican cities based on a theoretical and integrated approach to urbanization. Since the foundation of the city the urban layout was a heritage of classic Spanish design, centered on a main plaza and surrounded by rectilinear grid pattern of streets. Indeed, the formal organization of buildings were established focusing on Renaissance ideology, consisting on geometrically exact set of blocks. The original urban form configuration set a background to promote pedestrian and transit mode in future years. For a long time the growth of the urban area was limited by natural and artificial barriers. Since the decade of the 80's the economic activity and

population growth led to the expansion of the urban area surpassing these natural barriers. Rapid urbanization is one of the phenomenon that most affected the metropolitan area of the city of Puebla in the past three decades. Thirty years of sustained growth have transformed a city of 280 thousand inhabitants in a metropolis of almost two million, exceeding its original city limits causing the phenomenon of conurbation with peripheral agglomerations. Two comparable Household Travel Surveys are available: 1994 and 2011 [101].

Figure 2.3. Geographical location of Puebla



Source: <http://es.justmaps.org/maps/images/mexico/puebla-map1.gif>

2.2.3 Lille, France

The Urban Community of Lille (LMCU for Lille Métropole Communauté Urbaine) has a population of 1.1 million inhabitants. It is located in northern France close to the Belgium border and it is the fourth-largest metropolitan area in France after Paris, Lyon and Marseille. In 2008, the international metropolitan eurodistrict of Lille-Kortrijk, which also includes the Belgian cities of Kortrijk and Tournai, had an estimated population of 2.2 million inhabitants. Trade oriented since its origins, textile and industrial oriented afterwards, the Urban Community of Lille has made a reconversion since 1990 towards the service sector. Like most French cities with 1 million inhabitants it has a good mixed public transport system with metro, trams and buses. Three standardized Household Travel Surveys are available³¹: 1987, 1998 and 2006.

³¹ The present study does not takes into account the Household Travel Survey developed in 1976 due to compatibility issues.

Figure 2.4. Geographical location of Lille



Source: <http://www.cartesfrance.fr/>

2.2.4 Paris Region, France

The Paris Region (or Île-de-France) is composed of eight departments: Essonne, Hauts-de-Seine, Seine-Saint-Denis, Seine-et-Marne, Val-de-Marne, Val-d'Oise, Yvelines and Paris (Figure 2.5). In 2012, the Paris Region had a population of 11.2 million inhabitants [102], placing it as the most populated region of France. It concentrates the economic, administrative and political powers of a highly centralized country. In fact, the Paris Region holds 20% of France's population in an area that represents only 2% of the territory of Continental France [103]. Paris, which is the capital of the Paris Region, like most capitals of developed world has been always a hub for employment, attracting people not only from France but from other countries as well. Nevertheless, new developments have been concentrated gradually in the inner and outer suburbs since the 70's. Increased number of inhabitants and jobs outside Paris has transformed the Region to a polycentric

metropolitan area. In terms of travel activity, the number of trips within Paris³² have remained unchanged between 1991 and 2001, while growing substantially in the suburbs [103]. The Paris Region is an interesting case study due to its high travel demand³³, the wide range of transportation means supply and its urban form configuration.

On the one hand, in the Paris Region, like in the metropolitan areas of Barcelona, Berlin, Dublin and Madrid, the private vehicle is the most used transportation mode [103]. In fact, most suburb-to-suburb trips are very dependent on private vehicle. However, the growth of private vehicle use observed in previous decades have slowed down between 1991 and 2001. According to recent published data from OMNIL [104], private vehicle use has stabilized between 2001 and 2010 (+0.6%) while the average trip length was 300 meters shorter in 2010 compared to 2001. [105]. On the other hand, the Paris Region is known to be one of the European metropolitan areas (along with Madrid, Barcelona and Vienna, etc.) with higher use of public transportation³⁴ [105]. Public transport networks in the Paris Region offer a wide variety of modes. Actually, rail, metro, tramway and bus transport systems have been adapting³⁵ to the increasing urban sprawl since its beginning. The city of Paris and its suburbs have been progressively accessible by any public transport means. Several standardized Household Travel Surveys are available³⁶. The surveys considered in this study are those from 1991 and 2001.

³² Trips with origin and destination in Paris.

³³ The number of trips within Paris and the inner suburbs is 6.3 times higher than in Rome, 4.7 times higher than in Hamburg, 2.9 times higher than in Vienna and 2.6 times higher in Madrid and in London (Greater London) [104].

³⁴ Public Transportation mode accounts for about 40% in Paris.

³⁵ In fact, in some cases Public Transport System have been preceding the planned urban development in the inner and outer suburbs (urban sprawl).

³⁶ The present study does not takes into account the Household Travel Surveys developed in 1976, 1983 and most recent survey from 2011 available only since fall 2013.

Figure 2.5. Geographical location of Paris Metropolitan Area



Source: <http://www.cartesfrance.fr/>

2.3 Required data

This section describes the data requirements for the implementation of the Econometric modelling analysis, the Age-Cohort Travel Demand Forecast model and the GHG Emissions Assessment methodology applied in this study. Methodologies are presented in Chapters 3, 4 and 5 respectively.

A) Household Travel Surveys:

The Cross-Sectional Analysis presented in Chapter 3, the Age-Cohort Travel Demand Forecast model described in Chapter 4 and the GHG Emissions Assessment methodology from Chapter 5, all are based on daily mobility behavior obtained through Household Travel Surveys. These surveys describe

daily trips of residents within an urban area on a work day. Trips are captured at the disaggregated level in terms of transportation mode. At least two comparable successive surveys from each case study are needed. Section 2.4 shows full description of each Household Travel Survey used in this study.

B) Car fleet characteristics:

The GHG Emissions Assessment presented in Chapter 5 is based on BEED (Energy Environment Budget Travel) methodology. This method determines the energy consumption and pollutant emissions including CO₂ emissions due to on-road travel activity of residents within their urban area. Travel activity takes into account all transportation modes, including private vehicle, public transport (metro, tramway, bus, etc.), motorcycle, bicycle and walking trips. The BEED method relies on two sources of information: Travel activity at disaggregated level³⁷ collected from Household Travel Surveys and on vehicle's technological characteristics from each trip made by motorized modes observed in these surveys. More specifically, the vehicle's technological characteristics required for each motorized trip are:

- Type of fuel (e.g. gasoline, diesel, etc.)
- Vehicle's year of registration
- Vehicle's engine power measured in number of cylinders
- Existence of the catalytic converter in the vehicle, derived from its type of fuel and date of construction, according to national regulations

C) Demographic Projections:

The Age-Cohort Travel Demand Forecast methodology from Chapter 4 is based on data from Household Travel Surveys. In addition, this methodology rely on long term demographic projections. Once the Age-Cohort model is estimated with data from mobility surveys, the coefficients will be applied to future population in order to obtain future travel demand behavior (e.g. number of trips per person, travel distance per person, etc.) The unit of measurement used in the Age-Cohort model is the standard five years cohort, according to birth year. Hence, another requirement for the development of the mobility forecast model is detailed demographic forecasts by quinquennial age groups.

³⁷ Travel activity at a disaggregated level in terms of transportation mode for each trip.

2.4 Available data

2.4.1 Mexican sources

2.4.1.1 Juarez: Household Travel Surveys and Vehicle Characteristics

1996 Sampled field data

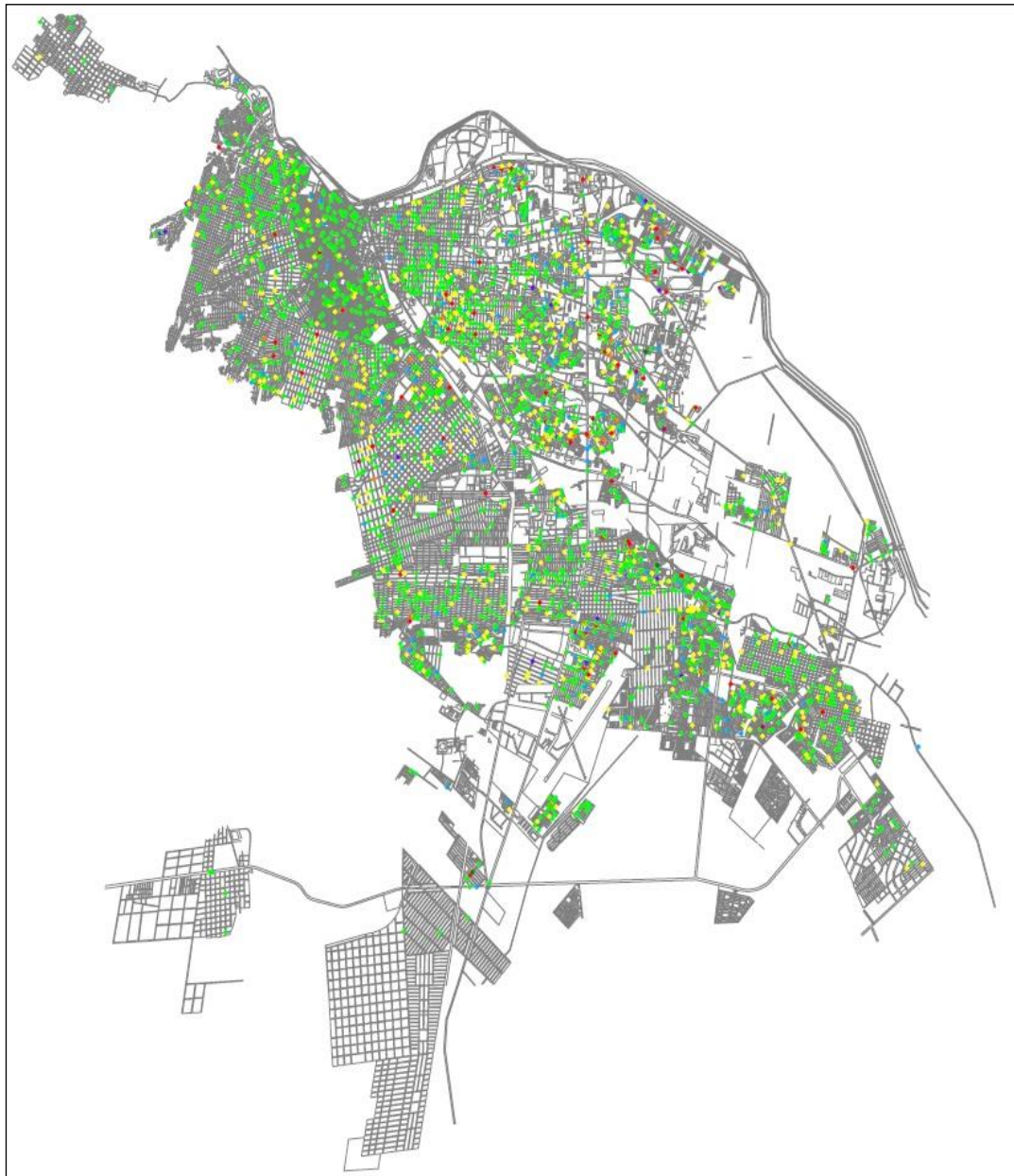
The first Household Travel Survey in Juarez was undertaken by the Municipal Institute of Research and Planning of the city of Juarez (IMIP³⁸) during October and November in 1996. Random selection of the samples through landline home telephone numbers was rejected since the service was unavailable to most low-income households at that time. The surveys were conducted through extensive use of the local school system of about 300 schools citywide due to very limited budget. This innovative process consisted on selecting one 6th grade group from every primary school and one 2nd grade group from every secondary school. Their teachers received extensive and specific training by IMIP to handle the questionnaires and were responsible for each group. Teachers trained and supervised over 11,000 students in order to conduct about 23,000 surveys. Students had to interview two of their next door neighbor households. From this process about 15,000 surveys made their way back to supervisors. Screening and validation process from IMIP personnel found about 7,000 incorrect questionnaires (incorrectly or not filled at all) and close to 4,000 incomplete (missing information). At the end, 4,016 questionnaires were correct. In 1997, after validation process the total number of correct questionnaires was geocoded on a GIS node coverage identifying all of the street intersections in the city (Figure 2.6) and entered into the electronic database MS-ACCESS (Figure 2.7).

In 1995, the National Institute of Statistics and Geography (INEGI³⁹) estimated 238,770 households in the city of Juarez. Hence, the 4,016 correct surveys represented about 1.57% of the universe of households. Figure 2.6 show that the sample was well distributed within the urban area and the concentration of surveys was consistent with population concentration.

³⁸ Instituto Municipal de Investigación y Planeación.

³⁹ Instituto Nacional de Estadística y Geografía

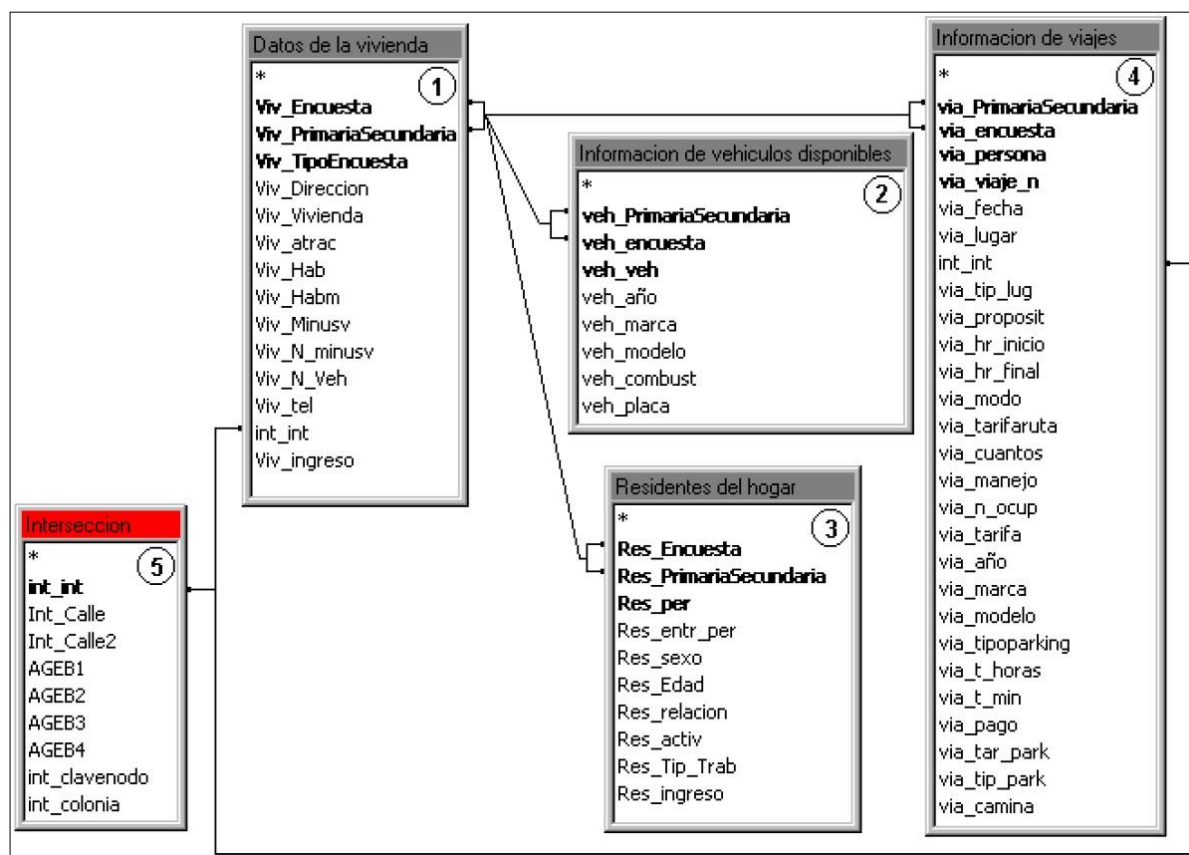
Figure 2.6. Household Travel Survey 1996 Study Area and location of correct household surveys



Source: [106].

The Household Travel Survey database is composed of four main tables describing socioeconomic information for each member of the household aged 5 or more, and their travel activity from the weekday before filling the survey (Tables 2.1. to 2.4.). A fifth table helped by providing details on GIS data (Table 2.5.). A general layout of the database and its component tables and fields is shown in Figure 2.7.

Figure 2.7. Household survey 1996 database layout



Source: [106].

Table 2.1. Household information information ⁴⁰

FIELD NAME	DESCRIPTION
<i>Viv_Encuesta</i>	Household sample no. (unique by Elementary or Jr High)
<i>Viv_PrimarySecundaria</i>	Survey conducted by Elementary or Junior High
<i>Viv_TipoEncuesta</i>	Survey conducted on neighbor or own household
<i>Viv_Direccion</i>	Household address
<i>Viv_Vivienda</i>	Type of household
<i>Viv_atrac</i>	Number of people that visited the household
<i>Viv_Hab</i>	Number of household residents
<i>Viv_Habm</i>	Number of HH residents age 5 years or older
<i>Viv_Minusv</i>	Handicapped in HH (Yes=1, No=0)
<i>Viv_N_Minusv</i>	Number of handicapped in household
<i>Viv_N_Veh</i>	Number of household vehicles
<i>Viv_tel</i>	Household telephone number
<i>int_int</i>	Primary key for relating tables (intersection index)
<i>Viv_ingreso</i>	Household monthly income code

⁴⁰ Spanish table name: Datos de la vivienda

Table 2.2. Household vehicles ⁴¹

FIELD NAME	DESCRIPTION
veh_PrimarySecundaria	Survey conducted by Elementary or Junior High
veh_Encuesta	Household sample no. (unique by Elementary or Jr High)
veh_veh	Household vehicle number
veh_año	Year of the vehicle
veh_marca	Make of the vehicle
veh_modelo	Model of the vehicle
veh_combust	Type of fuel code for the vehicle
veh_placa	Type of license plate code for the vehicle

Table 2.3. Household residents ⁴²

FIELD NAME	DESCRIPTION
Res_Encuesta	Household sample no. (unique by Elementary or Jr High)
Res_PrimarySecundaria	Survey conducted by Elementary or Junior High
Res_per	Household member number
Res_entr_per	Code indicating if member was present
Ressexo	Gender code of the household member
ResEdad	Age of the household member
Res_relacion	Relationship code to the household head
Res_activ	Activity code of the household member
Res_Tip_Trab	Type of work code of the household member
Res_ingreso	Monthly income code of the household member

Table 2.4. Trip information ⁴³

FIELD NAME	DESCRIPTION
via_PrimarySecundaria	Survey conducted by Elementary or Junior High
via_Encuesta	Household sample no. (unique by Elementary or Jr High)
via_persona	Household member number
via_viaje_n	Trip number (0 for initial origin)
via_fecha	Date of trip dairy
via_lugar	Place name of trip destination
int_int	Nearest intersection index of trip destination
via_tip_lug	Trip destination type code
via_proposit	Trip purpose code
via_hr_inicio	Trip starting time
via_hr_final	Trip ending time
via_modos	Trip mode of transportation code
via_tarifaruta	Bus/Taxi fare (only if these modes were used)
via_cuantos	Number of buses required for the trip
via_manejo	Code indicating if person was a driver
via_n_ocup	Number of passengers (only if person drove)
via_año	Year of auto (if this mode was used & person drove)
via_marca	Make of auto (if this mode was used & person drove)
via_modelo	Model of auto (if this mode was used & person drove)
via_tipoparking	Parking type code
via_t_horas	Parking time (total parking hours)
via_t_min	Parking time (residual parking minutes)
via_pago	Code indicating if person paid for parking
via_tar_park	Parking fare (only if person paid for parking)
via_camina	Blocks required to walk (from parking or bus stop)

⁴¹ Spanish table name : Información de vehículos

⁴² Spanish table name : Residentes del hogar

⁴³ Spanish table name : Información de viajes

Table 2.5. Intersection⁴⁴

FIELD NAME	DESCRIPTION
Int_Int	Primary key for relating tables (intersection index)
Int_Calle	Name of street 1
Int_Calle2	Name of street 2 (intersecting street 1)
AGEB	AGEB (census zone) where the intersection is located.
int_clavenodo	Transcad node code (for the intersection)
int_colonia	Subdivision where the intersection is located

Source tables 2.1. to 2.5: [106].

2006 Sampled field data

Ten years after the initial research effort of 1996, IMIP started the Integrated Transportation Study⁴⁵ in the City of Juarez, which led to the project "Desarrollo de alternativas para la eficiencia del transporte público de pasajeros en Ciudad Juárez y su impacto en el medio ambiente"⁴⁶ under the mixed funds grant 2005-01 from the Mexican National Council of Science And Technology (CONACYT)⁴⁷ and the local municipal government of Juarez. The project consisted on field data gathering (such as the Household Travel Survey and the road infrastructure and public transport inventories) and the development of Travel Demand Model (TDM). The design of the survey obeyed to the experience from the 1996 study. Based on georeferenced digital mapping generated by the IMIP and using the computer program ArcView a geographic information system (GIS) of the current road network was generated. In this GIS every streets and avenues of the city of Juarez were drawn. This generated a grid of nodes and arcs in which each arc and each node had the possibility to add information for each of the plotted elements. This GIS database had a total of 37,483 nodes in intersecting lines which represented streets and avenues. From this GIS of the 37,483 nodes, a selection of 1,870 nodes were randomly selected in order to choose the households to conduct the surveys (Figure 2.8). In order to maintain the randomness in the selection of the households to be surveyed, a protocol for selection of the household was followed, in which the interviewer selected the third house counting from the intersection, based on the identification code of the node. For instance, if the termination of the number code of the node was 0 or 1, the interviewer had to walk from the intersection point to the north and taking the west sidewalk. If the termination of the code was 9 the interviewer had to walk east taking

⁴⁴ Spanish table name : Intersección.

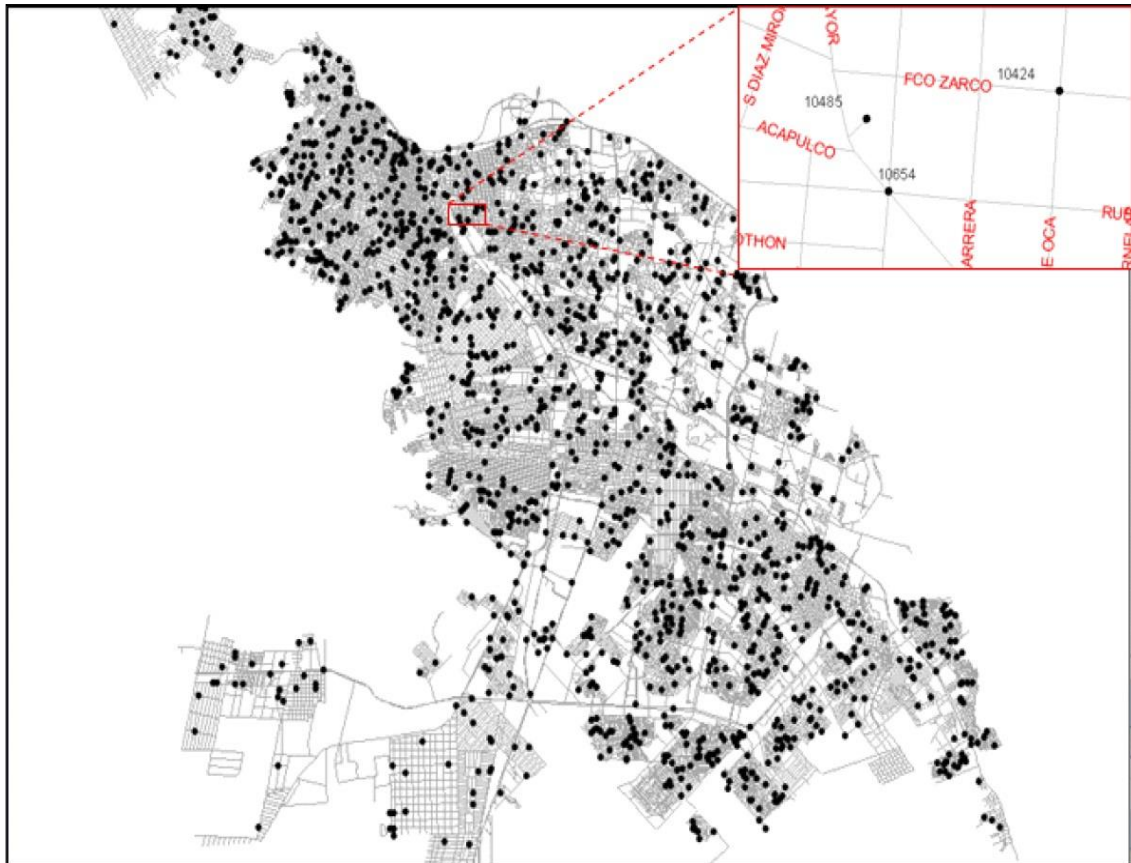
⁴⁵ Estudio Integral de Transporte (EIT).

⁴⁶ Developing alternatives for efficiency public passenger transport in Ciudad Juárez and its impact on the environment.

⁴⁷ Consejo Nacional De Ciencia Y Tecnología de México.

the south sidewalk until arriving to the third household. In the absence of household in the given position, then the interviewer had specific instructions to follow [107, 108].

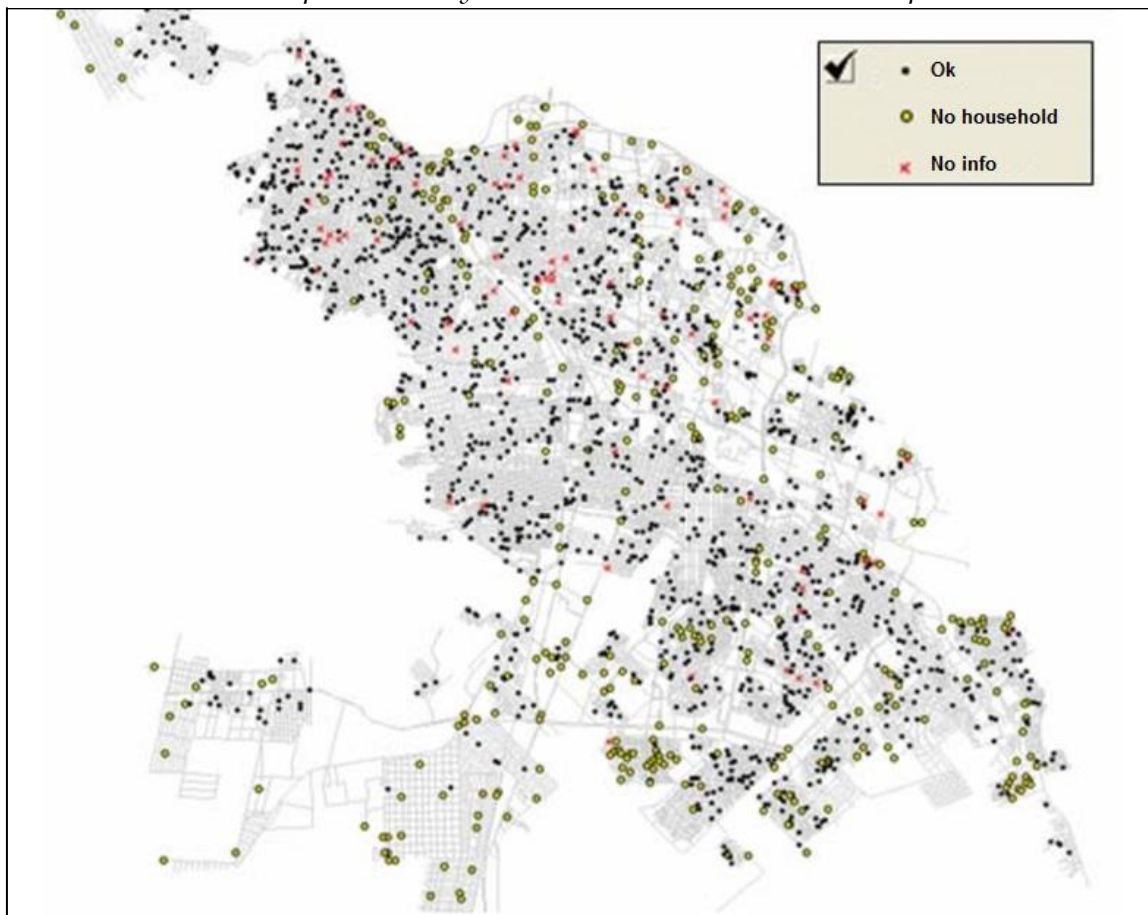
Figure 2.8. Household Travel Survey 2006 Study Area and location of original 1870 random sample intersections



Source: [108].

Once the household was selected, the interviewer proceeded to conduct the survey directly to each and every one of the residents of the household. The survey design requires each person aged 5 or older to describe as accurately as possible all the trips made on the weekday before the survey, except for the children for whom the parents could answer for them. It is important to underline that all interviewers worked for IMIP, all they wore uniform with IMIP's logo and name badge, drove vehicles with IMIP's logo, and showed a letter from the General Director of IMIP explaining the importance of the study to the whole community. At the end of the data field gathering, 351 nodes had no corresponding household, 91 households refused to answer the questionnaires and 1428 were completed surveys [107]. The distribution of filled, no answered and no household questionnaires was homogeneous within the study area (Figure 2.9).

Figure 2.9. Household Travel Survey 2006 Study Area and location of random sample (1428 completed surveys, 351 no household and 91 no response)



Source: [107].

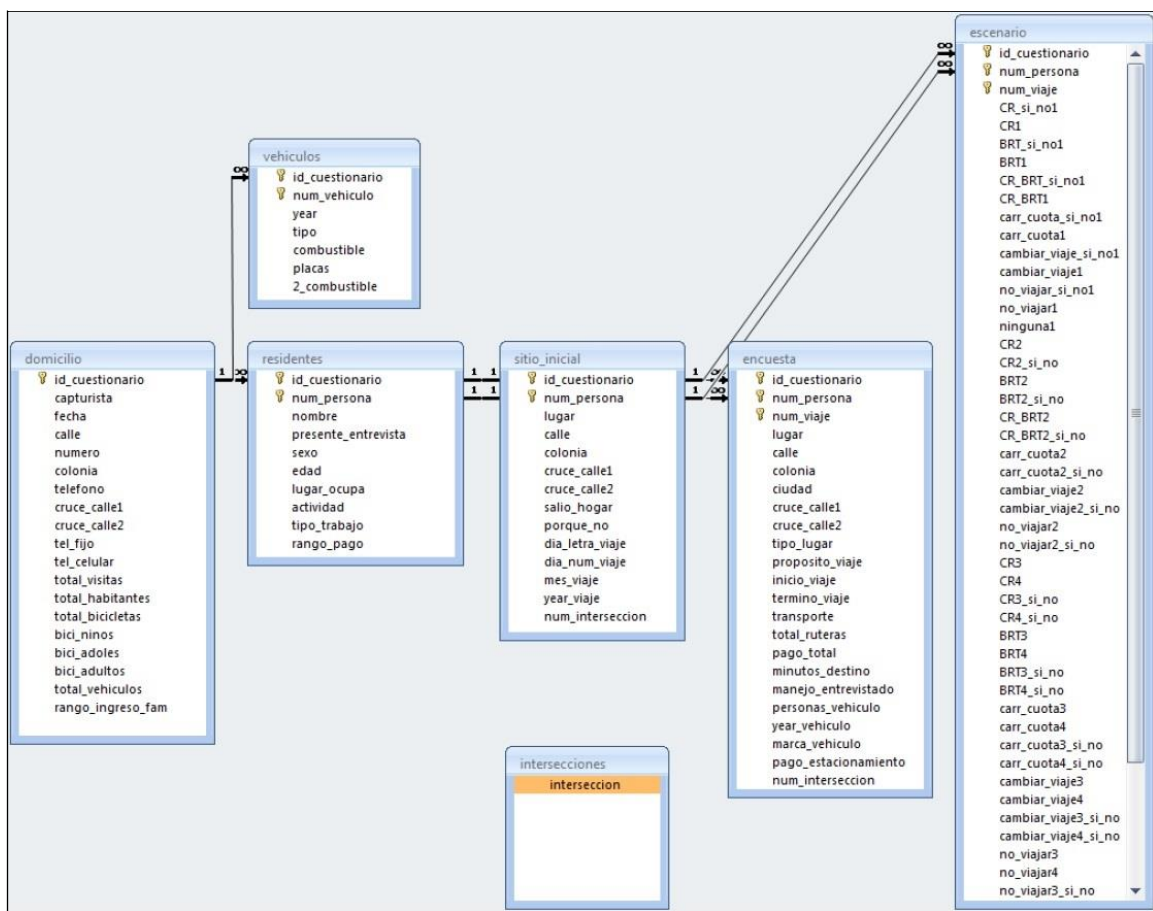
The capture process was carried out using Microsoft Office Access once each survey was completed and validated. In order to find the exact location of each household, the origins and destinations captured in the surveys, additional software packages such as AutoCad, ArcView, ArcMap, MapObjects were used. The database structure was very similar to the survey from 1996 and consisted mainly on 6 tables describing the households, vehicles, residents, and trips characteristics (revealed preference and stated preference) and additional tables with georeferenced data to help locate the information on a GIS [108]. The database of the 2006 Household Travel Survey contains the following tables:

- Domicilio: contains the address of the respondent (Table 2.6.),
- Vehiculos: contains information of family vehicles (Table 2.7.),
- Residentes: contains information of surveyed household residents (Table 2.8.),
- Sitio_inicial: contains the initial location of trips made by each person (Table 2.9.),
- Encuesta: contains data relating the trips made per each household resident, the means of transport used and vehicles owned in each household (Table 2.10.),
- Escenario: contains information on stated preferences of trips (Table 2.11.)

And the following support GIS tables:

- Cat_calles: contains the full list of streets in the city,
- Cat_colonias: contains the full list of neighborhoods in the city,
- Cat_encuestador: contains the list of interviewers,
- Cat_interseccion: contains the catalog of street's intersections in the city,
- Intersecciones: contains intersections of city streets,
- Cat_marcascarros: contains a catalog of vehicle brands,

Figure 2.10. Household survey 2006 database layout



Source: [108].

Figure 2.10 shows the database layout, which is an overview of the main tables, the key field or corresponding fields, and the relationship between multiple tables. Full description of tables and fields are found on tables 2.6. to 2.11.

Table 2.6. Household information⁴⁸

FIELD NAME	DESCRIPTION
id_cuestionario	Household sample number
Capturista	Id code of surveyor
Fecha	Date of survey
Calle	Household street name
Numero	Household street number
colonia_id	Household neighborhood code
Colonia	Household neighborhood name
Telefono	Household telephone number
cruce_calle1	Crossing street 1
cruce_calle2	Crossing street 2
tel_fijo	Number of landline telephones
tel_celular	Number of cellular telephones
total_visitas	Number of people that visited the household
total_habitantes	Number of household residents
total_bicicletas	Total number of bicycles
bici_ninos	Number of bicycles for children
bici_adoles	Number of bicycles for teenagers
bici_adultos	Number of bicycles for adults
total_vehiculos	Total number of vehicles
rango_ingreso_fam	Household monthly income code

Table 2.7. Household vehicles⁴⁹

FIELD NAME	DESCRIPTION
id_cuestionario	Household sample number
num_vehiculo	Household vehicle number
Year	Year of the vehicle
Tipo	Type of vehicle
combustible	Type of fuel code for the vehicle
2_combustible	Type of fuel if other
Placas	Type of license plate code for the vehicle

Table 2.8. Household residents⁵⁰

FIELD NAME	DESCRIPTION
id_cuestionario	Household sample number
num_persona	Resident sample number
Nombre	Name of the person surveyed
presente_entrevista	Code indicating if member was present
Sexo	Gender code of the household member
Edad	Age of the household member
lugar_ocupa	Relationship code to the household head
Actividad	Activity code of the household member
tipo_trabajo	Type of work code of the household member
rango_pago	Monthly income code of the household member

⁴⁸ Spanish table name : domicilio

⁴⁹ Spanish table name : vehiculos

⁵⁰ Spanish table name : residentes

Table 2.9. Initial location⁵¹

FIELD NAME	DESCRIPTION
id_cuestionario	Household sample number
num_persona	Household member number
Lugar	Place name of origin of first trip
Calle	Street name of origin of first trip
Colonia	Neighborhood of origin of first trip
cruce_calle1	Crossing street 1 of origin of first trip
cruce_calle2	Crossing street 2 of origin of first trip
salio_hogar	Did the person leave his/her home the day before the survey
porque_no	Reason for not leaving home
dia_letra_viaje	Day of the week of trip
dia_num_viaje	Day of the month of trip
mes_viaje	Month of trip
year_viaje	Year of trip
num_interseccion	Nearest intersection index of trip destination
num_viaje	Trip number (0 for origin of first trip)
tipo_lugar	Trip origin type code
proposito_viaje	Trip purpose code

Table 2.10. Trip information⁵²

FIELD NAME	DESCRIPTION
id_cuestionario	Household sample number
num_persona	Household member number
num_viaje	Trip number
Lugar	Place name of trip destination
Calle	Street name of trip destination
Colonia	Neighborhood of trip destination
Ciudad	City of trip destination
cruce_calles	Crossing streets of trip destination
tipo_lugar	Trip destination type code
proposito_viaje	Trip purpose code
inicio_viaje	Trip starting time
termino_viaje	Trip ending time
Transporte	Trip mode of transportation code
total_ruteras	Number of buses required for the trip
pago_total	Bus/Taxi fare (only if these modes were used)
minutos_destino	Minutes required to walk (from parking or bus stop)
manejo_entrevistado	Code indicating if person was a driver
personas_vehiculo	Number of passengers (only if person drove)
year_vehiculo	Year of the vehicle
marca_vehiculo	Vehicle brand
pago_estacionamiento	Code indicating if person paid for parking
num_interseccion	Nearest intersection index of trip destination

In addition to capturing observation of an action that has already taken place (Table 2.10.), a stated preference set of questions were included for the purpose of feeding discrete choice models in which the weight of time and transportation costs will be

⁵¹ Spanish table name : sitio inicial

⁵² Spanish table name : encuesta

estimated. This type of models shows the potential demand for transport systems (and/or their combination) not yet available for possible implementation (Table 2.11).

Table 2.11. Stated preferences scenarios⁵³

	Alternate decision	hypothetical scenarios
id_cuestionario	Household sample number	
num_persona	Household member number	
num_viaje	Trip number	
CR1	Cycle path	Congestion and fuel prices remain the same
CR_si_no1		Congestion and fuel prices remain the same
BRT1	Bus Rapid Transit	Congestion and fuel prices remain the same
BRT_si_no1		Congestion and fuel prices remain the same
CR_BRT1	Cycle path + Bus Rapid Transit	Congestion and fuel prices remain the same
CR_BRT_si_no1		Congestion and fuel prices remain the same
carr_cuota1	Toll lanes	Congestion and fuel prices remain the same
carr_cuota_si_no1		Congestion and fuel prices remain the same
cambiar_viaje1	Change trip intention	Congestion and fuel prices remain the same
cambiar_viaje_si_no1		Congestion and fuel prices remain the same
no_viajar1	No trip	Congestion and fuel prices remain the same
no_viajar_si_no1		Congestion and fuel prices remain the same
ninguna1	none of the provided options	Congestion and fuel prices remain the same
CR2	cycle path	Congestion doubles and fuel prices remain the same
CR2_si_no		Congestion doubles and fuel prices remain the same
BRT2	Bus Rapid Transit	Congestion doubles and fuel prices remain the same
BRT2_si_no		Congestion doubles and fuel prices remain the same
CR_BRT2	Cycle path + Bus Rapid Transit	Congestion doubles and fuel prices remain the same
CR_BRT2_si_no		Congestion doubles and fuel prices remain the same
carr_cuota2	Toll lanes	Congestion doubles and fuel prices remain the same
carr_cuota2_si_no		Congestion doubles and fuel prices remain the same
cambiar_viaje2	Change trip intention	Congestion doubles and fuel prices remain the same
cambiar_viaje2_si_no		Congestion doubles and fuel prices remain the same
no_viajar2	No trip	Congestion doubles and fuel prices remain the same
no_viajar2_si_no		Congestion doubles and fuel prices remain the same
ninguna2	none of the provided options	Congestion doubles and fuel prices remain the same
CR3	cycle path	Congestion remains the same and fuel price doubles
CR3_si_no		Congestion remains the same and fuel price doubles
BRT3	Bus Rapid Transit	Congestion remains the same and fuel price doubles
BRT3_si_no		Congestion remains the same and fuel price doubles
CR_BRT3	Cycle path + Bus Rapid Transit	Congestion remains the same and fuel price doubles
CR_BRT3_si_no		Congestion remains the same and fuel price doubles
carr_cuota3	Toll lanes	Congestion remains the same and fuel price doubles
carr_cuota3_si_no		Congestion remains the same and fuel price doubles
cambiar_viaje3	Change trip intention	Congestion remains the same and fuel price doubles
cambiar_viaje3_si_no		Congestion remains the same and fuel price doubles
no_viajar3	No trip	Congestion remains the same and fuel price doubles
no_viajar3_si_no		Congestion remains the same and fuel price doubles
ninguna3	none of the provided options	Congestion remains the same and fuel price doubles
CR4	cycle path	Congestion and fuel price doubles
CR4_si_no		Congestion and fuel price doubles
BRT4	Bus Rapid Transit	Congestion and fuel price doubles
BRT4_si_no		Congestion and fuel price doubles
CR_BRT4	Cycle path + Bus Rapid Transit	Congestion and fuel price doubles
CR_BRT4_si_no		Congestion and fuel price doubles
carr_cuota4	Toll lanes	Congestion and fuel price doubles
carr_cuota4_si_no		Congestion and fuel price doubles
cambiar_viaje4	Change trip intention	Congestion and fuel price doubles
cambiar_viaje4_si_no		Congestion and fuel price doubles
no_viajar4	No trip	Congestion and fuel price doubles
no_viajar4_si_no		Congestion and fuel price doubles
ninguna4	none of the provided options	Congestion and fuel price doubles

Source tables 2.6. to 2.11: [108].

⁵³ Spanish table name : Escenario.

2.4.1.2 Puebla: Household Travel Surveys and Vehicle Characteristics

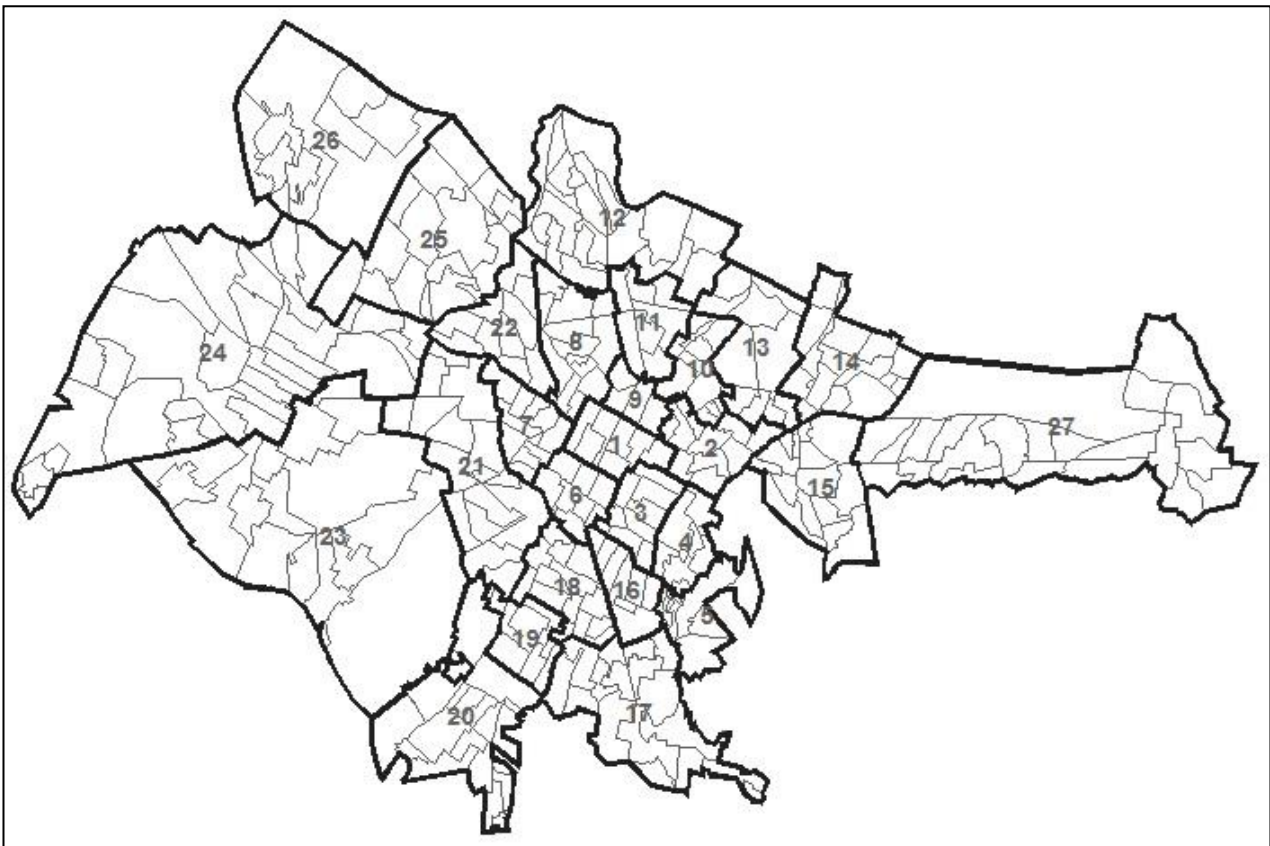
1994 Sampled field data

Description of the 1994 Household Travel Survey of the city of Puebla was obtained from [109]. This survey was the result of an agreement between Villes et Développement, Groupe Interuniversitaire de Montréal (GIM) and the Government of the State of Puebla in Mexico. By this agreement, the GIM took responsibility for organizing and implementing the survey in which the main objective was to know the travel patterns of residents in the metropolitan area of Puebla in terms of frequency, mode of transport used, timetables, trip purpose and spatial distribution. To conduct the survey, GIM was associated with the Faculty of Economics at the Benemerita Autonomous University of Puebla (BUAP) which collaborated with human resources, computers, administrative facilities needed for the project. Thanks to the agreement between the GIM and the BUAP, field and office staff was consisted mainly of students from the Faculty of Economics and other faculties. This ensured a staff with more than sufficient academic training to fulfill the tasks, in many cases, students had already experience in other types of surveys. A team of professors at the Faculty of Economics were also actively involved in the organizational tasks of the surveys, specifically in sampling the validation of the questionnaires, control of productivity and logistics. The survey took place under the framework of the Urban Development Project Angelópolis launched by the government for the metropolitan area of Puebla. To be more precise, the survey is part of the transport area of the Angelópolis Program, and was intended to provide baseline data to the consulting firm LOGIT of Sao Paulo, in charge of making the diagnosis of transport of passengers in the city. The survey was conducted through household interviews. At the end 3505 surveys were validated which constitutes a final sample of 1.42% of the estimated total number of households in the study area from the XI General Census of Population and Housing 1990⁵⁴. In total there was a database of over 16000 people. The survey was conducted in two stages, between November 1993 and February 1994, with the mandatory break of the Christmas season. The random sample of household required an initial list that would be bigger in order to compensate for sample rejections and to allow stratification of the sample by area.

⁵⁴ According to the XI General Census, in 1990 there was a total of 246,844 households inhabited in the study area.

This first selection was made from the list provided by the Federal Electricity Commission (CFE) which included information about the name and address of each subscriber to the electricity supply within the entire study area. Almost all households located within the area of the survey had electricity service, which meant that using the CFE listings most households were covered.

Figure 2.11. Household Travel Survey 1994 Study Area



Source: GIM, 1994 Puebla Survey.

A first random list using an automated selection, in which about one household from twenty, was obtained. This initial random list had about 13,000 household for the city of Puebla and 500 for each of the other municipalities. In the method of random sampling used, interviewers, supervised by field coordinators, proceeded to directly select the sample using the following guidelines: from a random place in an area to cover, the interviewer had to select a number of households according to a predefined percentage that was equal to the inverse of the fraction of the sample. For instance, if in an area with 6000 households the percentage of the sample had been previously fixed at 2% in order to obtain 120 homes, the selection was made every 50 households (1/50).

To ensure a balanced distribution of the sample and the representation of different socioeconomic levels, interviewers had to avoid consistently choosing the same type of property. This technique was used at the census tract level for the best spatial representation. At the end, more than 4000 interviews were conducted in order to reach the final sample number of 3505 households. The home visit took place from Tuesday to Friday between 15:00 and 21:00 and Saturday mornings. If the questionnaire was not complete after the first visit because of the absence of a family member, the interviewer had to return the next day to get the missing information. The interviewer could get up to three visits to try to complete the survey. If after the third attempt, still was missing data, the survey was coded as "incomplete". At the end of the day, the team leader or supervisor received the finished surveys and did a first check to ensure that no information was missing. The coordinator proceeded to a second verification of finished surveys paying attention to the omission of data and, especially, to the coherence of the information. In case of errors, the questionnaire was returned to the interviewer. Ten percent of the questionnaires was validated by a third verification from the field supervisor. These questionnaires were chosen randomly and verification could be made by telephone, if the household had a telephone, or by a home visit. In case of detecting errors or inconsistencies, all surveys conducted by the same interviewer were checked one by one in order to know whether it was false information by the interviewer or if it was a simple error. The field verification was made to a total of 376 questionnaires. No abnormalities were observed during this verification process which covered approximately 10% of the final sample. At the end, correct questionnaires were captured with a program created in dBase IV. The Household Travel Survey was designed to capture the most common variables usually captured on an origin-destination survey, such as number of trips, their purpose, mode, origin, destination, time and duration. As well as socioeconomic variables of households allowing to perform analysis of travel behavior by social classes. Collected data was stored in four main related databases (Tables 2.12. through 2.16.). The first table "Survey Control" contains only logistic data regarding the development and validation of the survey (e.g. date and time of visits, rating/coding of surveys, conducted verifications, etc.). The second table, "Household information" as the first table, it is a single record per household, and it refers to general information about the home, family members, the type of property and possession of means of transportation (e.g. motorized vehicles, bicycle, etc.) (Table 2.12.). A complementary table contains general data of available vehicles in the household (Table 2.13.).

Table 2.12. Household information

FIELD NAME	DESCRIPTION
NUM_FICH	Page number
NUM_PAGS	Number of pages
ZONA	Zone
AGEB	Code zone AGEB
DIR	Address
MUESTRA	sample number
H1	Date of trip (month and day)
H2	Day of trip (Monday, Thursday, ...)
H3	Type of Household
H4	Number of rooms in household
H5	Total number of household members
H6	Relationship members
H7	Telephone number
H8	Total numbers of vehicles (type, model, brand, year) incl.motorcycles and bicycles
FEXP	weight (expansion factor)

Table 2.13. Household vehicles

FIELD NAME	DESCRIPTION
Recnum	record number
Muestra	sample number
H8	Total numbers of vehicles (type, model, brand, year) incl.motos and bicycles
Tipo	Type of vehicle
Marca	Brand
Modelo	Model
Año	Year make
AGEB	Code zone AGEB
Zona	Zone

The fourth table "Households Residents" it is an unique record table (divided in two parts) that focuses on each of the household members of 5 years old and older and includes information on their position in the home, education, employment status and on the realization of trips the day before the interview (Tables 2.14. and 2.15.).

Table 2.14. Household residents

FIELD NAME	DESCRIPTION
MUESTRA	sample number
FICHA	Page
P1	Name and household number
P2	Status in household (head of household, etc.)
P3	Driver License (Yes, No)
P4	Type of driver license
P5	Education
P6	Activity, Work status.
P7	Profession
P8	Activity Sector
P9	Did you live in the same house the last 5 years?
P10	if not, where did you live (other state, other country)
P11	Did you make a trip yesterday? (Yes, No)

Table 2.15. *Additional family member's information*

FIELD NAME	DESCRIPTION
MUESTRA	sample number
ZONA	Zone of residence
H6	Family status
NOMBRE	Name
EDAD	Age
SEXO	Gender
PRESENTE	Physical present at the interview?
RESIDE	lives at the household?
H1	Date of trips
H2	Day of trips
JOUR	Day
SEXN	Gender
ZONEAGR	Zone of residence

The last table "Trip information" is a sequential table and cumulative by resident in which different household members and residents 5 years of age and older describe each one of the trips made the day before the interview. This table focuses strictly on the characteristics of these trips: purpose, origin, destination, times and transportation modes (Table 2.16.).

Table 2.16. *Trip information*

FIELD NAME	DESCRIPTION
MUESTRA	sample number
PERSONNE	Person
MOTIVO	Purpose
MOTIAGR	Purpose
ZORIG	Origin zone
ZDEST	Destination zone
HOR_SAL	Departure Time
HOR_LLE	Arrival Time
MODEAGR	Aggregated mode
MODE	Transportation Mode
FEXP	Weight
NMOD	Mode code
MOD_PRIO	Transportation Mode
ZONA	Zone
EDAD	Age
SEXO	Gender
ZONEAGR	Aggregated zone
H1	Date
H2	Day (number)
JOUR	Day (name of the week)

Source tables 2.12. to 2.16: [109].

2011 Sampled field data

Description of the 2011 Household Travel Survey of the city of Puebla was collected from [110]. The 2011 Household Travel Survey of Puebla is the result of an agreement between the consulting firm LOGIT-Puebla and the State Government of Puebla. By this agreement, LOGIT took responsibility for organizing and implementing the survey which had the objective to understand the trip patterns of residents with 5 years and more of metropolitan area of Puebla in terms of frequency, modes of transport, time, purpose and spatial distribution to perform the master transport plan 2011-2041. The survey was developed consistent with the OD survey conducted in 1994 by the GIM (Interuniversity Group of Montreal) in the framework of the Angelópolis project.

The 2011 survey was conducted through household interviews, and 5272 surveys were validated. This constitutes a sample of 1.06% of the total household's universe in the study area according to the General Census of Population and Housing of 2005 and its update of 2010. At the end, there was a database of over 20000 people. Between September and November 2010 LOGIT proceeded to the survey planning, the organization and training of staff and the implementation of the pilot survey. The surveys was conducted between November 6, 2010 and February 4, 2011, with an interruption on Christmas season. The survey was conducted in 2 phases: Phase 1 corresponds to the territory of the Household Travel Survey of 1994 (Figure 2.11). First phase had a total of 4,861 validated surveys conducted between November 6th in 2010 and January 3th in 2011. Second phase corresponded to the additional territory of San Pablo del Monte in the state of Tlaxcala and had a total of 411 validated surveys conducted between the 2th and 4th of February in 2011.

The questionnaire was designed to capture the classic variables of a survey of origin and destination with the support of the OD survey questionnaire 1994. The information is divided into five different tables (Tables 2.17. through 2.21.). Table 1 (Table 2.17.): "Survey Control" collects data on the development and validation of the survey (date and time of visits, the survey score, verifications performed, etc.). Table 2 (Table 2.18.) "Household Information": refers to general information about the household, the type of property, and possession of vehicles.

Table 2.17. Survey Control

FIELD NAME	DESCRIPTION
Id	Unique sample identifier
NoENCUESTA	Survey number
DOMICILIO	Address
NoEXTERIOR	Household number 1
NoINTERIOR	Household number 2
COLONIA	Neighborhood
CP	Zip Code
TELEFONO	Telephone number
ENTRECALLES	Adjacent Streets
REFERENCIA	Other reference near home
FECHA_ENCUESTA	Survey date
CIUDAD	City
MUNICIPIO	Municipality
AGEB	Statistical zone number
MUESTRA	Survey number
NOM_ENCUESTADOR	Interviewer name
NoENCUESTADOR	Interviewer number
VISITAS_POSTERIORES_FECHA_1	Date of following visit 1
VISITAS_POSTERIORES_HORA_1	Hour of following visit 1
VISITAS_POSTERIORES_TIPO_1	Type of following visit 1
VISITAS_POSTERIORES_FECHA_2	Date of following visit 2
VISITAS_POSTERIORES_HORA_2	Hour of following visit 2
VISITAS_POSTERIORES_TIPO_2	Type of following visit 2
VALIDADOR_1	Supervisor 1
OBSERVACIONES_1	Notes 1
FECHA_1	Date 1
VALIDADOR_2	Supervisor 2
OBSERVACIONES_2	Notes 2
FECHA_2	Date 2
VALIDADOR_3	Supervisor 3
OBSERVACIONES_3	Notes 3
FECHA_3	Date 3
VALIDADOR_4	Supervisor 4
OBSERVACIONES_4	Notes 4
FECHA_4	Date 4
GPS	GPS household location
HORA_INICIO_ENCUESTA	Start time of interview
ZONA	Zone
FACTOR 2010	Weight

Table 3 “Household residents” (Table 2.19.) focuses on each of the household members, residents aged 5 years or older and includes information on their activity and position in the home, school education, employment/education status. Interviewers collected information regarding even the resident made at least one trip the day before the interview or stayed at home all day.

Table 2.18. Household information

FIELD NAME	DESCRIPTION
Id	Unique sample identifier
FECHA_ENCUESTA	Survey date
NoENCUESTA	Survey number
NoENCUESTADOR	Interviewer number
ZONA	Zone
AGEB	Statistical zone number
MUESTRA	Survey number
TIPO_VIVIENDA	Type of household
CALIDAD_VIVIENDA	Quality of household
VIVIENDA_PROPIA	Owned or rented property
NoNIVELES	Household's number of floors
NoCUARTOS	Household's number of rooms
NoCAJONES_ESTACIONAMIENTO	Household's number of car space
MATERIAL_VIVIENDA	Household's construction materials
OTRO	Other
VEHICULOS_HOGAR	Vehicles in household
TIPO VEHICULO	Type of vehicle
COMBUSTIBLE	Type of fuel
EMPLACAMIENTO	License plates
OTRO	Other
MODELO	Model
AÑO	Year
FACTOR 2010	Weight

Table 2.19. Household residents

FIELD NAME	DESCRIPTION
Id	Unique sample identifier
FECHA_ENCUESTA	Survey date
NoENCUESTA	Survey number
ZONA	Zone
AGEB	Statistical zone number
MUESTRA	Survey number
NoENCUESTADOR	Interviewer number
HABITANTES_VIVIENDA	Household's residents
NOMBRE	Name
EDAD	Age
SEXO	Gender
CAPACIDADES_DIFERENTES	Handicapped?
PARENTEZCO	Family status
RESIDENTE	Resident or not
ESTUDIOS	School level
ACTIVIDAD	Activity
CIUDAD_TRABAJO	Work location place
LICENCIA	Driver License
EN_ENTREVISTA	Present at interview?

Table 4 “Trips information” is a sequential and cumulative record in which all household members 5 years and older, who made a trip the day before the interview, describe their travel activity (Table 2.20.). Thus, it focuses on the characteristics of per capita urban trips: origins, destinations, purpose, times and means of transportation.

Table 2.20. Trip information

FIELD NAME	DESCRIPTION
ID	Unique sample identifier
FECHA	Survey date
NO-ENCUESTA	Survey number
NoENCUESTADOR	Interviewer number
ZONA	Zone
AGEB	Statistical zone number
MUESTRA	Survey number
NOMBRE	Resident's name
ORIGEN_VIAJE	Trip origin
ORIGEN_ZONA	Zone of origin
ORIGEN_AGEB	Statistical zone of origin
ORIGEN_MUESTRA	Survey origin
SECUENCIA	Sequence number
ORIGEN_DIRECCION	Address of origin
MOTIVO_DESTINO	Purpose of origin
DESTINO_DIRECCION	Address of destination
DESTINO_REFERENCIA	Address of destination
ZONA_DESTINO	Zone of destination
AGEB_DESTINO	Statistical zone of destination
MUESTRA_DESTINO	Survey destination
SALIDA	Depart time
LLEGADA	Arrive time
MODO_A	Transport mode 1
RUTA_A	Public transport route number 1
MODO_B	Transport mode 2
RUTA_B	Public transport route number 2
MODO_C	Transport mode 3
RUTA_C	Public transport route number 3
MODO_D	Transport mode 4
RUTA_D	Public transport route number 4
MODO_E	Transport mode 5
RUTA_5	Public transport route number 5
MONTO DEL VIAJE	Total cost of trip
VIAJES_SEMANAL	Number of trips per week
ESTACIONAMIENTO	Parking
TIPO_MONTO	Parking cost
GASOLINA	Fuel type
PERIODO	Period
zona-DOM	Zone of household
AGEB-DOM	Zone of household

The 2011 Household Travel Survey also contains an additional section describing the use of the bicycle and other socioeconomic variables such as household's income, expenses, etc. (Table 2.21.).

Table 2.21. Bicycle use and income information

FIELD NAME	DESCRIPTION
Id	Unique sample identifier
FECHA_ENCUESTA	Survey date
NoENCUESTA	Survey number
NoENCUESTADOR	Interviewer number
ZONA	Zone
AGEB	Statistical zone number
MUESTRA	Survey number
NoBICICLETAS_CASA	Number of bicycles in household
UTILIZA_BICICLETA	Use of bicycle
FRECUENCIA	Frequency
HORA_DIA_SEMANA	Time, day, week
USAR_BICICLETA_CIUDAD	Bicycle use in city
RENTA_BICICLETA	Rent bicycle?
TIEMPO_RENTA	Time of rent
PAGO	Paid rent
FACTOR 2010	Weight
GASTOS_CANASTA_BASICA	Basic food basket expenses
PERIODO	Period
TIENDA	Superstore, groceries store
REFERENCIA	Reference
SALARIO_MINIMO_DIARIO	Daily minimum wage in household
HORA_FIN_ENCUESTA	End time of survey

Source tables 2.17. to 2.21: [110].

2.4.1.3 Mexican demographic projections

The potential magnitude and composition of the population structure in future years is a basic input for the Age-Cohort Travel Demand Forecast Model. Official organizations such as the Mexican National Institute of Statistics and Geography (INEGI), or the Municipal Planning and Research Institute of the city of Juarez (IMIP) have some information relating to population growth, but since their mission is not the development of population projections they only have general information obtained from the National Population Council from Mexico (CONAPO), which is the authority responsible for developing population forecasts in Mexico. In fact CONAPO, as established by the Regulations of the General Population Act⁵⁵, conduct population projections and the needed periodic updates corresponding to the recent changes in terms of fertility, mortality and migration, etc. Some population projections available are [111-115]. However, these population projections do not correspond to the methodological requirements of the Age-Cohort Model. The Age-Cohort demographic approach to Travel Demand projection is based, among other sources as described previously, on the annual estimates of the age-pyramid structure disaggregated at individual age groups, and at least up to the year 2030.

⁵⁵ Reglamento de la Ley General de Población.

This is necessary to longitudinally follow each individual in the studied population and observe the specificity and mobility profile of each age and generation. In addition, these demographic projections must correspond exactly to the study area of the Household Travel Surveys of the studied cities. Comparing demographic projections available with methodology requirements listed above we face the following problems and limitations.

a) Geographical aggregation bias

Most long-term projections available suffer from lack of geographic disaggregation and correspond mainly to national or federal entity. As stated by Partida [112]:

"Within the large body of projections that are available for Mexico, the vast majority correspond to the national level exercises".

When population forecasts at a municipality level exists, as in CONAPO's recent publications [112, 113], they are not disaggregated in terms of individual's age for each projected year. In addition, they are not geo-referenced, meaning that do not contain the geo-location by zone of residence of such projections, so it is not possible to know the exact spatial distribution of forecasted population over the projected years. Hence, it is not possible to identify; and therefore to exclude population corresponding to the zones located outside the study areas from the Household Travel Surveys.

When municipality-level population forecasts are available [111], the total projected population is highly aggregated by large age groups and there is no data relating the geo-location of zone of residence of projected population within the study area. The available projections mentioned above show only the total number of projected population for the year, without adequate disaggregation according to individual age (without grouping) over the projected years.

Given the difficulty to properly study "evolutionary geographies" [116], we have chosen to work at constant area. In all analyzes presented in this research travel activity and population forecasts are controled for geography (the same area of study over the years) to properly identify travel behavior dynamics from individuals corresponding to surveyed study area. In other words, the available projections do not allow to model the behavior of urban mobility at constant area (initial urban

area), because they only show global or total data per year which makes it difficult to assign it to the actual population corresponding to the areas within the specific geographic limits established at the Household Travel Surveys of Juarez (1996) and Puebla (1994); incurring the risk of introducing bias into the research.

It is noteworthy that in the case of Juarez, the IMIP conducted brief exercises of population projections that respected the study area of origin-destination travel surveys [117]. However, these were made only for the years 2015 and 2025, and were projected under scenarios of faster growth to the current growth rates making those projections obsolete and incorrect, being confirmed by the same authors years later⁵⁶ and also only for aggregate data without taking into account the age of individuals. CONAPO's interest in the mentioned publications has been to generate total macro level estimates. In order to do this for each municipality, the projections have been done without the complexity of adding more variables to consider in the forecasting model, and these exercises have been undertaken without the intention of determining the geographical distribution level of future population at a finer level for both: within the original territory as new urbanized areas of each city. The general assumption here was that cities do not grow in terms of urban area, which according to historical data observed in both origin-destination surveys, and publications from the School of Urban and Regional Economics at the University of Puebla in Puebla⁵⁷ and IMIP in Juarez this assumption has not been met. Again, the level of disaggregation of available projections do not correspond to the area of origin-destination surveys since there is no geo-location of population from the base year to at least the year 2030, hence it is difficult to detect geographical boundaries of data and therefore adjust to study area boundaries⁵⁸.

b) Overestimated population bias

Demographic fluctuations caused by the relocation of people from one area to another is a determining factor in population forecasts and in some cases can be a

⁵⁶ Multiple interviews with researchers from the Municipal Research and Planning Institute of Juarez México (IMIP). In particular with M.Sc. Alfredo Morales. General Coordinator of the Geo-statistic and Informatics Department and with M.Sc. Luis Martínez General Coordinator of the Urban Design Department.

⁵⁷ Facultad de Economía Urbana y Regional de la BUAP en Puebla.

⁵⁸ It is not in the scope of this research to study urban sprawl evolutions, dynamics and their explanatory factors.

major cause of population growth or deceleration in a region. A specialist demographer from CONAPO [112] states that in the case of Mexico:

"...it is extremely difficult to establish long-term assumptions about the future incidence of migration between states, this phenomenon of differences in population growth caused by migration between states is now more determinant than natural growth."

An example of change in trend in the growth rate or unexpected slowing down of population growth rates caused by other than natural deceleration are the cities of the north of Mexico, which are affected by the phenomenon of violence in recent years. In particular there is the case of Juarez that has radically changed its population trends, hence the validity on their population projections available. This by not taking into account, among other factors, the thousands of intentional homicides in the last years, or the hundreds of thousands of Juarez residents who migrated to the nearby city of El Paso in the United States of America (or other American cities) or to another Mexican cities due to the rise of high levels of violence in the city. Another factor that made population projections obsolete was the massive migration of workers to their hometown (e.g. Veracruz, Torreón, etc.) due to the economic slowdown of the industry along the Mexican border. The newspaper "El mundo" [118] reported in the article entitled "Más de 200,000 mexicanos huyen de Ciudad Juárez por la violencia"⁵⁹:

"Estimates of the size of the exodus vary, but academic researchers and authorities estimate between 75,000 and 200,000 people since mid-2008,"

With respect to this slowdown, in another article [119] Maria Tomasa Badillo, coordinator of the National Institute of Statistics, Geography and Informatics (INEGI) in Chihuahua, said the census indicates that:

"Juarez reached only an average annual population growth of 0.86 percent in the last decade".

The head of the National Population Council (CONAPO) of Mexico, Felix Velez confirmed to mass media [120] that Juarez reported a slowdown in population growth.

⁵⁹ More than 200,000 Mexicans run away from violence in the city of Juarez"

"Specifically, in the valley of Juarez, there was clearly a drop in population from 2005 to 2010, this is a part of the metropolitan area of Juarez, where a peak of population growth was observed in the period".

Local researchers from Juarez (IMIP, ICRC, UACJ) agree with these statements from national authorities, and estimate that available population projections from CONAPO and also the projections published at most recent Urban Development Plan of the city of Juarez developed by IMIP [121], are highly overestimated, therefore lose their validity because they were made before the unexpected events. Outlining the high population growth to future years, which has been observed previous the economic and social crisis, no longer reflect the current and/or future population⁶⁰.

c) Age aggregation bias

As stated by Dejoux et al. [122]:

"...the life cycle measures the importance or weight of age on individual behavior. The assessment life cycle allows to outline a curve with the characteristic changes attributed to age (which is known as profile-type) for a stabilized behavior. The generation (or cohort) identifies behaviors based on a group of individuals born in the same period, having experienced the same events".

For this reason age is a key feature for the cohort analysis of the demographic approach to travel demand, hence it needs to be coded individually for each age in the demographic projections. Regarding exiting population forecasts from CONAPO [111], age is coded in highly clustered categories (e.g. 0-14 years, 15-64 years, 65 years or older). However, disaggregated population projections by age is necessary for undertaking the multilevel analysis of variance used in the demographic Age-Cohort Travel Demand Forecast Model.

⁶⁰ Multiple interviews with researchers from the Municipal Research and Planning Institute of the city of Juarez. In particular with Dr. Salvador González-Ayala, M.Sc. Alfredo Morales, General Coordinator of the Geo-statistic and Informatics Department. M.Sc. Luis Martínez, General Coordinator of the Urban Design Department and with M.Sc. Alberto Nicolás López Duarte. Head of Urban Mobility Department.

By not knowing the detailed distribution of the characteristics of each age individually, the potential is lost in the regressions and forecasts of urban mobility incurring with this in ecological fallacy. According to [112] the ecological fallacy consists in:

“thinking that relationships observed for groups necessarily hold for individuals: If there is no confounding, the expected difference between effects for groups and effects for individuals is ‘aggregation bias’; in general, the difference is partly attributable to confounding and partly to aggregation bias.”

Thus, making inferences of individual behavior drawn from aggregates data leads to age aggregation bias and in general weakly supported results.

The evolution of mobility that will be presented in this study will be explained through the identification of determinant factors that explain these changes. As mentioned on previous chapter, one objective is to know to what extent the changes in the long-term mobility depend on changes in the population structure (e.g. population growth, age structure changes, etc.) and how much corresponds to changes in population behavior (e.g. telecommuting in new generations, tendency to more or less motorization, changes in public transport use, etc.). Therefore it is necessary to elaborate a more detailed population projections for Juarez and Puebla.

2.4.2 French sources

French Household Travel Surveys benefit of total homogeneity thanks to the fact that they were developed by the same agency, the Networks, Transport, Urban Planning and Public Facilities Studies Center (CERTU)⁶¹. This agency, which is part of the French Ministry of Ecology, Sustainable Development and Energy⁶², has been applying for more than thirty years the so-called CERTU’s standard method for identifying and observing national and local mobility trends. These harmonized Household Travel Surveys allows to gather different data such as the number of trips per person aged 5 years old and older on a weekday (excluding holidays and school vacations), trip purpose (e.g. leisure, work, study, shopping, other services, etc.), the modes of transport used (e.g. private vehicle, public transport, cycling, walking, etc.), and the hourly and spatial distribution of each trip [123-125].

⁶¹ Centre d’études sur les réseaux, les transports, l’urbanisme et les constructions publiques.

⁶² Ministère de l’Écologie, du Développement durable et de l’Énergie.

In the method of CERTU a trip is the action of getting from one place to another to perform an activity, using one or more modes of transport. The activity is called "purpose". Mode change is not a trip purpose. A transportation modes are means of transport such as private vehicle driver, private vehicle passenger, metro, tram, urban bus, suburban bus, intercity bus, train, work or school transportation, taxi, motorcycle, bicycle, walking. An order of priority specifies the principal mode used if multiple modes are used during a trip. These descriptions are consistent with the definitions from the Mexican surveys.

The questionnaires includes a "Household" database, a "Resident" Database, a "Trips" database completed for each respondent. This type of survey does not collect information on the travel activity of people living outside the study area, or the transport of goods outside the study area. A survey called "Screenline survey"⁶³ collects this type of information [124].

According to [123-125], the main principles of CERTU's standardized method are:

- a) Sample (household) is randomly chosen, the sample size is set to ensure a minimum reliability of the results allowing a sectorial analysis;
- b) surveys are conducted by trained interviewers;
- c) people, aged at least 5 years, living in the household are interviewed;
- d) all trips made the day before the survey by each respondent are collected. There are specific surveys with the objective of observe mobility on weekends (Saturday and Sunday), however as a rule, usually urban mobility refers to average trips made per person on a weekday excluding school holiday, weekends and holidays;
- e) the characteristics of these trips, purpose, origin geographical location, destination geographical location, times of departure and arrival, and all modes of transportation are taken into account, including walking.

⁶³ Enquête cordon.

2.4.2.1 Lille: Household Travel Surveys and Vehicle Characteristics

1987, 1998 and 2006 sampled field data

As mentioned before, the Household Travel Surveys from 1987, 1998 and 2006⁶⁴ of the Urban Community of Lille (LMCU), like in other French urban areas, were design and conducted using CERTU's standardized method [126, 127]. A difference between them is that the most recent survey from 2006 contains slightly more variables⁶⁵ and the zoning is more detailed compared from earlier surveys. However, the first survey from 1987 already contain all the usual variables from a classic transport survey, coinciding for example with the Mexican surveys shown in previous section [127]. The study area and zoning from 2006 is compatible to those from 1987 and 1998 [126] (Figure 2.12).

The 2006 zoning is also compatible with that from the French National Institute for Statistics and Economic Studies (INSEE)⁶⁶. The 2006 survey was conducted with the so-called renovated method, which consist on interviewing from each household one or two people 5 years and/or older. 8990 representative people of the population of the 85 municipalities of the Urban Community of Lille were interviewed in their households, in relation to their travel activity between January 2006 and June 2006. As in the case of all Household Travel Surveys in Lille, the sample size of 2006 ensures a minimum reliability of the results. For instance, the selection of households for this survey is derived from a random sample of 57 geographic areas listed of the General Directorate of Housing Taxes⁶⁷ and from a sample of 41 university residences households [126].

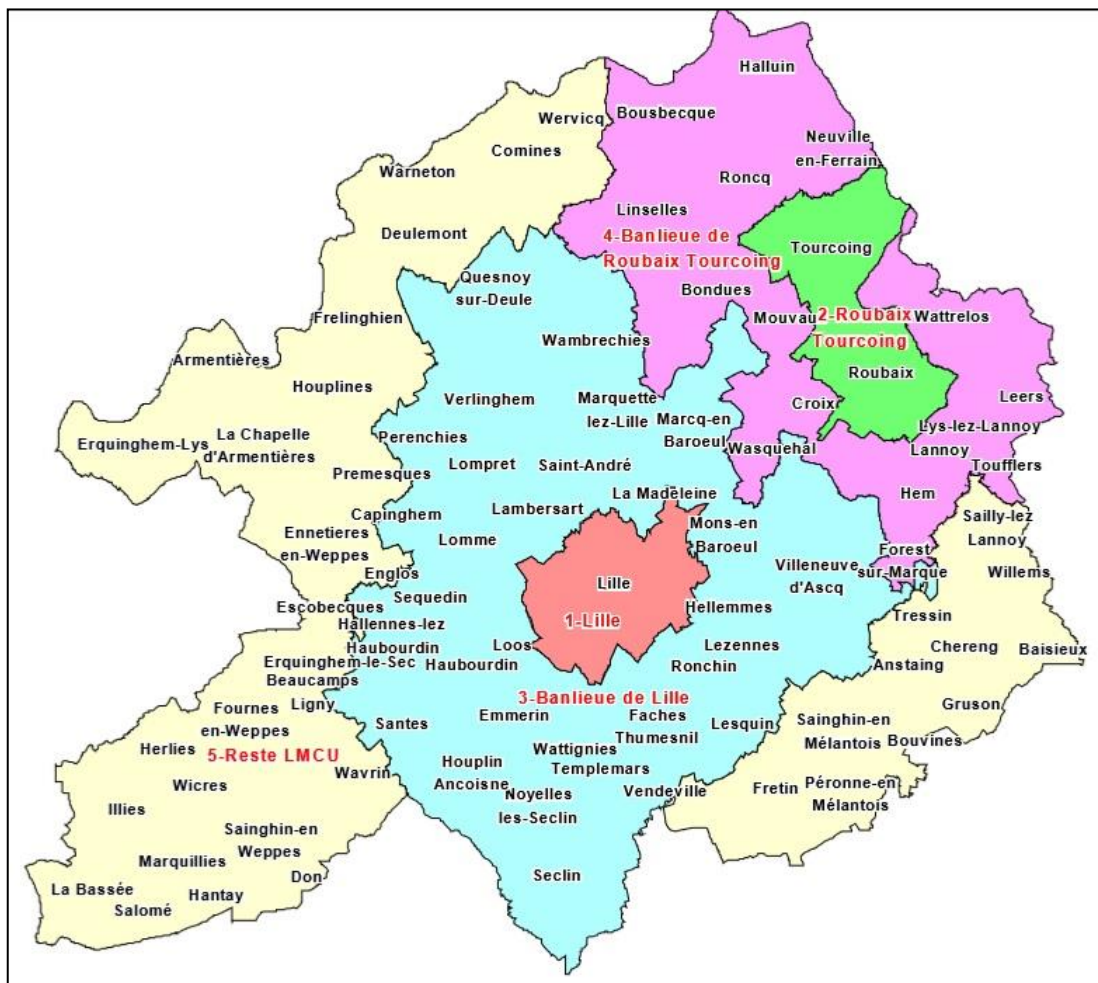
⁶⁴ Actually the firsts Households Travel Surveys of the city Urban Community of Lille were conducted in the years 1965 and 1976. In the present study only the last three surveys are taken into account.

⁶⁵ For instance the 2006 Household Transport Survey also contains a table completed by people from 16 years and older about their opinion of different transport services.

⁶⁶ Institut National de la Statistique et des Études Économiques.

⁶⁷ Direction Générale des Impôts.

Figure 2.12. LMCU Household Travel Surveys Study Area,



Source: [126].

2.4.2.2 Paris Region: Household Travel Surveys and Vehicle Characteristics

1991 and 2001 sampled field data

The Transport Global Survey (EGT)⁶⁸ is a large-scale transport survey that has been tracking for thirty-five years the travel behavior evolution of the inhabitants of the Region of Paris. It is a valuable source of information that helps develop regional planning policies and to provide services and transport infrastructure. The EGT survey is performed under the framework of a technical and financial partnership of stakeholders such as the Regional Directorate of Equipment from the Paris Region⁶⁹, the local government of the Paris Region⁷⁰, the city of Paris⁷¹, the Transport Syndicate

⁶⁸ Enquête Globale de Transport.

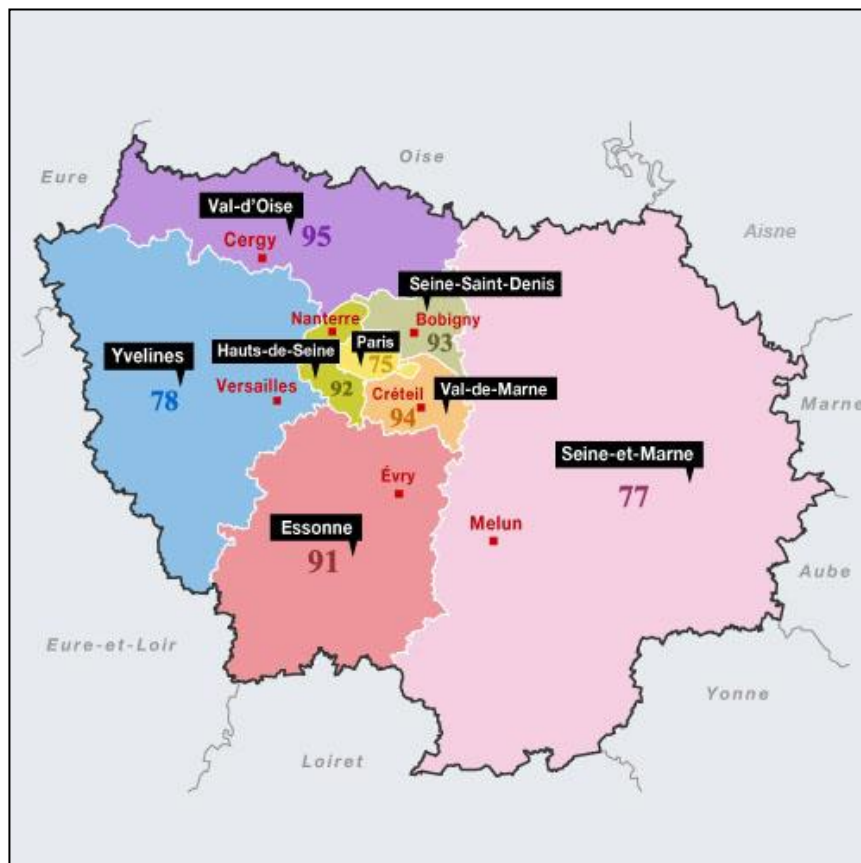
⁶⁹ Direction Régionale de l'Équipement d'Île de France.

⁷⁰ La région Île de France.

⁷¹ La ville de Paris.

of the Paris Region⁷², the Autonomous Operator of Parisian Transports (RATP)⁷³, the National society of French railways (SNCF)⁷⁴, the Regional Directorate of INSEE of the Paris Region⁷⁵, and the Planning and Urbanism Institute of the Paris Region⁷⁶. As in previous surveys of 1976 and 1983 surveyed households in 1991 and 2001⁷⁷ are derived from a sample of the general census of the population from INSEE. For instance, the 2001 survey, which was applied between October 2001 and April 2002 was conducted by surveying a large number of households: 18 000 surveyed housing units, in which about 10 500 households responded, representing a response rate of about 58%. The EGT's were design in order to be comparable over time, in terms of the data gathered and the study area zoning and geographical boundaries (Figure 2.13). However, the questionnaires have been gradually enriched with new questions over time [128].

Figure 2.13. Paris Metropolitan Area, Surveys Study Area



Source: http://www.limeil-brevannes.fr/?page_id=193

⁷² Syndicat des Transports d'Île de France.

⁷³ Régie autonome des transports parisiens.

⁷⁴ Société nationale des chemins de fer français.

⁷⁵ Direction Régionale de l'Insee d'Île de France.

⁷⁶ L'Institut d'Aménagement et d'Urbanisme de la Région Île de France.

⁷⁷ The present study does not takes into account the Household Travel Surveys developed in 1976, 1983 and most recent survey from 2011 available only since fall 2013.

The data gathering and survey design has been carried out with the conventional method applied in French cities, in which household's residents are interviewed face to face, thus facilitating further analysis. Each member of the household of six years or more⁷⁸ describe all trips traveled the day before the survey. Each trip has to be fully described in terms of transportation mode, trip purpose, origin's geographical location, destination's geographical location, etc. This information is stored, as in all Household Travel Surveys previously described, in the tables named "Household Information", "Resident Information" "Trips Information". In addition, each change or connection between transportation modes made within the same trip purpose is stored in the table "Transportation mode"⁷⁹ (Table 2.22.).

Table 2.22. Transportation mode

FIELD NAME	DESCRIPTION
DEPL	Number of travel
ENQ	Survey year
NLE	Additional Household Number
NQ	Number of household
NUMOY	Number transportation mode
NUMPERS	Number of the individual
POIDEPL	Final weight of trips
POIDS	Final weight of individuals
TCO	Number of transfers (between modes)
TCODCOM	INSEE commune Code
TCRE	Grid number of start of transportation mode
TCREIM	Grid number of initial mode of transport
TCRF	Grid number of end of transportation mode
TDLM	Distance traveled by mode transport (meters)
TDMTR91	Grouped mode of transportation (definition 1991)
TGCO	Municipality of residence of the household
TGDE	Department of residence of the household
TIT	Transport ticket
TMO	Mode of Transportation used
TMOT	Indicator of motorized trip
TNPAR	Number of routes for public transport
TPROXO	Indicator of proximity number of grid to the origin
TRES	Transport network used
TRES91	Transport network (definition 1991)
TRESR	Grouped transport network
TZSR	Area of residence EGT

Source: [128]

⁷⁸ The travel activity data gathering in the Region of Paris is focused on individuals 6 years or older, being a slight difference between other surveys described in present study, in which the norm is to interview people 5 years an older.

⁷⁹ Moyens de transport.

2.4.2.3 French demographic projections

The French National Institute for Statistics and Economic Studies INSEE has developed the Methodological Tool for Projection of Inhabitants, Workers (active persons), Students and Households named OMPHALE⁸⁰. INSEE applies for each year and for each sex and age, migration probabilities, fertility and mortality rates, the corresponding populations in forecasted years. These population forecasts are estimated taking into account past trends in fertility, mortality and migration observed on each study area [129]. The OMPHALE model has the precise population forecasts requirements⁸¹ to obtain long-term daily mobility projections through Age-Cohort Travel Demand Forecast Methodology.

2.5 Missing data reconstitution

This sections deals with imputation (for item non-response), correction (in case of erroneous data) and generation of data (when the information is not collected in the survey) in the interest of fulfilling the data requirements described in Section 2.3 (Table 2.23). Omitting this process may introduce important bias affecting the representativeness of the results obtained in this study. Although, as shown in Section 2.4, the case studies have a vast information constituting a very rich database, there is still missing, outlier or erroneous data for the appropriate application of the Econometric Modelling Analysis (Chapter 3), the Age-Cohort Travel Demand Forecast Model (Chapter 4) and the GHG Emissions Assesment methodology (Chapter 5). It is important to mention that, for Mexican case studies, the adaptation and application of travel surveys to research methodologies was a particularly exhausting and very difficult task. Actually, even if the development and organization of the survey meets international standards, it is afterwards, in the data processing, error checking and inspection phases of the implementation of the surveys where a lack of quality could be observed. In fact, Mexican Planning Organizations have in general difficulty to finance expensive Household Travel Surveys. When obtained, funds are usually limited to research and development prior to survey implementation and the actual survey implementation. Thus, a great data processing effort was necessary in order to make Mexican surveys comparable

⁸⁰ Outil méthodologique de projection d'habitants, d'actifs, de logements et d'élèves.

⁸¹ Population forecasts requirements for applying the Age-Cohort Travel Demand Model are described in Section 2.3.

and homogeneous to: 1) other survey from the same city, 2) surveys from other Mexican case study, and 3) French surveys.

Table 2.23. Missing, outlier or erroneous data

Case Study	Household Travel Survey	Database	Travel Distance	Demographic Projections	Vehicle Characteristics
Juarez	1996	✓	✗	✗	✗
	2006	✗	✗		✗
Puebla	1994	✓	✗	✗	✗
	2011	✗	✗		✗
Lille	1987	✓	✓	✓	*
	1998	✓	✓		*
	2006	✓	✓		*
Paris	1991	✓	✓	*	✗
	2001	✓	✓		✓

✗	Erroneous or missing values
*	Corrected by other sources
✓	Complete, accurate, reliable and ready to use data

a) Database errors

There was a major effort in the adaptation of the 2011 survey of Puebla. In particular, a visual inspection and manual correction of the databases, which could not have been corrected automatically using programming code, like other case studies. This correction step was accentuated by the lack of adequate documentation describing the datasets available (not the official survey, but the available data). The most common errors found were: duplicates of the exact household and resident records which were hard to identify due to different identification numbers, households without residents but recorded trips, residents with no households but declared to live in the study area, trips related to apparently no corresponding households and/or residents, duplicate of entire family, duplicate of trips per person and similar errors made during the input of data into the databases. This errors were corrected mainly by deduction. For instance, duplicate trips for an individual were identify

after careful inspection due to the fact that the person was recorded with two different ID numbers. His/her trips had departure and arrival time, transportation mode, trip purpose, departure and arrival zone and other trips characteristics which allowed the selection of only one unique trip instead of two identical and duplicated trips.

In Juarez, the zone configuration of 2006 survey does not correspond to 1996 survey, so it had to be adapted to the previous one. More precisely, a new shapefile layer had to be created by overlapping both zone configurations and running geoprocessing with GIS⁸² software ArcGIS in order to harmonize new 2006 layer in conformity with 1996 zone configuration.

b) Travel distance

Mobility surveys usually have erroneous travel distances; it is often missing or biased for different reasons [130]. The imputation of travel distances in the case studies is due to two types of problems. First, missing distances due to non-response. Secondly, to outliers⁸³ or extreme observations significantly distant from other observations of the same group (by mode of transportation, travel speed, time of trip and age⁸⁴). When data is missing in surveys, due to the partial or total non-response there are statistical techniques to overcome these irregularities replacing missing data with imputations. Imputation is a procedure that involves replacing the missing items with values taken from other respondents answers [130, 131]. This technique has been applied to surveys to produce complete and ready to use data. The imputation method applied on case studies consists on estimating the missing distances from correct observations. In particular with travel time and transportation mode, but also with origin and destination zones in some cases. When time speeds were considered also to be erroneous then travel distances were estimated with the origin and destination zones reported on each trip. Outlier and missing points were then excluded from the dataset observations and replaced by simulated (with travel speed and transportation mode) or estimated (with origin and destination zones) values.

⁸² Geographic Information Systems.

⁸³ Outliers in a normal proportion for this type of question.

⁸⁴ These are the selected variables to model travel distance. When no travel time was available, comparable origin and destination zones were used.

c) Demographic projections

Mexican demographic projections used in the Age-Cohort models were constructed based on CONAPO's statewide projections and adjusted to population trends observed on Household Travel Surveys for each city.

d) Vehicle characteristics

As described in Section 2.3, the BEED methodology for assessing GHG emissions due to on-road transport activity observed on mobility surveys requires specific technological characteristics of the private vehicle(s) used during the trip(s). Energy consumption and emissions estimations are obtained as a function of distance traveled and mode of transport used⁸⁵. For this last we need to specify the characteristics of car fleet that will determine the emission factors, and therefore the amount of pollutants emitted per kilometer traveled. These variables are necessary for each city and surveyed year with the aim to determine the influence and evolution of socioeconomic (e.g. gender, age, income, level of education, activity, etc.) and geographic factors (e.g. city center, inner suburb, outer suburb, etc.) on the generation of pollutant emissions from mobile sources (Chapter 5). These variables are: 1) Type of fuel (e.g. gasoline, diesel), 2) Vehicle's year of registration (e.g. 1988, 1995), 3) Vehicle's engine power measured in number of cylinders (e.g. 4 cylinders), 4) Existence of the catalytic converter in the vehicle (yes, no). The databases of mobility surveys of Juarez 1996 (Table 2.2.) [106]), Juarez 2006 (Table 2.7.) [108], Puebla 1994 (table 2.13.) [109], Puebla 2011 (Table 2.18.) [110], and Paris 1991 [128] do not allow to perform the BEED methodology due to lack of variables concerning the structure of the car fleet (in particular vehicle's engine power and existence of catalytic converter) and to missing values from available variables. Thus, it was imperative to make imputations of missing variables. For instance, the variable engine power was simulated based on the size, model and type of vehicle. Similarly, the variable catalytic converter was simulated based on the type of fuel, vehicle size and year. In addition, missing records from available variables were simulated based on available information. An example of this imputation methodology can be found for the case of Paris Region in Section 5.1.1, where the variable "fuel type" was not considered in the questionnaire of 1991 and therefore does not exist in the databases. Here we reconstructed through modeling the missing variable "Fuel Type" and also

⁸⁵ We will not add or modify in this study information on transport modes other than private motorized vehicles.

the presence of catalytic converter in the vehicle using available variables: those relating to the year of matriculation and the motor power. These simulation based on relationship between variables were made with SAS⁸⁶ software.

2.6 Chapter summary

First of all, the current chapter has justified the selection of case studies. Furthermore, the urban mobility data and the population projections available in French and Mexican cities were described, as well as the corrections needed in order to apply: 1) the econometric approach to travel demand analysis (Chapter 3), 2) the demographic approach to travel demand forecast (Chapter 4), and 3) the GHG emissions assessment methodology (Chapter 5). All described data is now homogeneous and is in accordance with all methodologies used in present research. The next chapter will deal with the Cross-Sectional Analysis of mobility surveys.

⁸⁶ Statistical Analysis System.

Chapter 3. DAILY MOBILITY EVOLUTION

Chapter 3. Daily mobility evolution

Introduction

After the process of error checking, data generation and replacing missing data with substituted values described in previous Chapter, the interest will be now focused on analyzing the evolution of daily mobility based on the available repeated cross-sectional Household Travel Surveys.

A primary task for monitoring the evolution of mobility, not only in different case studies but from different years, is to control for geographic area. Indeed, in this study the urban area of the different cities was considered constant over time in order to assess the travel behavior evolution within the same study area. Controlling for study area was necessary in order to better draw mobility indicator evolution observed within the same urban zone. Another important fact is that in order to minimize the bias with respect to the interaction between urban form and urban transport, mainly given the fact that the analyzed cities have very different urban form configurations (e.g. land use, transport systems, built environment, urban tissue, etc.) and different processes of formation of human settlements, and specially data availability issues for the generation of more complex urban form classification, the urban form variable “zone”, will be classified into three main categories:

- the city-center or just “center”, which usually have high population density and mixed land use,
- the “inner suburbs” with medium density,
- and the “outer suburbs” with low density and typically more industry and/or open space compared to preceding zones.

It is important also to recall that all data presented in this research describes travel activity of an ordinary weekday from all population from 5 or 6 years old and older (depending on the survey). Despite the fact that all modes of transportation were recorded in the surveys, the interest of the present study will be concentrated on the evolutions of the heaviest and most important modes of transportation: “Public Transport”, “Private Vehicle Driver”, “Private Vehicle Passenger” and lastly a global category named “All Modes” which includes the sum of all modes of transportation from public transport to non-pollutant modes such as walking.

As shown in previous Chapter, in some cases income is not available at an individual level (i.e. Puebla 1994, Lille and Paris Region –all years) or household level (i.e. Puebla 1994), as well as the variable regarding the possession of driving license which is not available in Juarez. However, all available and useful information from Household Travel Surveys will be used in each analysis of this Chapter.

These analyses will be organized in two sections for each case study:

Section 3.1, “**General travel behavior overview**”, describes general indicators of travel activity at both household and individual level in terms of the geographic, socioeconomic and demographic characteristics.

Section 3.2, “**Econometric modelling trend analysis**”, has the objective of identifying the main influencing factors of household motorization and travel behavior and their evolution over time. More exactly, the intention is to measure statistically for each case study, the changes between parameters of their most important explanatory factors by comparing their significance and strength of effects in order to identify which ones “gain” or “lose” influence from one year to another. Like for most of durables, the diffusion of car ownership has started in high income groups [132]. In developed countries, at the beginning of motorization, the wealthiest households often lived in city-centers and car ownership used to be higher in these high density areas. Then, high density has slowed down the diffusion of car ownership in city-centers, while its social diffusion has favoured its diffusion in the suburbs with less density pressure. Thus nowadays, at least in Northern Cities, car ownership is higher in the suburbs than in city-centers. At what stage of this process can be situated the different case-studies presented in this thesis? Additional underlying questions of this analysis for each case study from France and Mexico are:

- What are the principal explanatory factors of daily urban travel by mode? For instance, what is the impact of household’s and individual’s income on travel behavior? Or, does income, activity of the person or zone of residence affects variables such as private vehicle ownership and use⁸⁷? How strong are these correlations? and what are the observed trends?
- What is the ranking of explanatory variables for travel activity at different points in time and between case studies?

⁸⁷ When the income variable is available in the surveys.

3.1 General travel behavior overview

Vehicle ownership by households is commonly the most important factor in many case studies around the world for explaining travel activity in private vehicle. Moreover, correlations and evolutions of vehicle use and vehicle ownership with respect to socioeconomic and geographical factors often tend to be similar. Statistical significance of these factors for explaining vehicle ownership, as well as including vehicle ownership as another potential explanatory factor for individuals travel behavior by mode is described in section 3.2.

General overview of Household Travel Surveys show different multi-motorization trends in terms of yearly Relative Percentage Change (RPCh) of Frequency (Tables 3.1 to 3.5 and Figures 3.1 to 3.5). For instance, car deprivation evolution is negative in Juarez (-0.9%) and Lille (-0.8%), meaning that in the recent survey fewer households were observed without a private vehicle. An increase of +1% was observed in the Paris Region for the same category. Puebla had the stronger shift towards car-deprived households with +9.1%. The only case study with negative trends of mono-motorized (one car) households was Juarez (-1.4%). More pronounced positive evolutions for mono-motorized households were observed in Puebla with +7.2%. The only city with a downward trend of households with two vehicles was Puebla with -3.4%. Evolutions of this category are similar in Juarez and the Paris Region, with +1.2% and +1.6% respectively, while Lille had an increase of +5.8%. Evolutions for the category of households with three private vehicles are different in each city. Puebla had -9.4% in terms of yearly evolution rate. A positive trend was observed in Juarez (+1.7%) as well in the Paris Region (+2.4%: 3 or more vehicles) and Lille (+7.4%). Finally, households with 4 or more vehicles, had similar evolutions in Juarez (+7.3%) and Lille (+19.2%), while in Puebla the observed trend was -11.7%. In general the multi-motorization phenomenon is more clear in Juarez due to the negative evolution trends for the categories of households with zero and one vehicles, and, as Lille and Paris Region, positive Relative Percentage Changes for multi-motorized homes. Puebla had an inverse trend compared to Juarez, a negative trend has been observed for the number of multi-motorized households, while a positive evolution has been observed in the car deprivation category. In fact, the share of car-deprived households in Puebla accounted for 60.7% in 1994 while in 2011 the share increased to 66.2%. Mono-motorized homes accounted for 29.9% in both years.

Table 3.1 Household vehicle ownership evolution between 1996 and 2006, Juarez

Vehicles in the HH	1996		2006		Period Evolution	Year Evolution
	Frequency	Percent	Frequency	Percent	RPCh* of Frequency	RPCh* of Frequency
0	82140	29.7%	74591	27.9%	-9.2%	-0.9%
1	107843	39.0%	92790	34.7%	-14.0%	-1.4%
2	65602	23.8%	73468	27.5%	+12.0%	+1.2%
3	16194	5.9%	18873	7.1%	+16.5%	+1.7%
4 or more	4410	1.6%	7639	2.9%	+73.2%	+7.3%
Total	276189	100%	267361	100%	-0.03%	-0.003%

*Relative Percentage Change (RPCh)

Figure 3.1. Household vehicle ownership evolution between 1996 and 2006, Juarez

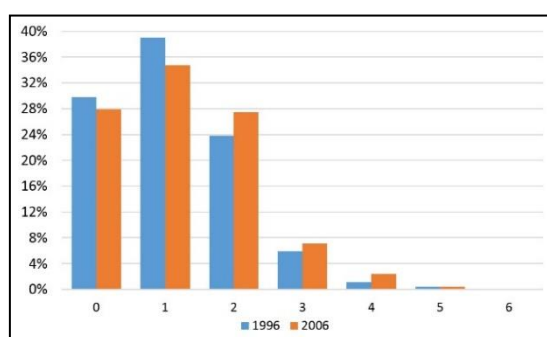


Table 3.2. Household vehicle ownership evolution between 1994 and 2011, Puebla

Vehicles in the HH	1994		2011		Period Evolution	Year Evolution
	Frequency	Percent	Frequency	Percent	RPCh of Frequency	RPCh of Frequency
0	171428	60.7%	280807	66.2%	+63.8%	+9.1%
1	84433	29.9%	126911	29.9%	+50.3%	+7.2%
2	18631	6.6%	14180	3.3%	-23.9%	-3.4%
3	5527	2.0%	1897	0.5%	-65.7%	-9.4%
4 or more	2303	0.8%	412	0.1%	-82.1%	-11.7%
Total	282323	100%	424207	100%	+0.5%	+0.07%

Figure 3.2. Household vehicle ownership evolution between 1994 and 2011, Puebla

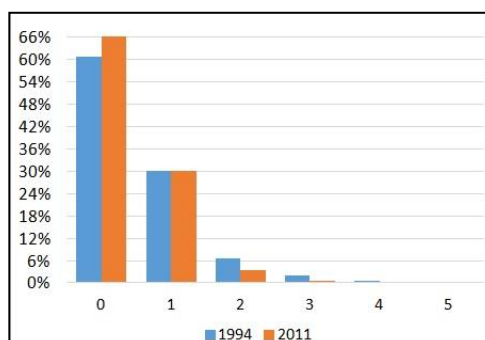


Table 3.3. Household vehicle ownership evolution between 1987, 1998 and 2006, Lille

Vehicles in the HH	1987		1998		2006		Evolution 1987-1998	Evolution 1998-2006	Evolution 1987-2006	Year Evolution
	Frequency	Percent	Frequency	Percent	Frequency	Percent	RPCh of Frequency			
0	111304	29.8%	103576	24.2%	93685	20.5%	-6.9%	-9.5%	-15.8%	-0.8%
1	188826	50.5%	200304	46.8%	204736	44.8%	+6.1%	+2.2%	+8.4%	+0.4%
2	65483	17.5%	106144	24.8%	137100	30.0%	+62.1%	+29.2%	+109.4%	+5.8%
3	7200	1.9%	14552	3.4%	17366	3.8%	+102.1%	+19.3%	+141.2%	+7.4%
4 or more	885	0.2%	3424	0.8%	4113	0.9%	+286.9%	+20.1%	+364.7%	+19.2%
Total	373697	100%	428000	100%	457000	100%	+14.5%	+6.8%	+22.3%	+1.2%

Figure 3.3. Household vehicle ownership evolution between 1987, 1998, 2006 Lille

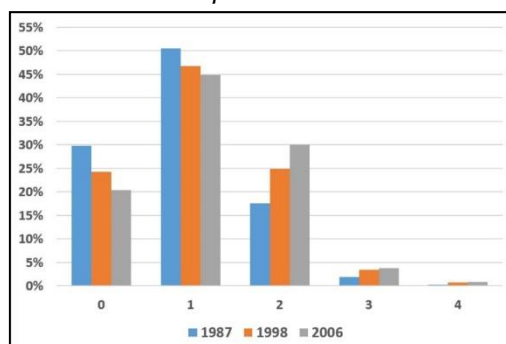
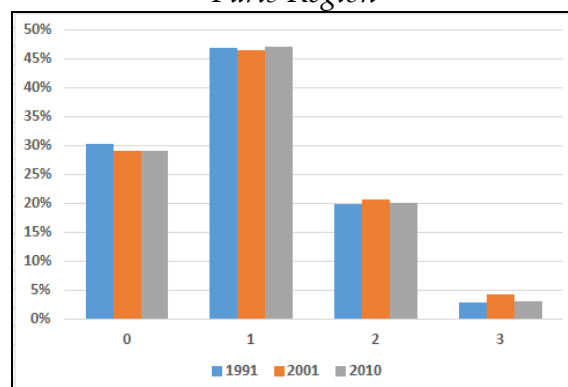


Table 3.4. Household vehicle ownership evolution between 1991, 2001 and *2010 Paris Region

Vehicles in the HH	1991		2001		2010*		Evolution 1991-2001	Evolution 2001-2010	Evolution 1991-2010	Year Evolution
	Frequency	Percent	Frequency	Percent	Frequency	Percent	RPCh of Frequency			
0	1288906	30.4%	1343340	29.1%	1421000	29.0%	+4.2%	+5.8%	+10.2%	+1.0%
1	1991017	46.9%	2140060	46.4%	2303000	47.0%	+7.5%	+7.6%	+15.7%	+1.6%
2	845374	19.9%	954567	20.7%	980000	20.0%	+12.9%	+2.7%	+15.9%	+1.6%
3 or more	118769	2.8%	174327	3.8%	147000	3.0%	+46.8%	-15.7%	+23.8%	+2.4%
Total	4244066	100%	4612294	100%	4900000	100%	+8.7%	+6.2%	+15.5%	+1.5%

*Source: [104]

Figure 3.4. Household vehicle ownership evolution between 1991, 2001 and *2010, Paris Region



*Source: [104]

In all case studies the share of vehicle ownership by zone of residence have similar patterns for center and outer suburbs (Figures 3.5 to 3.8). In fact, the share of total motorized private vehicles of households located in the center tends to decrease. This shift is greater in Mexican cities (from 19% to 16% in Juarez, and from 45% to 30% in Puebla), while in France the decrease is less pronounced going from 13% to 11% in both cities. The share of vehicle ownership in the outer suburbs increased in all case studies. It is more pronounced in Juarez (18% to 30%), then the city of Puebla going from 19% to 26%. The increase is smaller in French cities. This share has been gradually increasing in Lille (42% in 1987, 45% in 1998 and 47% in 2006) and lastly the Paris Region which went from 51% in 1991 to 54% in 2010. Furthermore, the share of total vehicles in the inner suburbs had different evolutions. The distribution of vehicles in the inner suburbs has stabilized in Lille (45%, 43% and 43% in 1987, 1998 and 2006 respectively). Juarez and Paris experiment decreases of the proportion of vehicles in the inner suburbs, going from 63% to 55% in Juarez and from 36% to 34% in Paris. Finally, the share of vehicle ownership in households located in Puebla's inner suburbs increased from 36% to 43%. As expected, private vehicle use seems to be correlated to vehicle ownership. In fact the shares of total number of trips and travelled kilometers evolved similarly as those from vehicle ownership at household by zone of residence. Shares of number of trips and travelled kilometers in Private Vehicle adapt following the trend towards the decrease of vehicle household ownership in the city center and its increase in outer suburbs, shifting with similar magnitudes than those from vehicle ownership in all case studies (Figures 3.5 to 3.8). Statistical significance of vehicle ownership and urban form classification as explanatory variables for Private Driver, Public Transport and "All modes" trips and kilometers will be described in section 3.2.

Figure 3.5. Evolution of vehicle ownership in the household, number of trips and travelled kilometers by mode and zone of residence, 1996 and 2006, Juarez

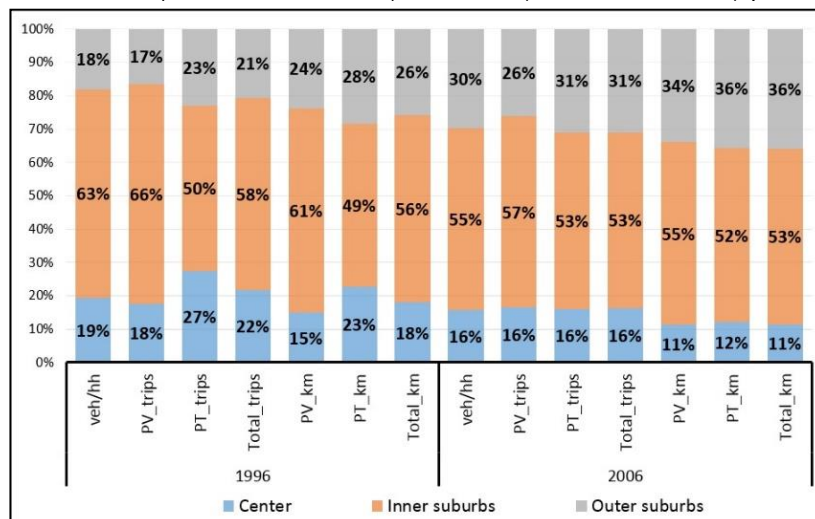


Figure 3.6. Evolution of vehicle ownership in the household, number of trips and travelled kilometers by mode and zone of residence, 1994 and 2011, Puebla

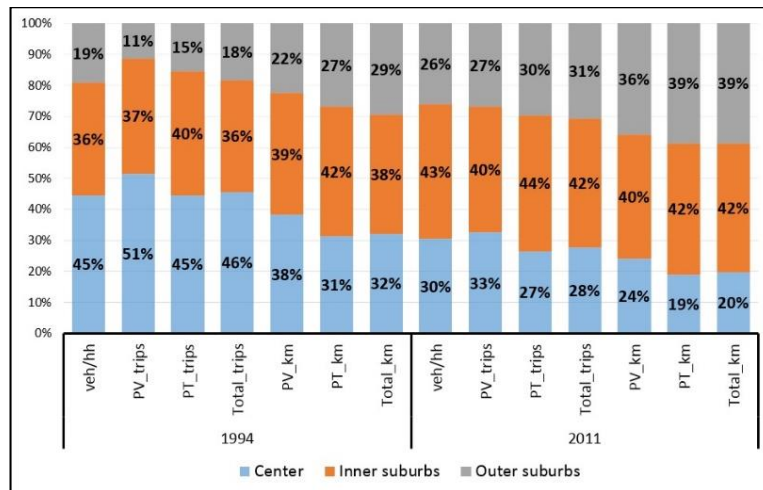


Figure 3.7. Evolution of vehicle ownership in the household, number of trips and travelled kilometers by mode and zone of residence, 1987, 1998 and 2006, Lille

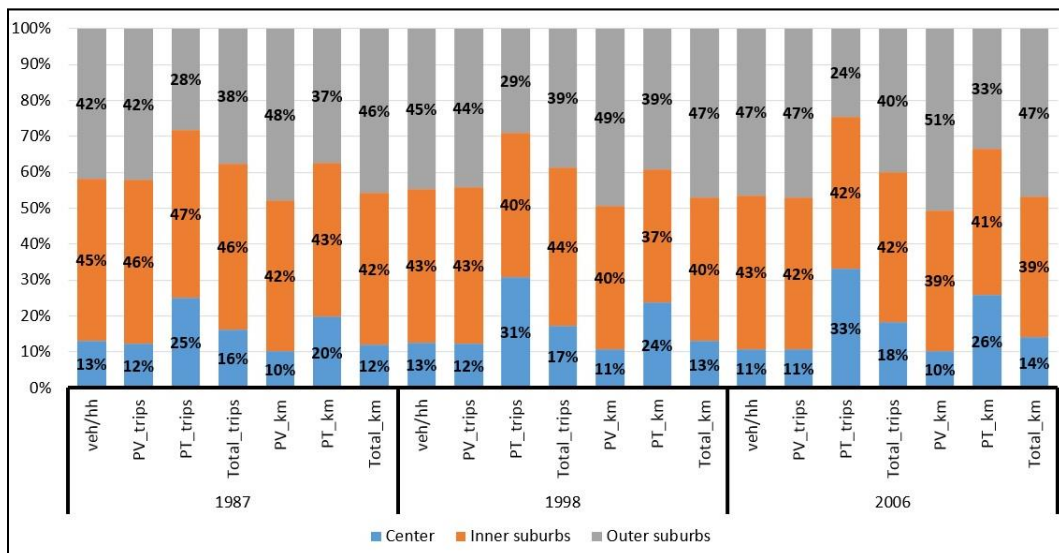
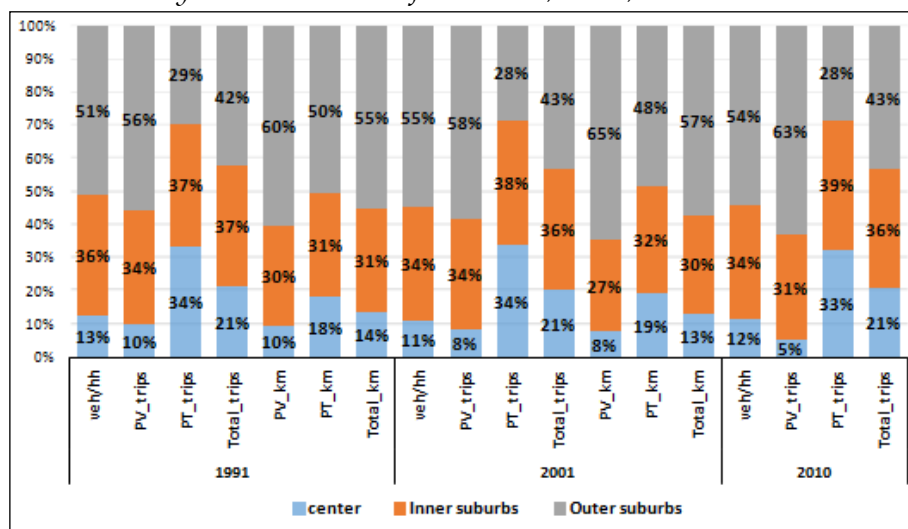


Figure 3.8. Evolution of vehicle ownership in the household, number of trips and travelled kilometers by mode and zone of residence, 1991, 2001 and *2010 Paris



*Source: [104]

The distribution of number of households, population, trips and travel distance by zone of residence are shown from Table 3.5 to Table 3.8.

Table 3.5. Evolution of number of households, population, trips and travel distance by zone of residence, 1996 and 2006, Juarez

	1996		2006		Period Evolution	Year Evolution
zone of residence	Inhabitants	Percent	Inhabitants	Percent	RPCh* of Frequency	RPCh* of Frequency
Center	215411	22.3%	162438	16.8%	-24.6%	-2.5%
Inner suburbs	543143	56.2%	503042	52.0%	-7.4%	-0.7%
Outer suburbs	207693	21.5%	301960	31.0%	+45.4%	+4.5%
All	966247	100%	967440	100%	+0.1%	+0.01%
zone of residence	Households	Percent	Households	Percent	RPCh* of Frequency	RPCh* of Frequency
Center	65602	23.8%	48305	18.0%	-26.4%	-2.6%
Inner suburbs	152014	55.0%	134354	50.3%	-11.6%	-1.2%
Outer suburbs	58573	21.2%	84702	31.7%	+44.6%	+4.5%
All	276189	100%	267361	100%	-3.2%	-0.3%
zone of residence	Inhab/hh		Inhab/hh		RPCh* of Average	RPCh* of Average
Center	3.3	-	3.4	-	+2.4%	+0.2%
Inner suburbs	3.6	-	3.7	-	+4.8%	+0.5%
Outer suburbs	3.5	-	3.6	-	+0.5%	+0.05%
All	3.5	-	3.6	-	+3.4%	+0.3%
zone of residence	Trips	Percent	Trips	Percent	RPCh* of Frequency	RPCh* of Frequency
Center	415385	21.6%	317687	16.2%	-23.5%	-2.4%
Inner suburbs	1105236	57.6%	1033270	52.8%	-6.5%	-0.7%
Outer suburbs	398916	20.8%	604819	30.9%	+51.6%	+5.2%
All	1919537	100%	1955776	100%	+1.9%	+0.2%
zone of residence	Trips/per		Trips/pers		RPCh* of Average	RPCh* of Frequency
Center	1.9	-	2	-	+1.6%	+0.2%
Inner suburbs	2	-	2.1	-	+1.0%	+0.1%
Outer suburbs	1.9	-	2	-	+4.2%	+0.4%
All	1.99	-	2.02	-	+1.8%	+0.2%
zone of residence	Kilometers	Percent	Kilometers	Percent	RPCh* of Frequency	RPCh* of Frequency
Center	1637124	18.0%	1153310	11.4%	-29.6%	-3.0%
Inner suburbs	5105544	56.0%	5332245	52.6%	+4.4%	+0.4%
Outer suburbs	2367700	26.0%	3653716	36.0%	+54.3%	+5.4%
All	9110368	100%	10139271	100%	+11.3%	+1.1%
zone of residence	Km/per		Km/per		RPCh* of Average	RPCh* of Average
Center	7.6	-	7.1	-	-7.0%	-0.7%
Inner suburbs	9.4	-	10.6	-	+12.5%	+1.3%
Outer suburbs	11.4	-	12.1	-	+5.8%	+0.6%
All	9.4	-	10.5	-	+11.2%	+1.1%

*Relative Percentage Change (RPCh)

In Juarez, is in the inner suburbs where about half of the population and households are located in both years. On the one hand, the location of population and households tend to decrease in the city-center as well as in the inner suburbs. On the other hand, the outer suburbs experience important increases of both, population and number of households. Juarez had a slight increase of total trips taking into

account all modes of transportation including walking, going from 1.92 to 1.96 million trips. The increase was more pronounced for travel distance between each survey with a relative percentage change of +11.3%. Translating this evolution into per capita indicators, and regardless the zone of residence, we can observe that the inhabitants of the city of Juarez make almost the same number of total trips per person in 2006 (2.02 trip/person) in relation to 1996 (1.99 trip/person). The total distance travelled is higher in 2006 with a relative percentage change of +11.2% compared to base year 1996. Meaning that people generated almost the same number of trips in both years but travelled longer distances in the recent survey. The farther to the city-center the person lives, the higher the travelled kilometers per capita.

Table 3.6. Evolution of number of households, population, trips and travel distance by zone of residence, 1994 and 2011, Puebla

	1994		2011		Period Evolution	Year Evolution
zone of residence	Inhabitants	Percent	Inhabitants	Percent	RPCh* of Frequency	RPCh* of Frequency
Center	498675	42.4%	459976	26.5%	-7.8%	-1.1%
Inner suburbs	419738	35.7%	731835	42.1%	+74.4%	+10.6%
Outer suburbs	257074	21.9%	546763	31.5%	+112.7%	+16.1%
All	1175487	100%	1738574	100%	+47.9%	+6.8%
zone of residence	Households	Percent	Households	Percent	RPCh* of Frequency	RPCh* of Frequency
Center	126680	44.9%	115549	27.2%	-8.8%	-1.3%
Inner suburbs	99258	35.2%	177049	41.7%	+78.4%	+11.2%
Outer suburbs	56384	20.0%	131609	31.0%	+133.4%	+19.1%
All	282322	100%	424207	100%	+50.3%	+7.2%
zone of residence	Inhab/hh		Inhab/hh		RPCh* of Average	RPCh* of Average
Center	3.9	-	4	-	+1.1%	+0.16%
Inner suburbs	4.2	-	4.1	-	-2.3%	-0.3%
Outer suburbs	4.6	-	4.2	-	-8.9%	-1.3%
All	4.2	-	4.1	-	-1.6%	-0.2%
zone of residence	Trips	Percent	Trips	Percent	RPCh* of Frequency	RPCh* of Frequency
Center	947483	45.4%	827957	27.6%	-12.6%	-1.8%
Inner suburbs	755528	36.2%	1244120	41.4%	+64.7	+9.2%
Outer suburbs	385611	18.5%	929497	31.0%	+141.0%	+20.4%
All	2088622	100%	3001574	100%	+43.7%	+6.2%
zone of residence	Trips/per		Trips/pers		RPCh* of Average	RPCh* of Average
Center	1.9	-	1.8	-	-6.4%	-0.9%
Inner suburbs	1.8	-	1.7	-	-5.1%	-0.7%
Outer suburbs	1.5	-	1.7	-	+13.8%	+2.0%
All	1.8	-	1.7	-	-2.8%	-0.4%
zone of residence	Kilometers	Percent	Kilometers	Percent	RPCh* of Frequency	RPCh* of Frequency
Center	2493375	32.1%	2345878	19.7%	-5.9%	-0.8%
Inner suburbs	2980140	38.4%	4976478	41.8%	+67.0%	+9.6%
Outer suburbs	2287959	29.5%	4592809	38.5%	+100.7	+14.4%
All	7761474	100%	11915165	100%	+53.5%	+7.6%
zone of residence	Km/per		Km/per		RPCh* of Average	RPCh* of Average
Center	5	-	5.1	-	+2.6%	+0.4%
Inner suburbs	7.1	-	6.8	-	-4.5%	-0.6%
Outer suburbs	8.9	-	8.4	-	-5.6%	-0.8%
All	6.6	-	6.9	-	+3.8%	+0.5%

*Relative Percentage Change (RPCh)

The trend of human settlements and transport behavior by urban form characteristics in Puebla (Table 3.6), shows that the settlement of inhabitants and households in the city-center has lost also preference over time. Opposed to Juarez, the inner suburbs experience growth in terms of population and households, with relative percentage changes of +74.4% and +78.4% respectively. Similar to Juarez, the most recent survey from Puebla shows that the outer suburbs had the highest positive relative percentage changes of frequency. Household size, or the number of people living in the same household, decreased for outer suburbs and inner suburbs. Despite the important increases of people and homes in the outer suburbs, is in the inner suburbs where most people live in the city of Puebla in 2011 with about 42%. Similar trends are observed for number of trips and kilometers travelled. In other words, even if the positive evolution of trips and kilometers is higher for the inhabitants of outer suburbs, the inhabitants of inner suburbs make the majority of trips and kilometers in both years. The global increase in number of trips (+43.7%) in the city of Puebla seems to be linked mostly to the strong increase of its population in the period from 1994 to 2011 (+47.9%). Indeed, the average number of daily trips per capita seems to have stabilized. With respect to the distance there was, according to surveys, an increase in the total travel distance in the city of +53.5% and an increase of +3.9% of the average per capita travel distance.

Considering the principle of constant area for the analysis, the population in Lille increased by 8.4% between 1987 and 1998, while it remained stable from 1998 to 2006, like in Juarez with +0.1%, taking into account the sum of population living in the center, inner and outer suburbs (Table 3.7). In Lille, this slight population growth was distributed slightly towards the city-center, reversing the decentralization effect. Unlike French case studies, in Juarez and Puebla there was an expansion effect in the suburbs and a contraction effect in the city-center (decentralization effect). In Lille, the rising trend of total and per capita trips observed in the 1987-1998 period was reversed according to the latest 2006 survey. This change of trend was also observed for travel distance but with less impact, stabilizing total and per capita kilometers travelled at the level reached in 1998.

Like for both Mexican case studies, the increase of population and households in the Paris Region is greater in the outer suburbs compared to the center, +13.8% vs +5.1% for population (1991 to 2010) and +14.2% vs +6.4% for the number of households (1991 to 2001). The majority of trips and kilometers are made by the inhabitants of the outer suburbs. The share is about 42% and for total trips and even more pronounced

for travelled kilometers (56%) in all years. Per capita evolutions are modest compared to other case studies. For instance, there are no noticeable changes in per capita trips and travelled kilometers in the inner suburbs. Global per capita trips and kilometers evolutions are +0.6% and +0.4% respectively (Table 3.8).

Table 3.7. Evolution of number of households, population, trips and travel distance by zone of residence, 1987, 1998 and 2006, Lille

	1987		1998		2006		Evolution 1987-1998	Evolution 1998-2006	Year Evolution
zone of residence	Inhabitants	%	Inhabitants	%	Inhabitants	%	RPCh* of Frequency		
Center	153292	16.5%	172827	17.1%	175543	17.4%	12.7%	1.6%	0.8%
inner suburbs	422796	45.4%	441295	44.7%	441466	44.7%	4.4%	0.0%	0.2%
outer suburbs	355027	38.1%	394784	39.1%	392619	39.9%	11.2%	-0.5%	0.6%
Total	931116	100%	1008906	100%	1009628	100%	8.4%	0.1%	0.4%
zone of residence	Households	%	Households	%	Households	%	RPCh* of Frequency		
Center	72560	19.4%	87312	20.4%	89115	19.5%	20.3%	2.1%	1.2%
inner suburbs	170495	46.6%	183612	42.9%	196510	43.0%	7.7%	7.0%	0.8%
outer suburbs	130642	35.0%	157076	36.7%	171375	37.5%	20.2%	9.1%	1.6%
Total	373697	100%	428000	100%	457000	100%	14.5%	6.8%	1.2%
zone of residence	Inhab/hh		Inhab/hh		Inhab/hh		RPCh* of Average		
Center	2.1		2.0		2.0		-5.7%	-0.5%	-0.3%
inner suburbs	2.5		2.4		2.2		-3.9%	-6.5%	-0.5%
outer suburbs	2.7		2.5		2.3		-6.9%	-8.8%	-0.8%
Total	2.5		2.4		2.2		-5.7%	-6.3%	-0.6%
zone of residence	Trips	%	Trips	%	Trips	%	RPCh* of Frequency		
Center	549170	16.3%	715294	17.3%	711445	18.3%	30.2%	-0.5%	1.6%
inner suburbs	1558244	46.2%	1814052	44.9%	1620009	42.7%	16.4%	-10.7%	0.2%
outer suburbs	1267402	38.6%	1600205	39.8%	1555641	40.0%	26.3%	-2.8%	1.2%
Total	3374816	100%	4129550	100%	3887095	100%	22.4%	-5.9%	0.8%
zone of residence	Trips/ per		Trips/ per		Trips/ per		RPCh* of Average		
Center	3.6		4.1		4.1		15.5%	-2.1%	0.7%
inner suburbs	3.7		4.1		3.7		11.5%	-10.7%	0%
outer suburbs	3.6		4.1		4.0		13.5%	-2.2%	0.6%
Total	3.6		4.1		3.9		12.9%	-5.9%	0.3%
zone of residence	Kilometers	%	Kilometers	Percent	Kilometers	%	RPCh* of Frequency		
Center	1023353	12.0%	1449290	13.0%	1564388	14.1%	41.6%	7.9%	2.8%
inner suburbs	3577478	42.1%	4452349	40.9%	4367750	39.2%	24.5%	-1.9%	1.2%
outer suburbs	3893952	46.8%	5260916	47.1%	5201456	47.7%	35.1%	-1.1%	1.8%
Total	8494784	100%	11162556	100%	11133594	100%	31.4%	-0.3%	1.6%
zone of residence	km/per		km/per		km/per		RPCh* of Average		
Center	6.7		8.4		8.9		25.6%	6.3%	1.8%
inner suburbs	8.5		10.1		9.9		19.2%	-1.9%	0.9%
outer suburbs	11.0		13.3		13.2		21.5%	-0.6%	1.1%
Total	9.1		11.1		11.0		21.3%	-0.3%	1.1%

*Relative Percentage Change (RPCh)

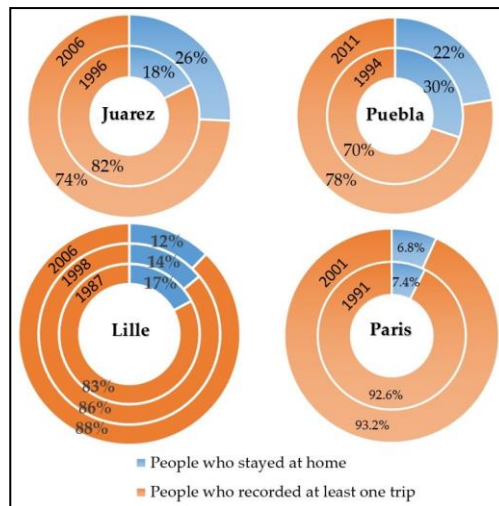
Table 3.8. Evolution of number of households, population, trips and travel distance by zone of residence, 1991 and 2001, Paris Region

	1991		2001		2010 [†]		1991-2001 Evolution	2001-2010 Evolution	Year Evolution
zone of residence	Inhabitants	Percent	Inhabitants	Percent	Inhabitants	Percent	RPCh* of Frequency		
Center	1925712	20.3%	1970572	20.6%	2024000	19.3%	+2.3%	+2.7%	+0.3%
Inner suburbs	3575813	38.6%	3690653	37.7%	3894000	37.2%	+3.2%	+5.5%	+0.5%
Outer suburbs	4003776	42.1%	4388176	44.7%	4556000	43.5%	+9.6%	+3.8%	+0.7%
All	9505302	100%	10049401	100%	10474000	100%	+5.7%	+4.2%	+0.5%
zone of residence	Households	Percent	Households	Percent			RPCh* of Frequency		
Center	1073623	25.3%	1142698	25.8%			+6.4%		+0.6%
Inner suburbs	1587615	37.4%	1662653	36.0%			+4.7%		+0.5%
Outer suburbs	1582829	37.3%	1807002	39.2%			+14.2%		+1.4%
All	4244066	100%	4612353	100%			+8.7%		+0.9%
zone of residence	Inhab/hh		Inhab/hh				RPCh* of Average		
Center	1.8		1.7				-3.9%		-0.4%
Inner suburbs	2.3		2.2				-1.4%		-0.1%
Outer suburbs	2.5		2.4				-4.0%		-0.4%
All	2.2		2.2				-2.7%		-0.3%
zone of residence	Trips	Percent	Trips	Percent	Trips	Percent	RPCh* of Frequency		
Center	6986555	21.3%	7053172	21.5%	8420000	20.7%	+1%	+19.4%	+1.1%
Inner suburbs	12017780	37.6%	12516277	36.4%	14610000	35.9%	+4.1%	+16.7%	+1.1%
Outer suburbs	13873030	42.2%	14819202	43.1%	17650000	43.4%	+6.8%	+19.1%	+1.4%
All	32877366	100%	34388651	100%	40680000	100%	+4.6%	+18.3%	+1.2%
zone of residence	Trips/per		Trips/per		Trips/per		RPCh* of Average		
Center	3.6		3.6		4.2		-1.3%	+15.6%	+0.8%
Inner suburbs	3.4		3.4		3.8		+0.9%	+10.4%	+0.5%
Outer suburbs	3.5		3.4		3.9		-2.5%	+13.9%	+0.6%
All	3.5		3.4		3.9		-1.1%	+14.2%	+0.6%
zone of residence	kilometers	Percent	kilometers	Percent	kilometers	Percent	RPCh* of Frequency		
Center	21079734	14.8%	21859863	13.2%	23576000	13.1%	+3.7%	+7.9%	+0.6%
Inner suburbs	47761631	31.2%	49318114	30.7%	52596000	29.2%	+3.3%	+6.6%	+0.5%
Outer suburbs	84221771	55.0%	94604846	57.1%	104135000	57.8%	+12.3%	+10.1%	+1.2%
All	153063135	100%	165782823	100%	180307000	100%	+8.3%	+8.8%	+0.9%
zone of residence	km/per		km/per		km/per		RPCh* of Average		
Center	10.9		11.1		11.6		+1.3%	+4.9%	+0.4%
Inner suburbs	13.4		13.4		13.5		+0%	+0.8%	+0.0%
Outer suburbs	21.0		21.6		22.9		+2.5%	+5.8%	+0.5%
All	16.1		16.5		17.2		+2.4%	+4.3%	+0.4%

†Source: [104] *Relative Percentage Change (RPCh)

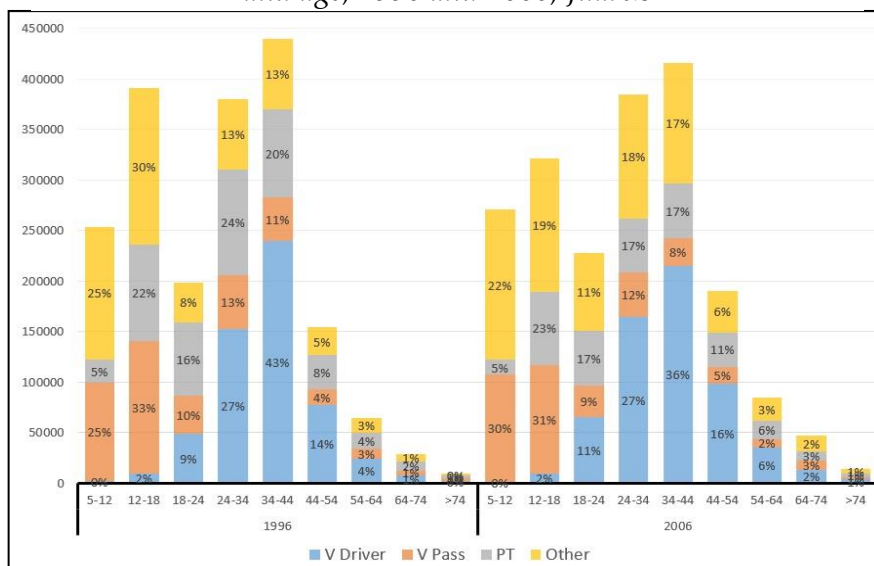
An interesting evolution was observed in Juarez in terms of people who stayed at home versus people who made at least one trip the day before the travel survey (Figure 3.9). In fact, in 2006 more people stayed at home on a regular weekday (26% vs 18%) meaning that in 2006 fewer people travel but those who did made more trips and travelled longer distances compared to people who also made at least one trip in 1996. Contrary to Juarez, the cities of Puebla, Lille and the Paris Region had increasingly more people with at least one trip in the most recent survey. Section 3.2 show changes of explanatory variables of travel inactivity observed between surveys.

Figure 3.9. People making no trips vs at least 1 trip, Juarez, Puebla, Lille and Paris



Travel behavior by age (Figures 3.10 to 3.13) shows noticeable changes from one survey to another. In general and in all case studies, the share of number of trips increase slightly but in a homogeneous way in all transportation categories for people aged 44 and older (Vehicle Driver, Vehicle Passenger, Public Transport and Other modes). Hence, it is important to take into account travel behavior shifts between age-cohorts for developing long-term travel demand projections. In Juarez, in 1996 “Private Vehicle Driver” mode had a peak at 34-44 years old (43% of total trips as a vehicle driver), while in 2006 the peak coincides with the same age category as in 1996 but is less pronounced (only 36%); and other age categories made more trips in 2006 as a driver except the age bracket of 24-34 years old which remained with the same share of private vehicle driver trips (27% in both years). People from 24 to 44 years old use less public transport in 2006 compared to 1996.

Figure 3.10. Evolution of number of trips by transport mode and age, 1996 and 2006, Juarez



*V Driver: Private Vehicle Driver, V Pass: Private Vehicle Passenger, PT: Public Transport, Other: Bicycle, walking, etc.

Puebla's surveys show peaks of "All modes" travel trips at the age bracket from 24 to 34 years old, then followed by those from 18-24 years old in 1994 and by 34-44 in 2011 (Figure 3.11). The peak of Vehicle Driver mode is also the same in both years but less pronounced in 2011 with 34% of the total in 1994 and down to 29% in 2011. The share is divided by two for the individuals aged 18-24 (from 12% to 6%), while all categories from 44 years and older increase their shares of Vehicle Driver mode (18% to 24% for 44-54 years old, from 8% to 12% for 54-64 years old, from 3% to 5% for 64-74 years old, and from 0% to 1% for those 74 and older).

Figure 3.11. Evolution of number of trips by transport mode and age, 1994 and 2011, Puebla

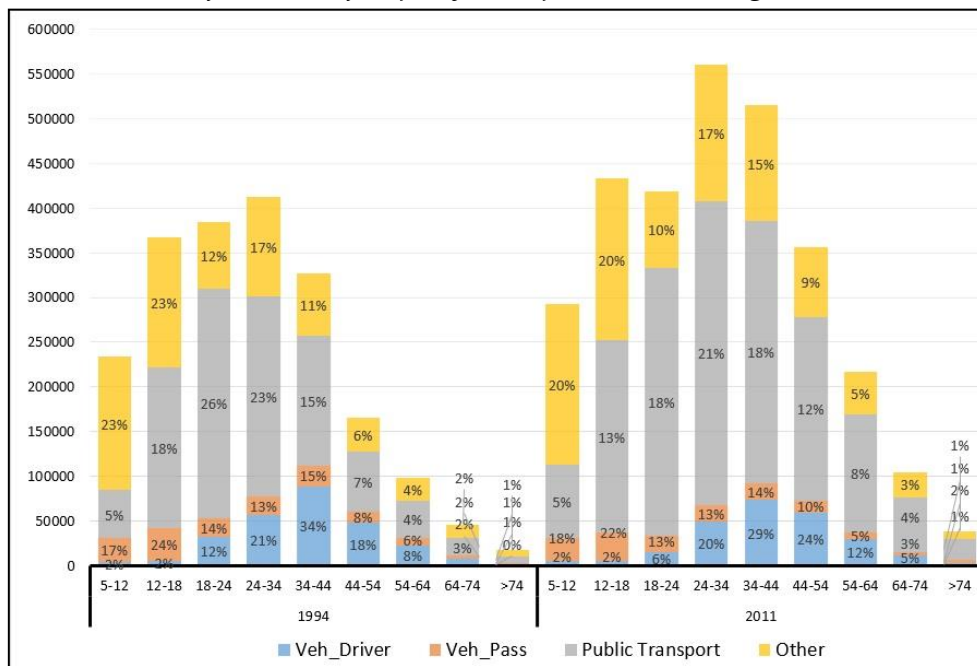
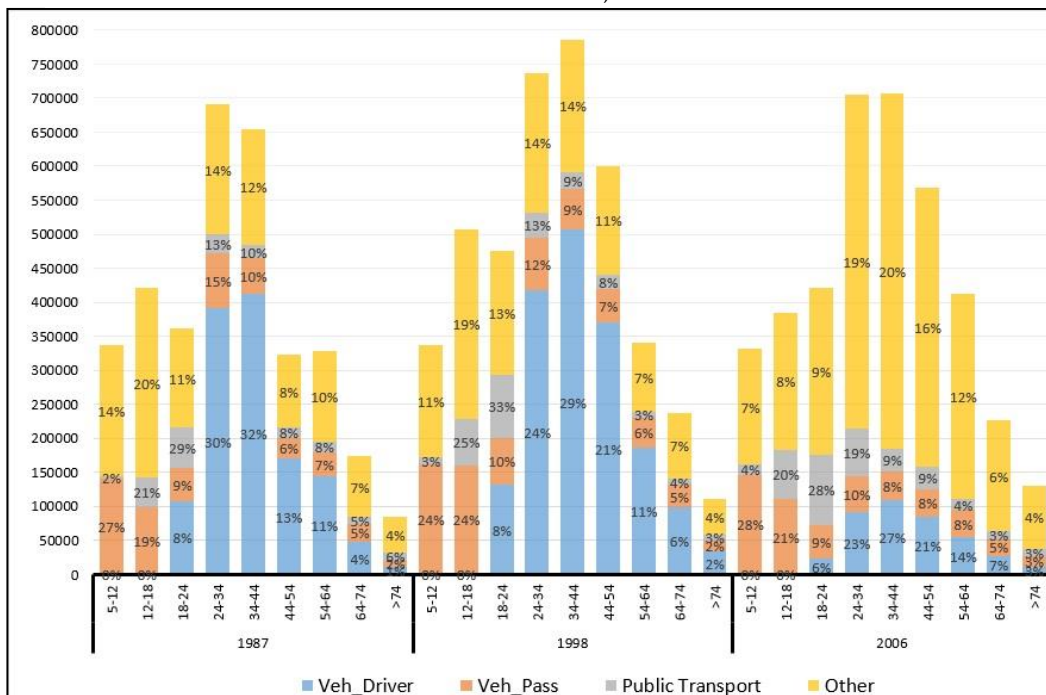


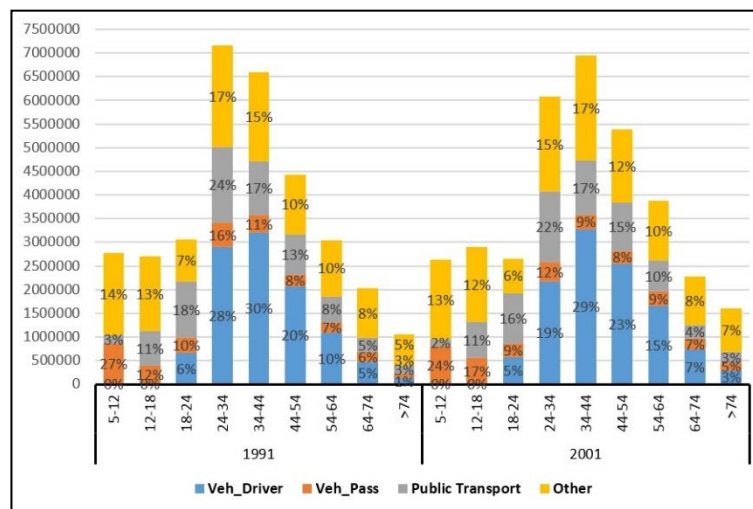
Figure 3.12. Evolution of number of trips by transport mode and age, 1987, 1998 and 2006, Lille



The shares of Private Vehicle Driver and Private Vehicle Passenger change similarly in Lille like in the previous cities. The peaks of Vehicle Driver in 1987, 1998 and 2006 are around 34-44 years old, but less pronounced with time, as well as the age bracket of 24-34 years old which had a decline from 30% in 1987 to 23% in 2006 of total Private Vehicle Driver trips. Another important shift was the age bracket of individuals of 44 to 54 years old, which were responsible of 13% of total Vehicle Driver trips in 1987 and up to 21% in 2006.

The peaks for Vehicle Driver in the Paris Region were around the age bracket of 34-44 years old. Similar to Lille, the age bracket of 24-34 years old had a decline from 28% in 1991 to 19% in 2001 for total Private Vehicle Driver trips. The age bracket of individuals from 44 to 54 years old was responsible of 20% of total Vehicle Driver trips in 1991 and 23% in 2001. Older individuals also had important increases. Individuals from 54 to 64 went from 10% Vehicle Driver and 7% Vehicle Passenger trips in 1991 to 15% and 9% respectively.

Figure 3.13. Evolution of number of trips by transport mode and age, 1991 and 2001, Paris Region



Trip generation by gender (Figure 3.14) show that “All modes” trips are almost equally distributed between men and women. In Juarez, males made 46.7% of “All modes” trips in 1996 and 49.5% in 2006. Puebla, Lille and the Paris Region had slight increases in the share of trips travelled by women. Increases went from 49.7% to 53.4% in Puebla, 50.5% to 53.7% in Lille (from 1987 to 2006) and from 51.6% to 52.3% in the Paris Region.

Figure 3.15 show that in all case studies and years, males traveled more trips in Private Vehicle as a Driver. However there is a convergent evolution of activity between men and women. In other words, women are gradually being responsible of more Vehicle Driver trips.

Figure 3.14. Evolution of total trips by gender, Juarez, Puebla, Lille, Paris

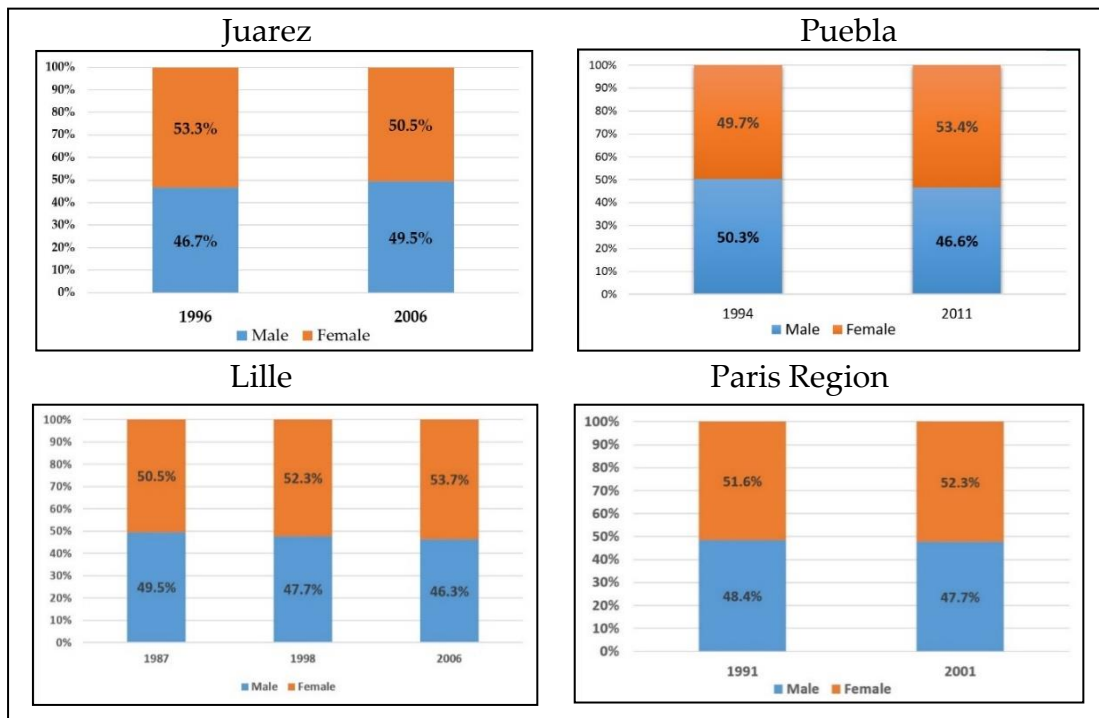
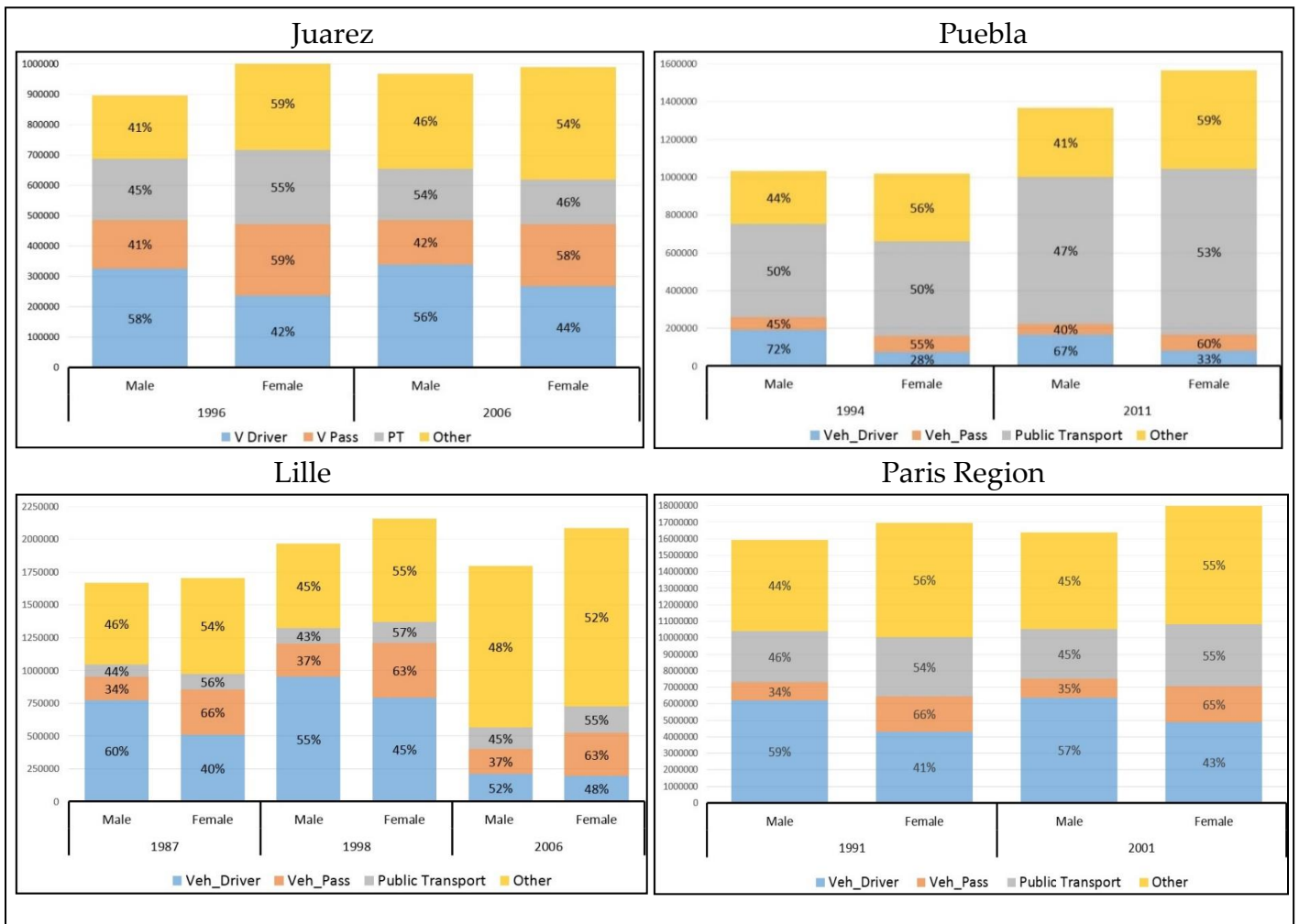
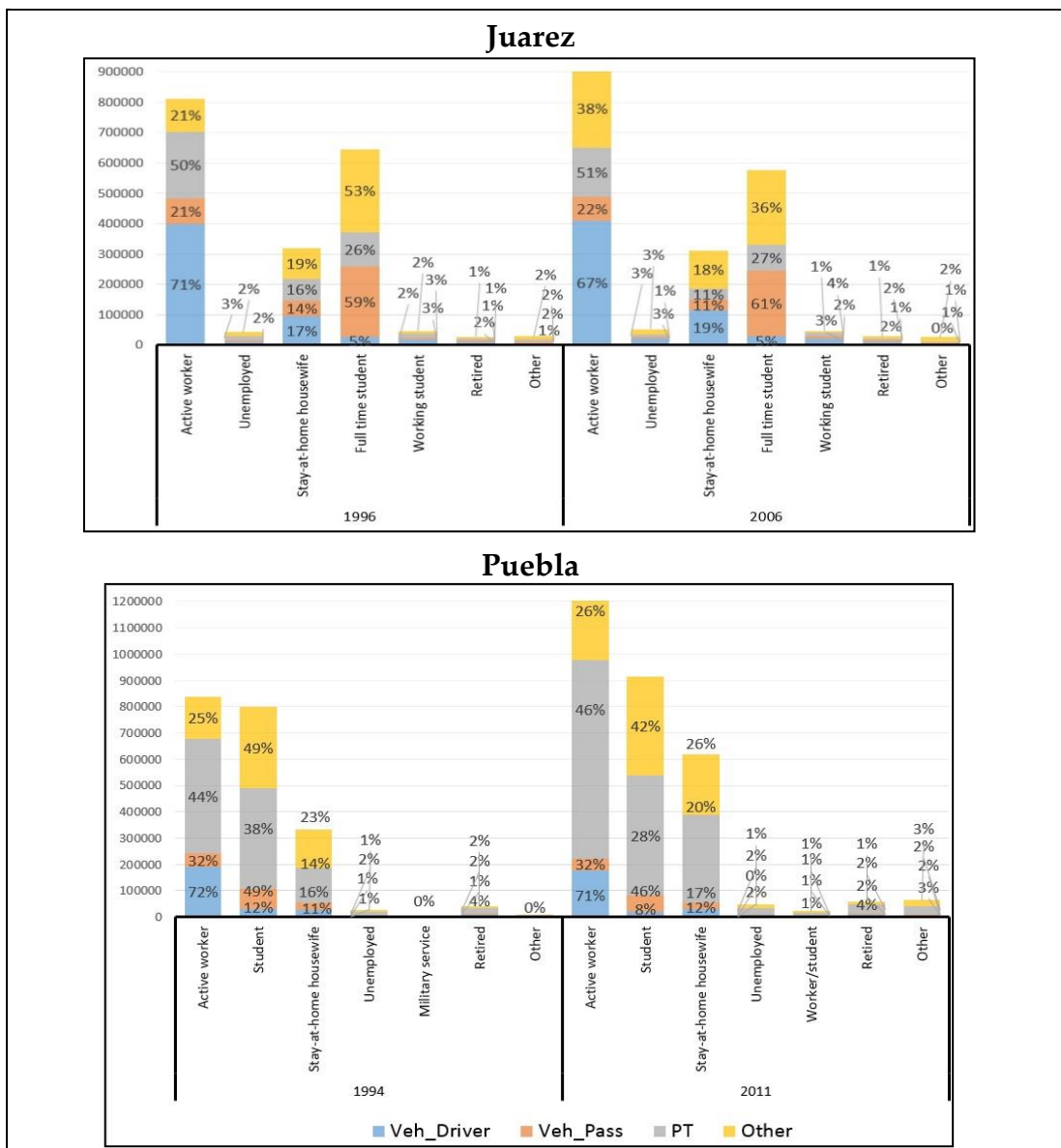


Figure 3.15. Evolution of number of trips by mode and gender



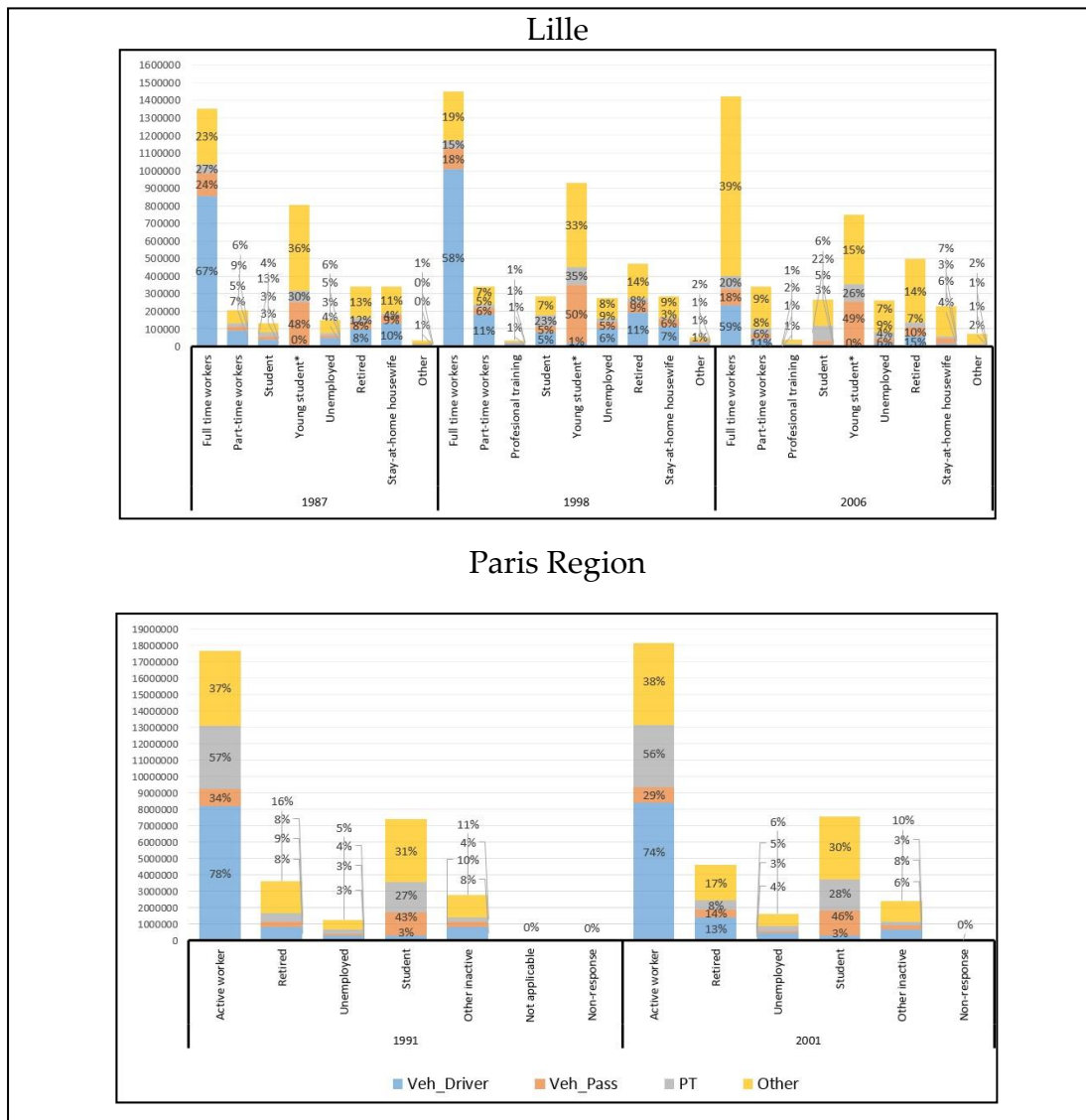
The shares of driver women in Juarez went from 42% to 44%, in Puebla the shares increased from 28% to 33%, from 40% to 48% in Lille and lastly from 41% to 43% in the Paris Region. In addition, the shares of Vehicle Passenger trips are higher for females in all cities and have stabilized with 58% in Juarez, 60% in Puebla, 63% in Lille and 65% in the Paris Region. Shares of Public Transport trips by gender differ between the studied cities. In Juarez females accounted for 55% in 1996 and 46% in 2006. Women in Puebla accounted for 50% in 1994 and 53% in 2011. The distribution by gender has stabilized in the French cities, where women accounted for approximately 55% of the total Public Transport trips in both Lille and Paris Region. It is important to recall that section 3.2 will describe the statistical significance of age, gender as well as the following socioeconomic and geographic variables as explanatory variables for travel activity by mode.

Figure 3.16. Evolution of number of trips by mode and activity, Juarez and Puebla



The pattern of number of trips disaggregated by mode and principal activity of surveyed individuals had slight changes from one year to another (Figures 3.16 and 3.17). In all case studies the two activity groups that reported more trips were, in order of importance, active worker and full time student, then stay-at-home housewife in Mexican surveys and retired individuals in the French side. Indeed, retired individuals in French cities reported significant travel activity compared to Mexican cities which had very little travel activity also from unemployed and other categories. Retired individuals increase their share of Vehicle Driver modes from 8% to 15% in Lille and from 8% to 13% in the Paris Region. In Juarez, active worker changed from being responsible of 71% of Private Vehicle trips in 1996 to 67% in 2006.

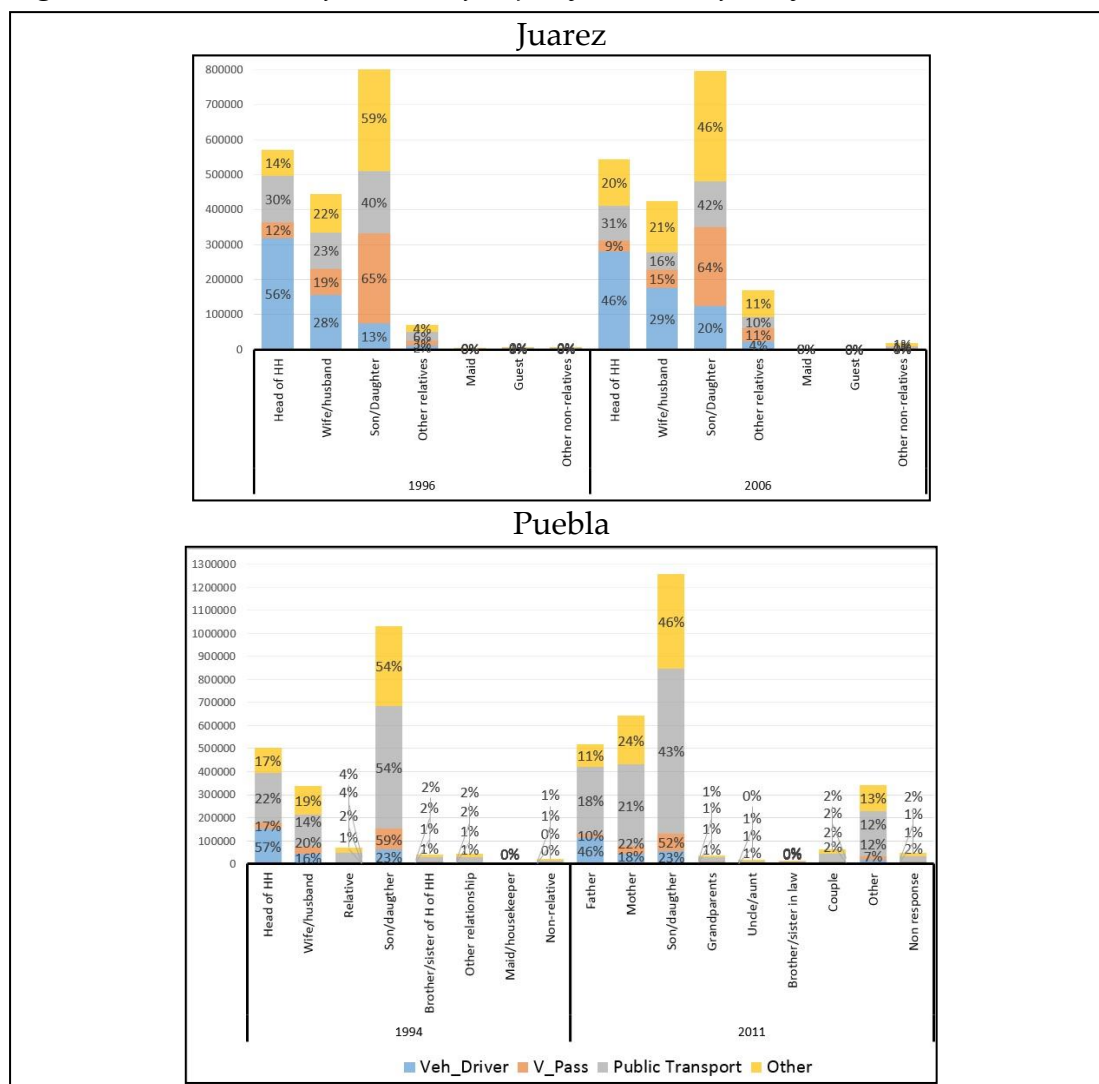
Figure 3.17. Evolution of number of trips by mode and activity, Lille and the Paris Region



Vehicle Car Passenger and Public Transport remain stable for the same category and lastly “other modes” shifted from 21% of total other modes trips in 1996 to 38% in 2006. Stay-at-home housewife gained two points in Vehicle Driver mode (from 17% to 19%) while using less Private Vehicles as a Passenger (from 14% to 11%) and Public Transport (16% to 11%). In Puebla, there were no relevant changes between 1994 and 2011. Active workers generated more trips in both years, and accounted for the majority of Vehicle Driver trips (72% in 1994 and 71% in 2011), and most of Public Transport trips as well (44% and 46%). Students accounted for the majority of Vehicle Passenger and other modes trips in both years.

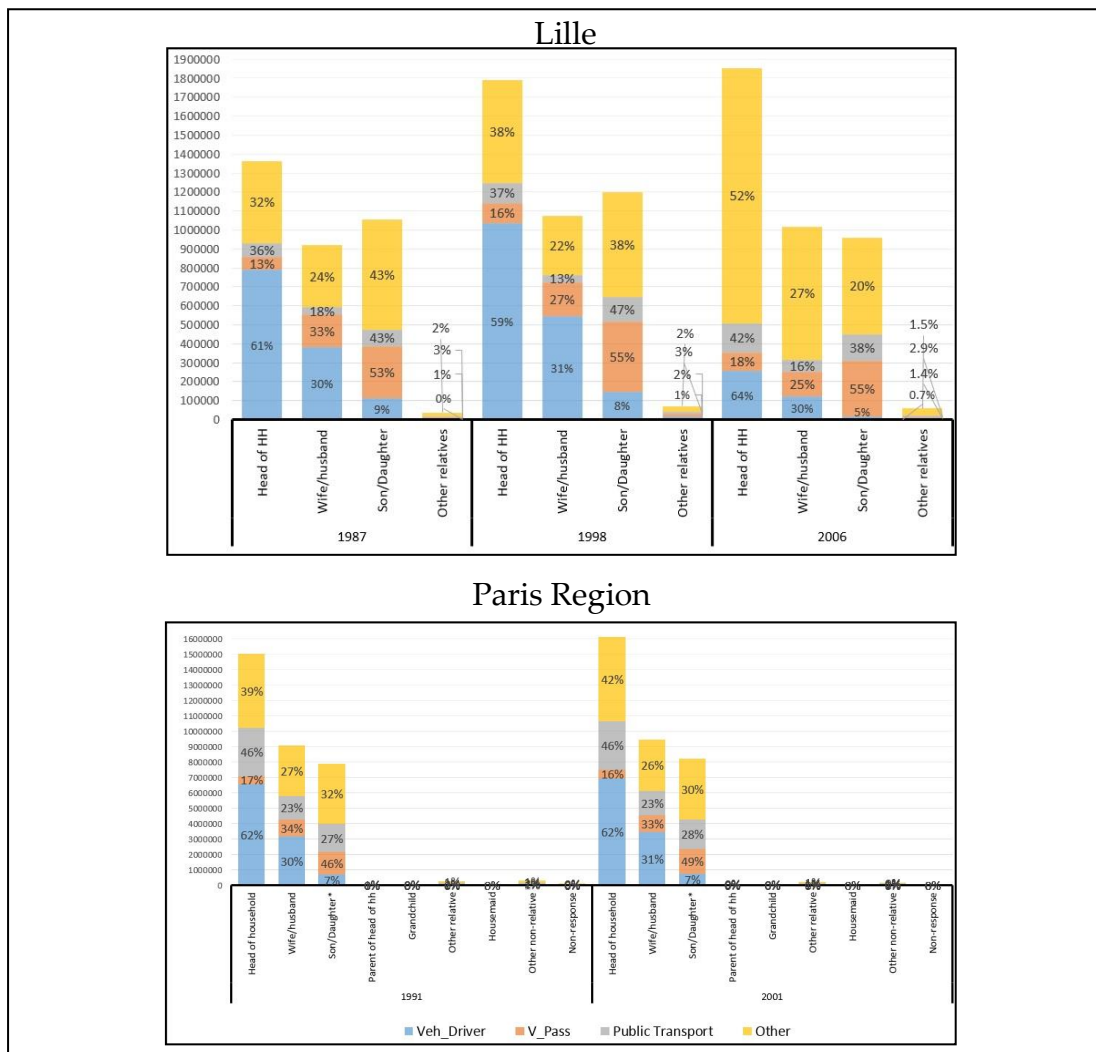
Disaggregated numbers of trips by mode and position in the family (also called family role) indicates that the order of importance of travel demand between family roles is in general stable in all case studies and, in the case of the Paris Region there is no noticeable evolution (Figures 3.18 and 3.19).

Figure 3.18. Evolution of number of trips by mode and family role, Juarez and Puebla



The more remarkable difference between countries is that, in Mexican cities, the category that had more “All modes” trips was “Son/daughter” in all surveys. This category accounts in Juarez and Puebla in all years, for the majority of trips made as a Vehicle Passenger, by Public Transport and “Other modes”. In the French case studies, the head of household is always the person who travels the most taking into account all modes of transportation and also for Vehicle Driver, Public Transport and Other modes. The second family role in order of importance in Mexican cities and in both years in terms of trip generation is the “Head of Household”. This category accounts for the majority of Vehicle Driver trips, which decreases from 56% in 1996 to 46% in 2006.

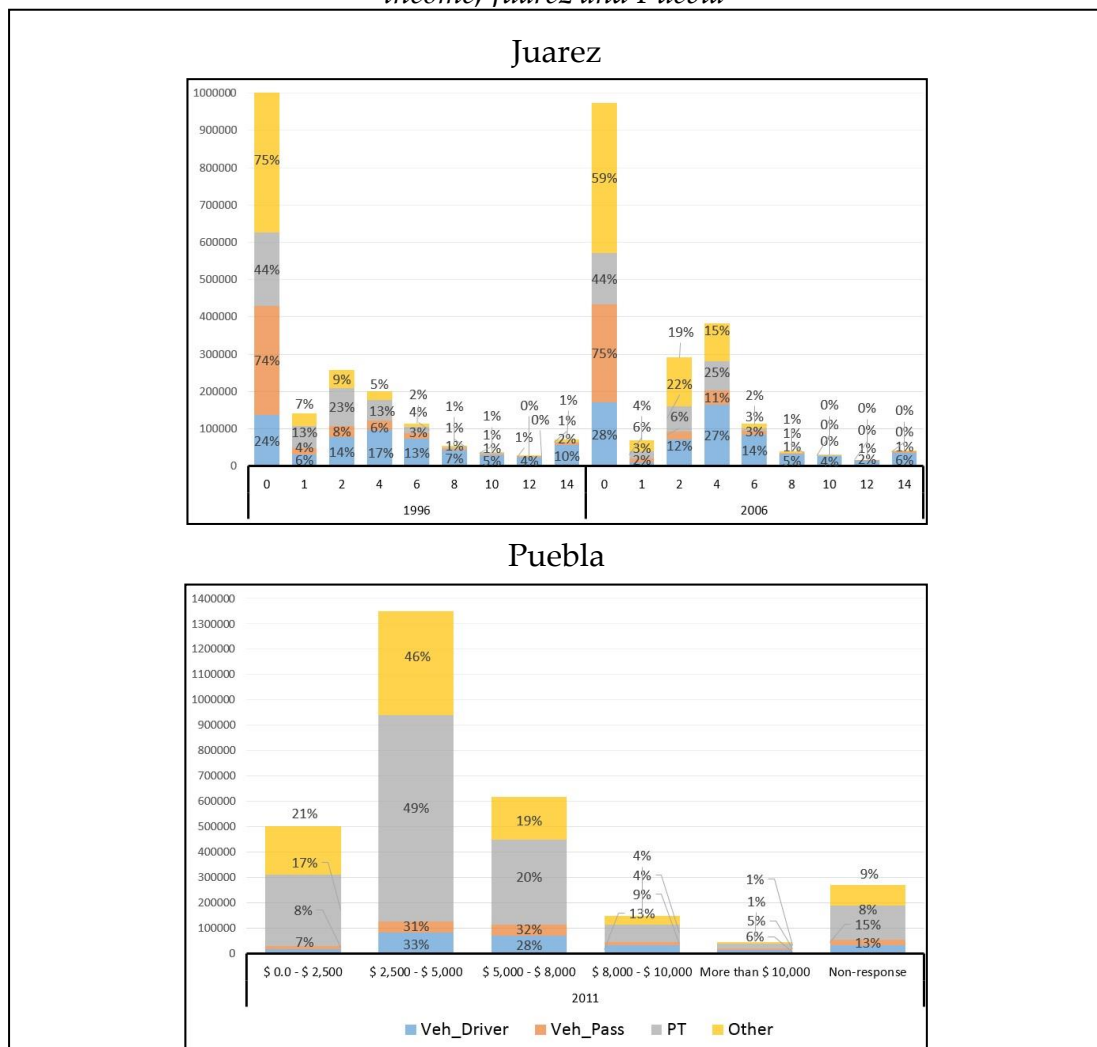
Figure 3.19. Evolution of number of trips by mode and family role, Lille and the Paris Region



Categories for family role do not match exactly between surveys from Puebla. However, head of the household plus wife/husband category accounted for 73% of Vehicle Driver mode in 1994. In 2011, father plus mother category accounted for 64% of the same mode. After head of household, “Wife or husband” category traveled the majority of trips in French cities. In general, transport modes shares by family role had stable proportions over time. This could anticipate no major differences on parameters between surveys as explanatory variables for travel activity.

When analyzing transport activity, it seems that per capita monthly income (in Juarez) and household monthly income (in French cities and Puebla 2011) had an influence on the transportation mode choice (Figure 3.20 and 3.21). People declaring zero monthly income show a significant share of private vehicle driver trips in Juarez and Puebla. Individuals who drove cars and declared no income in these cities are mostly students, retired, unemployed and housewives.

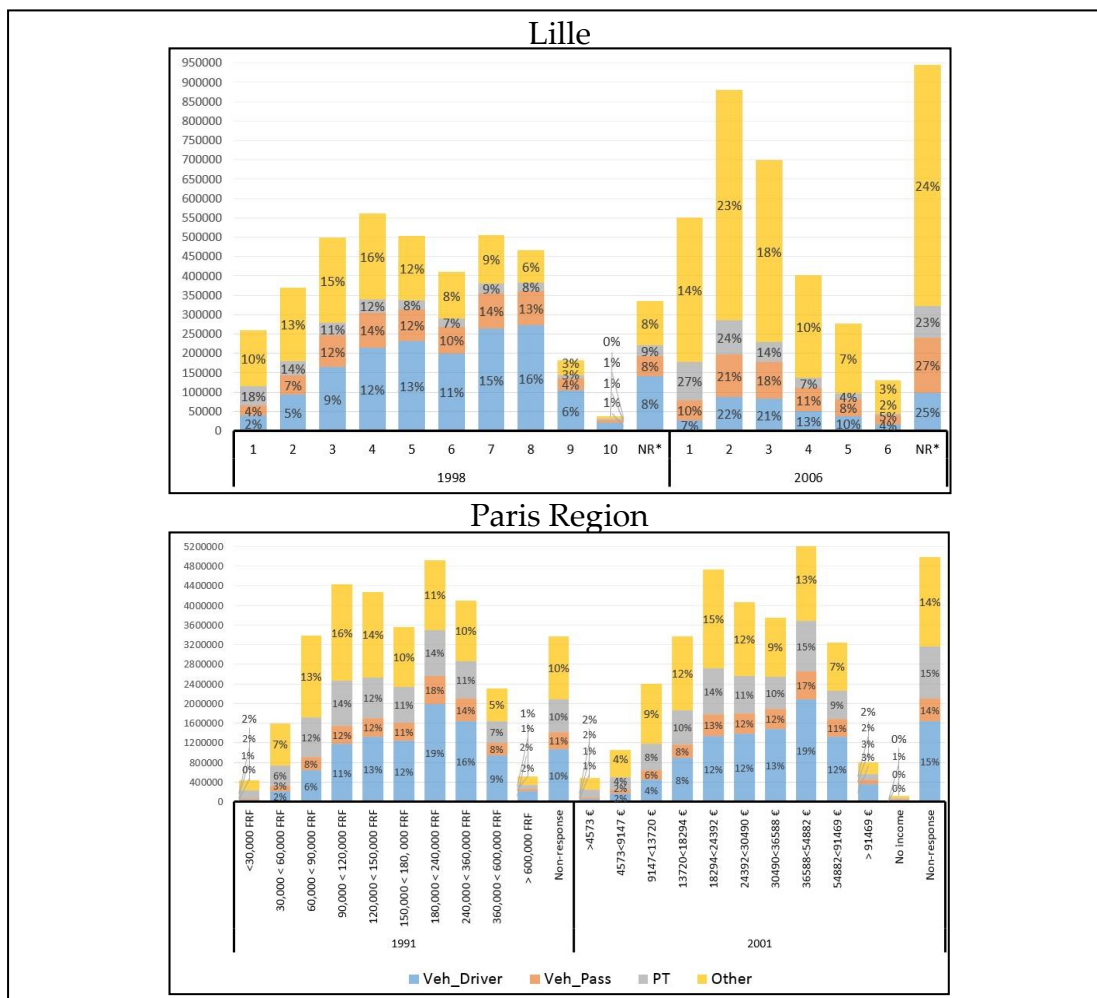
Figure 3.20. Evolution of number of trips by mode and per capita income, Juarez and Puebla



In all cities, the sum of trips traveled by people from each income category form similar curves of Vehicle Driver mode when ignoring non-response and no income categories.

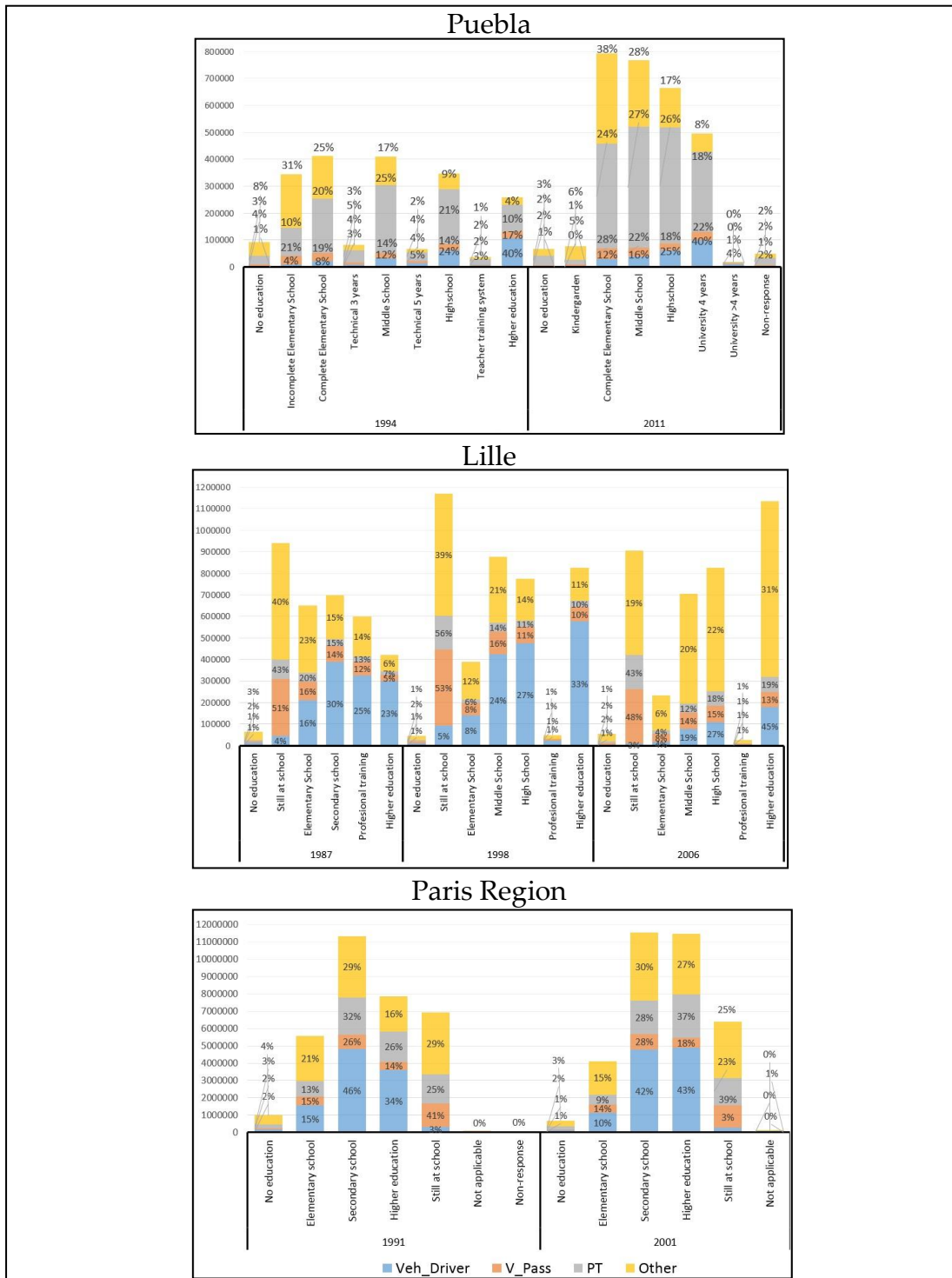
Paris Region had similar distribution between income categories and apparently no major changes between surveys for Public Transport, Vehicle Passenger and Other modes. The influence of lower categories of income on Public transport use is stronger in Mexican cities. An analysis of the impact of income as an explanatory variable of travel demand by mode can be found in the next section.

Figure 3.21. Evolution of number of trips by mode and household income, Lille and the Paris Region



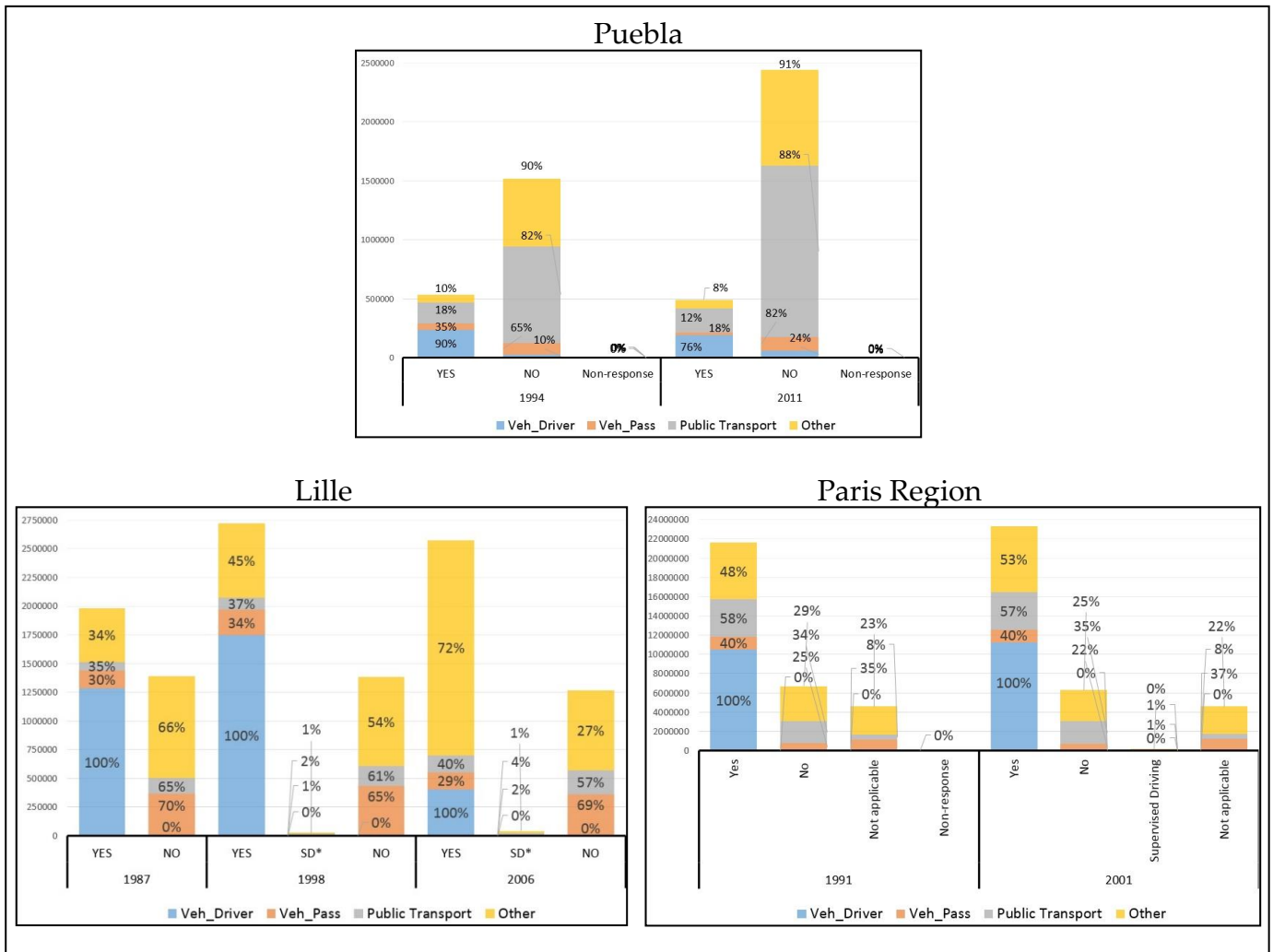
Like monthly income, the level of education seems to be correlated with mode choice. As can be seen in Figure 3.22, individuals with higher education account for about 40% of total Vehicle Driver trips in Puebla, Lille and the Paris Region. Level of education it is not available in Juarez. Moreover, the Paris Region had well shown homogeneous distributions for Public Transport trips for “Still at school”, “Secondary school” and “Higher education” categories and for both surveys.

Figure 3.22. Evolution of number of trips by mode and level of education, Puebla, Lille and Paris Region



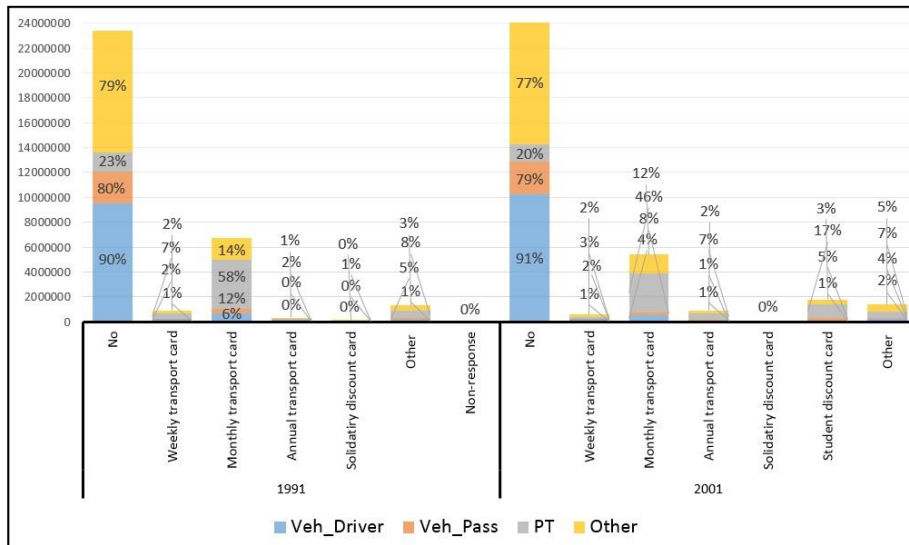
An interesting shift can be observed regarding driving license and vehicle driver mode in Puebla (Figure 3.23). In 1994, 90% of total Vehicle Driver trips were made by people with a driving license, while in 2011 the share decreased to 76%. Having a driving license is mandatory in Mexico for driving a vehicle. Nevertheless, Vehicle Driver trips are increasingly traveled by people with no driving license.

Figure 3.23. Evolution of number of trips by mode and possession of driving license



As could be expected, people with a driving license in France accounted for 100% of Vehicle Driver trips (98.5% according to the National Travel Survey in 2007). In Lille, people with no driving license traveled about 70% of Total Vehicle Passenger trips, about 60% Public transport trips. In the Paris Region, those who didn't have a driving license were responsible for about 35% of Public Transport trips, and about 22% of Vehicle Passenger and 25% of other modes. In Paris Region, license holders traveled also most of Public Transport, Vehicle Passenger and Other modes (57%, 40% and 53% respectively). This is not the case in Lille in which people with no driving license accounted for the majority of the transportation modes mentioned above. The possession of transport card variable is only available in the Paris Region. People with no transport card traveled 91% of Vehicle Driver trips, 79% of Vehicle Passenger, about 77% other modes trips and only 20% of Public Transport trips in 2001 (shares from 1991 are similar) (Figure 3.24).

Figure 3.24. Evolution of number of trips by mode and possession of transport card, 1991 and 2001, Paris Region



Figures 3.25 and 3.26, and Tables 3.9 to 3.12 show that commuter trips, which are daily trips to the place of work or school, accounted for 31.7% and 29.1% in Juarez (1996 and 2006 respectively); 34.6% and 33.4% in Puebla (1994 and 2011 respectively); 21.2%, 20.7% and 20.2% in Lille (1997, 1998 and 2006 respectively); and 27.3%, 25.6% and 25.7% in the Paris Region (1991, 2001 and 2010 respectively). A slightly decrease is observed in each case study from one year to the other one.

Figure 3.25. Trip purpose, Juarez and Puebla

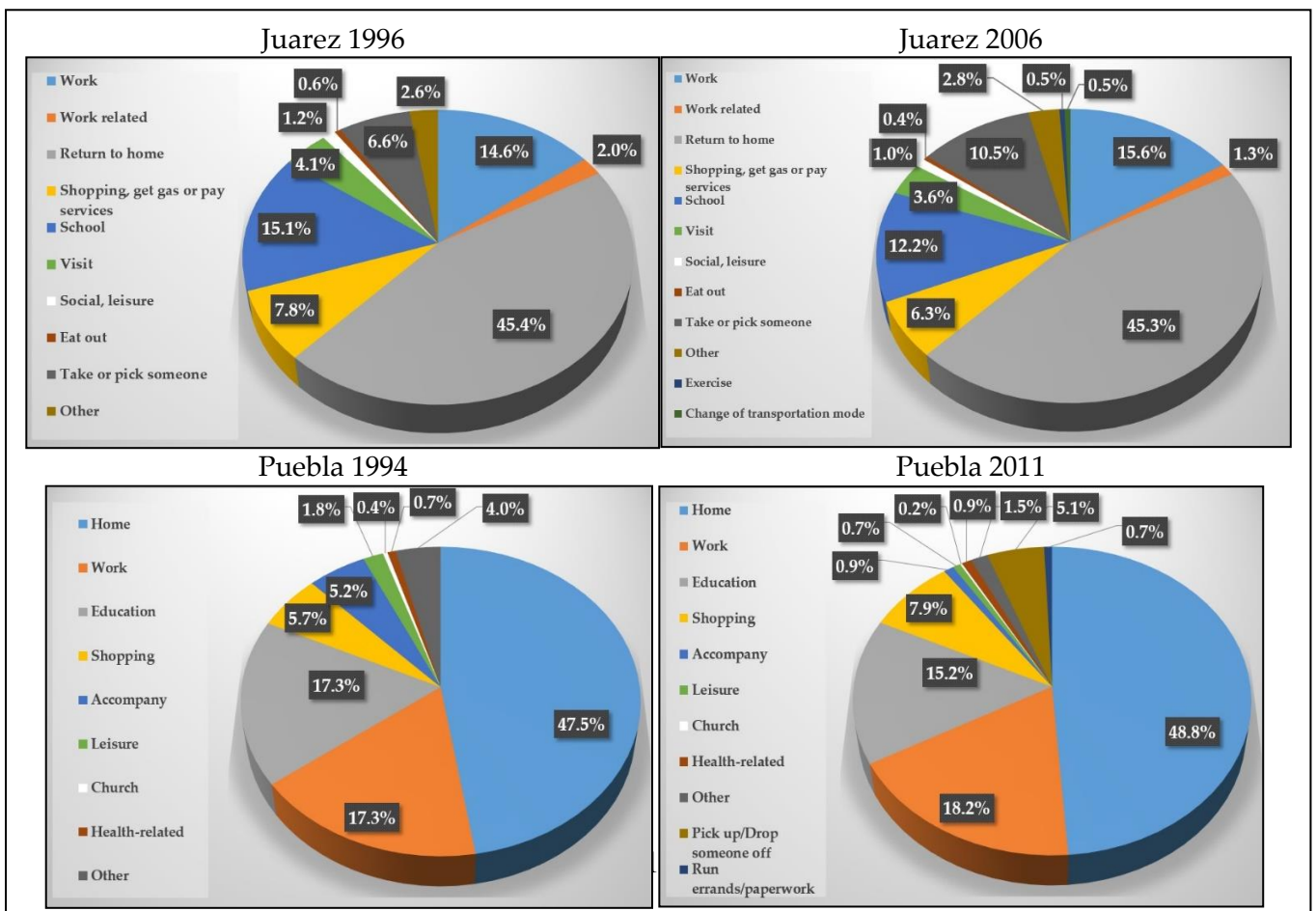


Table 3.9. Trip purpose evolution between 1996 and 2006, Juarez

Trip Purpose	1996	%	Trip Purpose	2006	%
Work	280805	14.6%	Work	305106	15.6%
Work related	38589	2.0%	Work related	25388	1.3%
Return to home	870600	45.4%	Return to home	885435	45.3%
Shopping, get gas or pay services	150429	7.8%	Shopping, get gas or pay services	123570	6.3%
School	290591	15.1%	School	237704	12.2%
Visit	79246	4.1%	Visit	70323	3.6%
Social, leisure	22947	1.2%	Social, leisure + Exercise	27859	1.4%
Eat out	10750	0.6%	Eat out	8762	0.4%
Picking up or dropping someone off	126104	6.6%	Picking up or dropping someone off	205576	10.5%
Other	49477	2.6%	Change of transportation mode + other	66054	3.4%
Total	1919537	100%	Total	1955776	100%

Table 3.10. Trip purpose evolution between 1994 and 2011, Puebla

Trip purpose	1994	%	Trip purpose	2011	%
Home	972705	47.5%	Home	1430786	48.8%
Work	355332	17.3%	Work	532921	18.2%
Education	355263	17.3%	Education	444820	15.2%
Shopping	117678	5.7%	Shopping	231117	7.9%
Accompany	107347	5.2%	Accompany	26317	0.9%
Leisure	36907	1.8%	Leisure	20136	0.7%
Church	8223	0.4%	Church	5214	0.2%
Health-related	15220	0.7%	Health-related	25908	0.9%
Other	81273	4.0%	Other	44515	1.5%
-	-	-	Pick up/Drop someone off	148912	5.1%
-	-	-	Run errands/paperwork	20384	0.7%
Total	2049948	100%	Total	2931028	100%

Table 3.11. Trip purpose evolution between 1987, 1998 and 2006, Lille

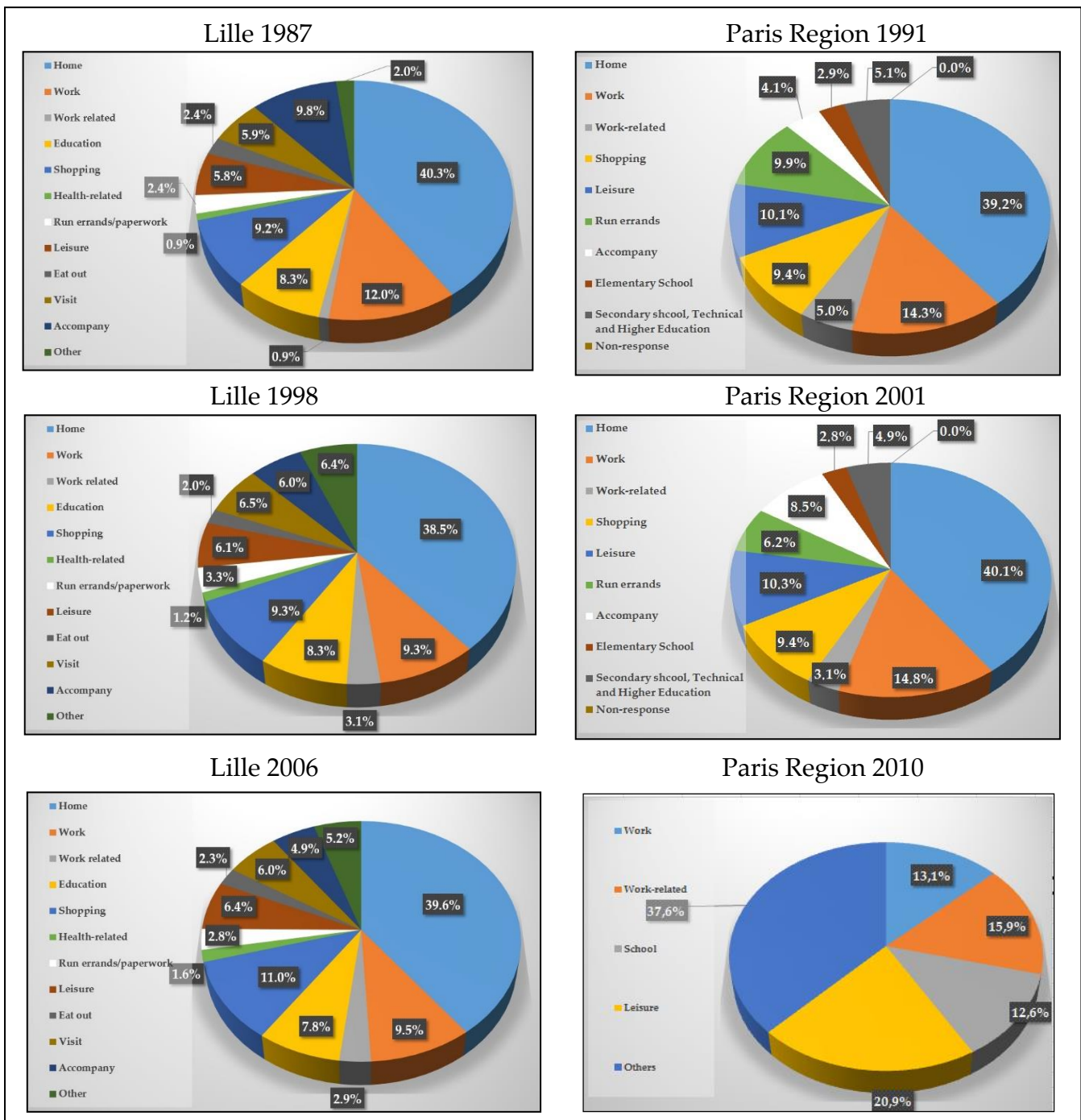
Trip purpose	1987	%	1998	%	2006	%
Home	1361130	40.3%	1591964	38.5%	1537726	39.6%
Work	405252	12.0%	383980	9.3%	370741	9.5%
Work related	31344	0.9%	128355	3.1%	112652	2.9%
Education	280794	8.3%	341738	8.3%	301591	7.8%
Shopping	311371	9.2%	384169	9.3%	427406	11.0%
Health-related	29818	0.9%	49097	1.2%	62004	1.6%
Run errands/paperwork	82534	2.4%	134620	3.3%	108918	2.8%
Leisure	195072	5.8%	251821	6.1%	249663	6.4%
Eat out	79557	2.4%	81240	2.0%	89994	2.3%
Visit	199071	5.9%	268900	6.5%	232974	6.0%
Accompany	330432	9.8%	248373	6.0%	189743	4.9%
Other	68442	2.0%	265447	6.4%	203685	5.2%
Total	3374816	100.0%	4129705	100.0%	3887095	100.0%

Table 3.12. Trip purpose evolution between 1991, 2001 and *2010, Paris Region

Trip purpose	1991	%	2001	%	Trip purpose	2010 *	%
Home	12894714	39.2%	13773658	40.1%	Work	5310000	13.1%
Work	4691398	14.3%	5076780	14.8%	Other professional affaires	6460000	15.9%
Work-related	1657182	5.0%	1057385	3.1%	School	5110000	12.6%
Shopping	3090515	9.4%	3220984	9.4%	Leisure	8510000	20.9%
Leisure	3331706	10.1%	3555642	10.3%	Others	15290000	37.6%
Run errands	3258987	9.9%	2136986	6.2%	Total	40680000	100%
Accompany	1335704	4.1%	2924285	8.5%			
Elementary School	940545	2.9%	959336	2.8%			
Secondary school, Technical and Higher Education	1676616	5.1%	1679740	4.9%			
Non-response	0	0%	3855	0.01%			
Total	32877367	100%	34388651	100%			

* Source: [104]

Figure 3.26. Trip purpose, Lille and Paris Region



In Juarez, going to school (for education purposes and not to work at school), decreased from 15.1% in 1996 to 12.2% in 2006. Another difference was the purpose of picking up or dropping someone off with an increase from 6.6% to 10.5%. Accompany had a decrease in Puebla and Lille of 4.3% (1994 to 2011) and 4.9% (1987 to 2006), respectively. Conversely, in the Paris Region, the same purpose had an increase of 4.4%. Finally, the purpose run errands in the Paris Region had a decrease from 9.9% in 1991 to 6.2% in 2001. The rest of trip purposes remained stable between surveys.

Juarez, as most of northern cities in Mexico is very dependent on private vehicle (Figure 3.27 and Table 3.13). The trend set by both surveys indicates not only the importance and stabilization of private vehicle as a transportation mode (49.9% in 1996 and 49% in 2006) but also that there are more drivers (from 29.3% to 31%) and less passenger (from 20.6% to 18%). Besides the trend of inefficient use of the private vehicle, the public transport mode decreases from 23.1% to 21.8%.

Puebla had interesting evolutions in terms of mode choice. While Public Transport increased its share of total trips going from 45.9% a 52.9%, the use of Private Vehicle had a decrease in both driver and passenger modes. Indeed, according to the Household Travel Surveys from Puebla, Vehicle Driver had a decrease from 12.4% in 1994 to 7.7% in 2011, as well as Vehicle Passenger going from 7.2% to 4.3% in the same years (Figure 3.27 and Table 3.14). In the next section the socioeconomic and geographic variables available will be analyzed in order to identify the changes of explanatory variables for mode choice that could have generated this downward trend. The downward trend of private vehicle use for the inhabitants of Puebla seems to be linked, at least in part, to less vehicle ownership at households shown in Table and Figure 3.02.

Figure 3.27. Trip Mode Choice, Juarez and Puebla

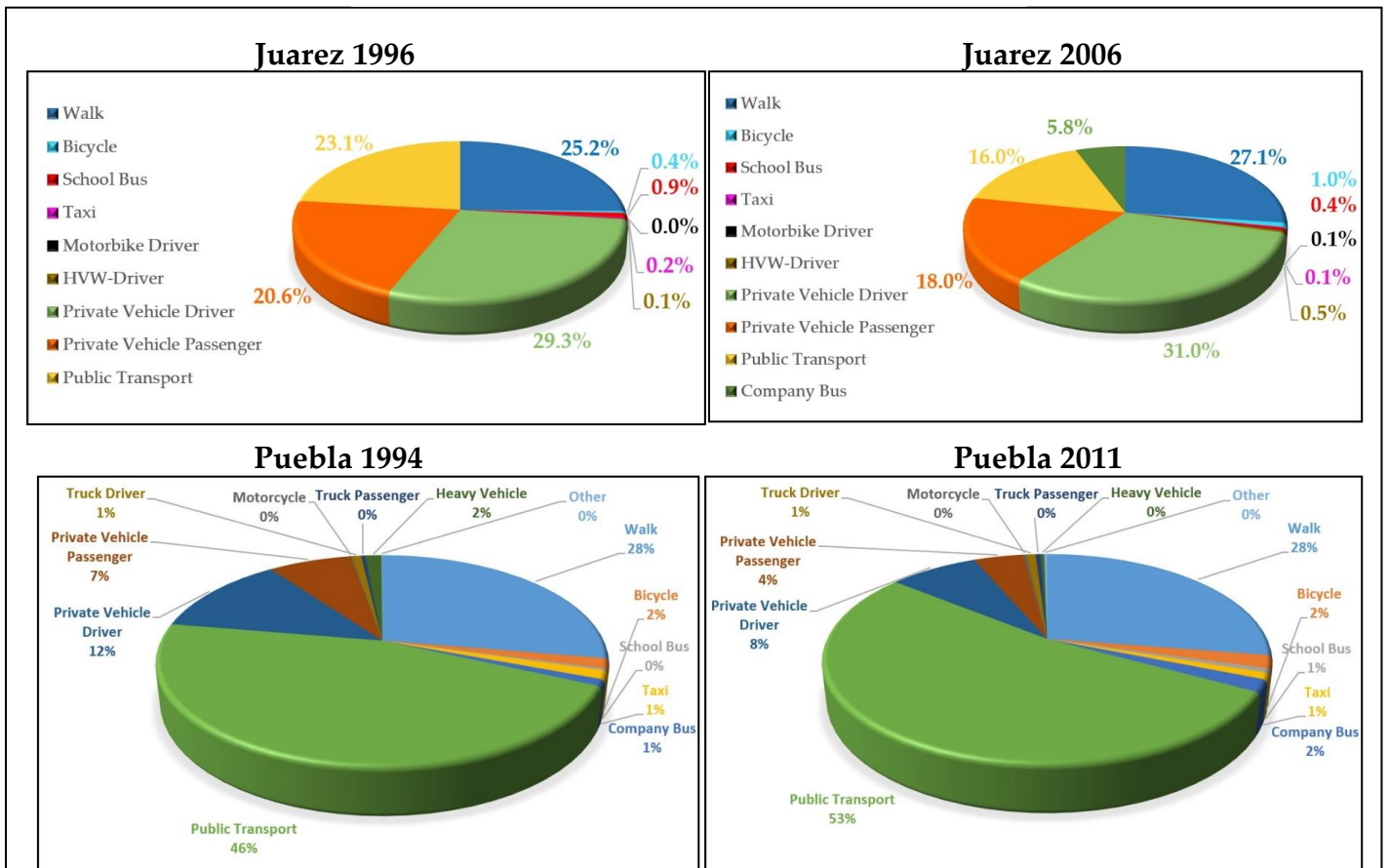


Table 3.13. Trip mode choice evolution between 1996 and 2006, Juarez

Trip mode choice	1996	%	2006	%
Walk	483881	25.2%	530452	27.1%
Bicycle	7993	0.4%	18873	1.0%
School Bus	16814	0.9%	8313	0.4%
Taxi	4686	0.2%	2022	0.1%
Motorbike Driver	896	0%	2022	0.1%
Heavy Vehicle Work Driver	2205	0.1%	8987	0.5%
Private Vehicle Driver	562782	29.3%	606167	31.0%
Private Vehicle Passenger	395953	20.6%	352287	18.0%
Public Transport	444327	23.1%	426654	21.8%
Total	1919538	100%	1955776	100%

Table 3.14. Trip mode choice evolution between 1994 and 2011, Puebla

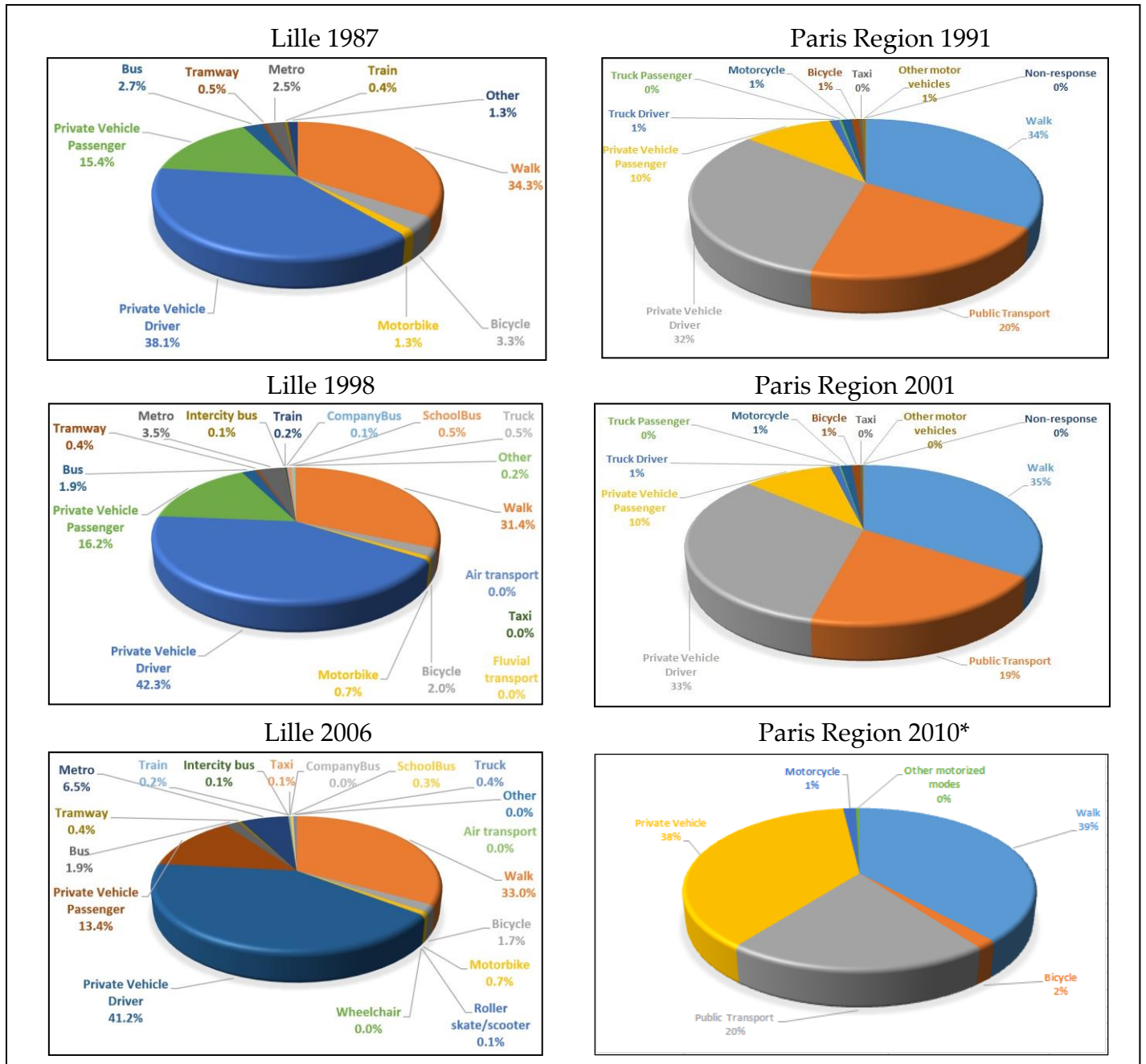
Trip mode choice	1994	%	2011	%
Walk	567719	27.7%	807342	27.5%
Bicycle	30841	1.5%	58880	2.0%
School Bus	6295	0.3%	18485	0.6%
Taxi	26539	1.3%	29005	1.0%
Company Bus	20197	1.0%	54491	1.9%
Public Transport	941033	45.9%	1552970	52.9%
Private Vehicle Driver	253811	12.4%	226698	7.7%
Private Vehicle Passenger	147420	7.2%	127380	4.3%
Motorcycle	2742	0.1%	7759	0.3%
Truck Driver	16009	0.8%	23171	0.8%
Truck Passenger	7260	0.4%	12407	0.4%
Heavy Vehicle	28822	1.4%	9645	0.3%
Other	1462	0.1%	7525	0.3%
Total	2050148	100%	2935758	100%

Lille shows an apparent peak in Vehicle Driver trips, going from 38.1%, 42.3% and 41.2% from 1987, 1998 and 2006 respectively. Vehicle Passenger trips went down from 15.4% in 1987, 16.2% in 2006 to 13.4% in 2006 (Figure 3.28 and Table 3.15).

Table 3.15. Trip mode choice evolution between 1987, 1998 and 2006, Lille

Trip Mode Choice	1987	%	1998	%	2006	%
Walk	1158285	34.3%	1295269	31.4%	1281753	33.0%
Bicycle	111332	3.3%	81030	2%	65875	1.7%
Motorbike	44692	1.3%	29279	0.7%	26626	0.7%
Private Vehicle Driver	1286753	38.1%	1746634	42.3%	1601246	41.2%
Private Vehicle Passenger	520893	15.4%	669012	16.2%	521823	13.4%
Bus	92260	2.7%	77624	1.9%	74171	1.9%
Tramway	17611	0.5%	17081	0.4%	13965	0.4%
Metro	83822	2.5%	146515	3.5%	250935	6.5%
Train	13654	0.4%	8924	0.2%	7889	0.2%
Other	45514	1.3%	58338	1.4%	42812	1.1%
Total	3374815	100%	4129706	100%	3887095	100,00%

Figure 3.28. Trip mode choice, Lille and Paris Region



* Source: [104]

According to the “peak travel” phenomenon, the stabilization in transportation mode choice has been also observed in the Paris Region where Private Vehicle Driver trips covered 32% of trips in 1991 and 32.7% in 2001 and Private Vehicle Passenger accounted for 9.8% of trips in 1991 and 9.6% in 2001, representing 41.8% in 1991 and 42.3% in 2001 of Private Vehicle trips, which in 2010 accounted for 37.8%. Public Transport remains stable, having a slight decrease in 2001, going from 20.1% in 1991 to 19.5% in 2001, being 20.3% in 2010 (Figure 3.28 and Table 3.16).

Table 3.16. Trip mode choice 1991, 2001 and *2010, Paris Region

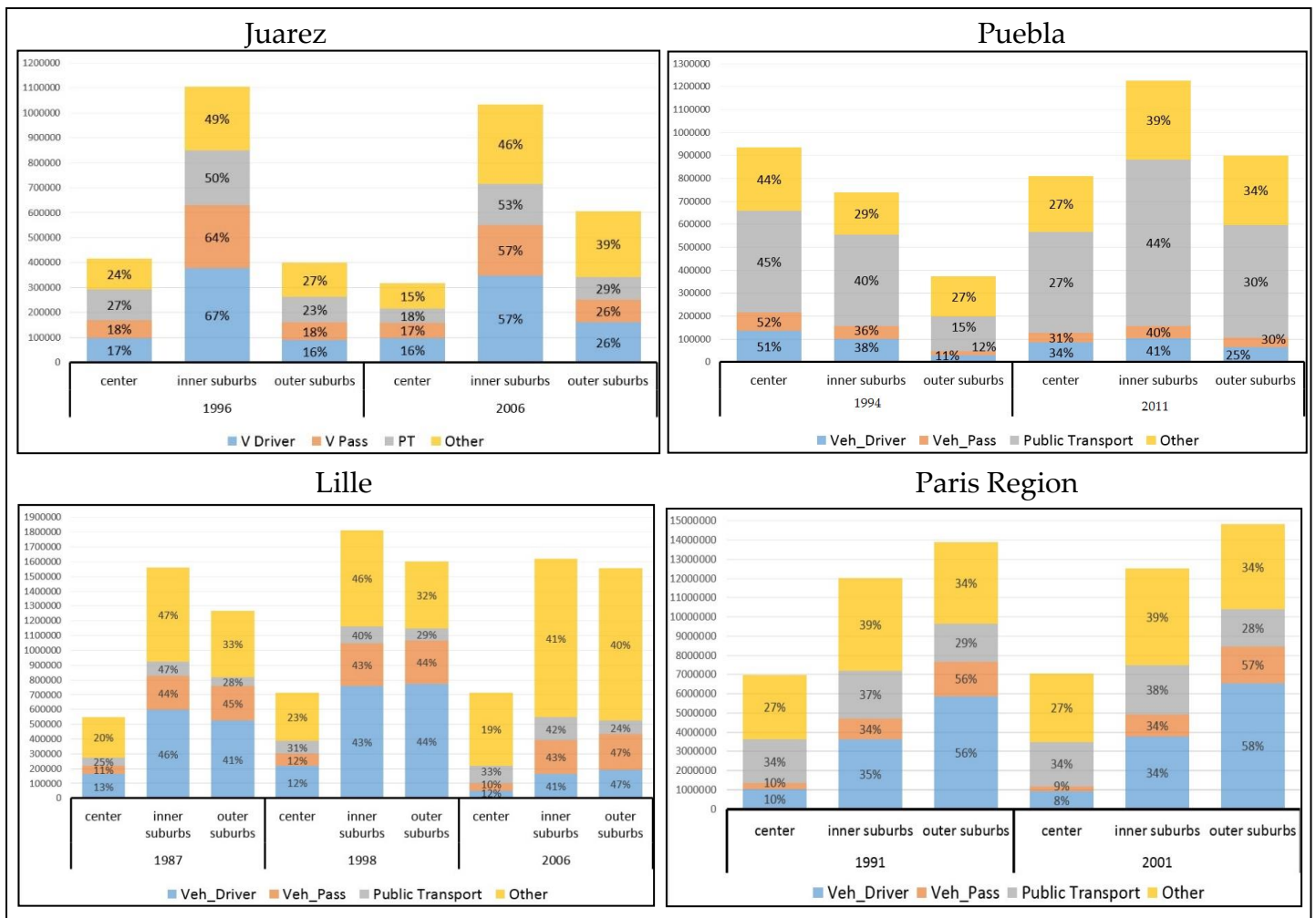
Trip mode choice	1991	%	2001	%	Trip mode choice	2010 *	%
Walk	11217369	34.1%	11860829	34.5%	Walk	15630000	38.4%
Public Transport	6609794	20.1%	6700787	19.5%	Public Transport	8270000	20.3%
Private Vehicle Driver	10527598	32.0%	11257825	32.7%	Private Vehicle	15390000	37.8%
Private Vehicle Passenger	3208901	9.8%	3313466	9.6%	Motorcycle	570000	1.4%
Truck Driver	343379	1.0%	340049	1.0%	Other motor vehicles	170000	0.4%
Truck Passenger	91153	0.3%	64461	0.2%	Bicycle	650000	1.6%
Motorcycle	363696	1.1%	415555	1.2%	Total	40680000	100%
Bicycle	273631	0.8%	293902	0.9%			
Taxi	113482	0.4%	87608	0.3%			
Other motor vehicles	128108	0.4%	54169	0.2%			
Non-response	255	0%	0	0%			
Total	32877365	100%	34388651	100%			

* Source: [104]

Previous chapter briefly described the role that could play the urban form in the transport activity (e.g. transportation mode choice, share of number of trips and/or share of travel distance by zone, etc.). The share of number of trips disaggregated by mode and zone of residence (Figure 3.29) show that the majority of trips were made by people living in the inner suburbs in Juarez, Puebla 2011 and Lille; and in the outer suburbs in the Paris Region.

In Juarez, the sum of trips from people living in the center was slightly lower in 2006 compared to 1996, while the sum of trips of people living in the outer suburbs had significantly increased in 2006 compared to 1996. Activity in the center seems to have stabilized for Vehicle Driver and Vehicle Passenger (about 17% and 18% respectively in both years), the decrease was in the use of Public Transport and Other Modes (from 27% to 18% and 24% to 15% respectively). The sum of trips from inner suburbs also had a slight decrease. In this zone all modes stabilized except for Vehicle Driver that accounted for 67% of trips to only 57% in 2006. The only zone that increased in terms of total number of trips was outer suburbs. The increase of trip generation in the outer suburbs seems to be proportional, meaning that all transport modes increased for people living in this zone. For instance, Vehicle Drivers living in outer suburbs went from being responsible of 16% of trips in 1996 to 26% in 2006, Vehicle Passenger had 18% in 1996 while in 2006 up to 26%, Public Transport accounted for 18% of trips in 1996 and 29% in 2006, and lastly, Other Modes from 27% up to 39% in 2006. In fact, it seems that the decrease of trips and travel distance for people living in the center and the increase of these variables for households living in the outer suburbs is actually linked to the evolutions of total number of households and total population in those zones as mentioned previously in this chapter.

Figure 3.29. Evolution of number of trips by mode and zone of residence



The evolution of the number of trips by mode and zone of residence in Puebla, shows that outer suburbs doubled its share of Vehicle Driver (11% to 25%), Vehicle Passenger (12% to 30%) and Public Transport (15% to 30%). Inner suburbs had slight increases of the proportion of total trips by mode for Vehicle Driver (38% to 41%), Vehicle Passenger (36% to 40%), Public Transport (40% to 44%) and other modes (29% to 39%). The city center lost almost half in the proportion of all means of transport.

Inner suburbs in Lille had a decrease in the proportion of Vehicle Driver trips, going from 46% in 1987 to 41% in 2006. This mode remained stable between all years with 12% of all Vehicle Driver trips. Similarly to Juarez, Puebla and the Paris Region, the outer suburbs of Lille experienced some growth in the proportion of this motorized mode, going from 41% in 1987 to 47% in 2006. Moreover, its city-center had a slight decrease in Vehicle Passenger (10% in 2006 vs 12% in 1998), and in Other modes (19% in 2006 vs 23% in 1998) while Public Transport gained importance in terms of

proportion of total trips (33% in 2006 vs 31% in 1998). Vehicle Passenger remained stable over the years in all zones with 10% in the city-center, about 43% in the inner suburbs, and approximately 46% in outer suburbs.

As shown in Figure 3.29, the shares of trips by mode and zone of residence from the Paris Region have been very stable over time. The transportation mode category named “Other” do not change between surveys; the center reported 27% of “Other” mode trips in both years, inner suburbs 39% and outer suburbs 34%. The city center accounted for 34% of Public Transport in both years, inner suburbs about 38% and outer suburbs approximately 28%. Center, inner and outer suburbs had 9%, 34% and 57% respectively for Vehicle Passenger in both years. Lastly, Vehicle Driver went from 10% to 8% in the city-center, from 35% to 34% in the inner suburbs and from 56% to 58%.

Disaggregated analysis by origin and destination of trips (regardless the zone of residence of the trip maker) shows also the increase of magnitude of travel activity in the outer suburbs (Tables 3.17 and 3.25). In fact, origin-destination trip matrix (Tables 3.17 and 3.18) show that in the 1996 survey from Juarez, center/center intra-zone trips (trips with origin and destination in the same zone) accounted for 14.1% in 1996 while in 2006 it decreased to 11.1%. In 1996, 39.4% were inner suburbs/inner suburbs trips and 37% in 2006. Outer suburb/outer suburb trips had an increase from 11.2% to 20% from 1996 to 2006.

Table 3.17. Origin-Destination trip matrix by zone in 1996, Juarez

Origin	Destination				
	Center	inner suburbs	outer suburbs	Total	
Center	270469	198666	30182.3	499317	Frequency
	14.1%	10.4%	1.6%	26.0%	Percent
	54.2%	39.8%	6.0%		Row Percent
	54.3%	18.7%	8.5%		Column Percent
Inner suburbs	197701	756900	110255	1064855	Frequency
	10.3%	39.4%	5.7%	55.5%	Percent
	18.6%	71.1%	10.4%		Row Percent
	39.7%	71.0%	31.0%		Column Percent
Outer suburbs	30389	109910	215066	355365	Frequency
	1.6%	5.7%	11.2%	18.5%	Percent
	8.6%	30.9%	60.5%		Row Percent
	6.1%	10.3%	60.5%		Column Percent
Total	498559	1065476	355503	1919538	
	26.0%	55.5%	18.5%	100%	

Table 3.18. Origin-Destination trip matrix by zone in 2006, Juarez

Origin	Destination				
	Center	inner suburbs	outer suburbs	Total	
center	221303	169179	23815	414297	Frequency
	11.3%	8.7%	1.2%	21.2%	Percent
	53.4%	40.8%	5.8%		Row Percent
	53.6%	16.8%	4.5%		Column Percent
inner suburbs	166258	723446	117504	1007208	Frequency
	8.5%	37.0%	6.0%	51.5%	Percent
	16.5%	71.8%	11.7%		Row Percent
	40.2%	71.6%	22.1%		Column Percent
outer suburbs	25612.7	117279	391380	534272	Frequency
	1.3%	6.0%	20.0%	27.3%	Percent
	4.8%	22.0%	73.3%		Row Percent
	6.2%	11.6%	73.5%		Column Percent
Total	413173	1009904	532699	1955776	
	21.1%	51.6%	27.2%	100%	

Trip generation and attraction by zone of origin and destination from Puebla show that intra-zone trips in the city center accounted for 37.5% in 1994 and 20.7% in 2011. Moreover, inner suburbs intra-zone trips were responsible for 15.1% of total trips in Puebla in 1994 and 20.5% in 2011. Finally, trips generated and attracted by the outer suburbs accounted for 8.1% in 1994, doubling its share up to 16.3% in 2011 (Tables 3.19 and 3.20).

Table 3.19. Origin-Destination trip matrix by zone in 1994, Puebla

Origin	Destination				
	center	inner suburbs	outer suburbs	Total	
center	768433	273540	68751	1110723	Frequency
	37.5%	13.3%	3.4%	54.2%	Percent
	69.2%	24.6%	6.2%		Row Percent
	69.1%	42.5%	23.4%		Column Percent
inner suburbs	275555	309889	59286	644729	Frequency
	13.4%	15.1%	2.9%	31.5%	Percent
	42.7%	48.1%	9.2%		Row Percent
	24.8%	48.2%	20.2%		Column Percent
outer suburbs	68582	60214	165900	294696	Frequency
	3.4%	2.9%	8.1%	14.4%	Percent
	23.3%	20.4%	56.3%		Row Percent
	6.2%	9.4%	56.4%		Column Percent
Total	1112570	643642	293937	2050148	
	54.3%	31.4%	14.3%	100%	

Table 3.20. Origin-Destination trip matrix by zone in 2011, Puebla

Origin	Destination				
	center	inner suburbs	outer suburbs	Total	
center	606116	334000	158919	1099035	Frequency
	20.7%	11.4%	5.4%	37.4%	Percent
	55.2%	30.4%	14.5%		Row Percent
	55.1%	31.3%	20.7%		Column Percent
inner suburbs	334279	602360	130993	1067632	Frequency
	11.4%	20.5%	4.5%	36.4%	Percent
	31.3%	56.4%	12.3%		Row Percent
	30.4%	56.4%	17.1%		Column Percent
outer suburbs	158930	131931	478231	769091	Frequency
	5.4%	4.5%	16.3%	26.2%	Percent
	20.7%	17.2%	62.2%		Row Percent
	14.5%	12.0%	62.3%		Column Percent
Total	1099325	1068291	768142	2935758	
	37.5%	36.4%	26.2%	100%	

Origin-Destination trip matrix by zone in Lille (Tables from 3.21 to 3.23) shows slow changes in terms of intra-zones trips. Center/center trips accounted for 14.6% in 1987 and 15.1% of total trips in 2006. Inner-suburbs intra-zone trips accounted for 36.9% of total trips in 1987 and down to 33.1% in 2006. Finally, Outer suburbs intra-zone trips showed an increase from 26.4% to 28.5% of total trips.

Table 3.21. Origin-Destination trip matrix by zone in 1987, Lille

Origin	Destination				
	center	inner suburbs	outer suburbs	Total	
Center	493466	119636	94332,8	707435	Frequency
	14.6%	3.5%	2.8%	21.0%	Percent
	69.8%	16.9%	13.3%		Row Percent
	69.7%	7.9%	8.3%		Column Percent
inner suburbs	119322	1244807	157422	1521552	Frequency
	3.5%	36.9%	4.7%	45.1%	Percent
	7.8%	81.8%	10.4%		Row Percent
	16.9%	81.8%	13.8%		Column Percent
outer suburbs	95243	158293	892294	1145830	Frequency
	2.8%	4.7%	26.4%	34.0%	Percent
	8.3%	13.8%	77.9%		Row Percent
	13.5%	10.4%	78.0%		Column Percent
Total	708030	1522737	1144049	3374816	
	21%	45.1%	33.9%	100%	

Table 3.22. Origin-Destination trip matrix by zone in 1998, Lille

Origin	Destination				
	center	inner suburbs	outer suburbs	Total	
Center	589726	152731	115990	858447	Frequency
	14.3%	3.7%	2.8%	20.8%	Percent
	68.7%	17.8%	13.5%		Row Percent
	68.5%	8.5%	7.9%		Column Percent
inner suburbs	151405	1438082	200930	1790418	Frequency
	3.7%	34.8%	4.9%	43.4%	Percent
	8.5%	80.3%	11.2%		Row Percent
	17.6%	80.3%	13.6%		Column Percent
outer suburbs	119341	201005	1160494	1480841	Frequency
	2.9%	4.9%	28.1%	35.9%	Percent
	8.1%	13.6%	78.4%		Row Percent
	13.9%	11.2%	78.6%		Column Percent
Total	860472	1791818	1477415	4129705	
	20.8%	43.4%	35.8%	100%	

Table 3.23. Origin-Destination trip matrix by zone in 2006, Lille

Origin	Destination				
	Center	inner suburbs	outer suburbs	Total	
center	585291	147755	108580	841626	Frequency
	15.1%	3.8%	2.8%	21.7%	Percent
	69.5%	17.6%	12.9%		Row Percent
	69.5%	9.1%	7.7%		Column Percent
inner suburbs	149727	1286748	196009	1632485	Frequency
	3.9%	33.1%	5.0%	42.0%	Percent
	9.2%	78.8%	12.0%		Row Percent
	17.8%	78.9%	13.9%		Column Percent
outer suburbs	107688	195782	1109514	1412984	Frequency
	2.8%	5.0%	28.5%	36.4%	Percent
	7.6%	13.9%	78.5%		Row Percent
	12.8%	12.0%	78.5%		Column Percent
Total	842706	1630286	1414104	3887095	
	21.7%	41.9%	36.4%	100%	

The analysis of origin and destination of trips for the Paris Region (Tables 3.24 and 3.25) shows also slow changes in terms of intra-zones trips. Center/center trips accounted for 20.5% in 1991 and 19.1% of total trips in 2001. Inner-suburbs intra-zone trips accounted for 27.6% of total trips in 1991 and 28.3% in 2001. Finally, Outer suburbs intra-zone trips had also an increase from 33.9% in 1991 to 35.7% of total trips in 2001.

Table 3.24. Origin-Destination trip matrix by zone in 1991, Paris Region

Origin	Destination				
	Center	inner suburbs	outer suburbs	Total	
center	6656106	1432897	622797	8711800	Frequency
	20.25%	4.4%	1.9%	26.5%	Percent
	76.4%	16.5%	7.2%		Row Percent
	76.41%	12.5%	4.9%		Column Percent
inner suburbs	1435465	9061660	952652	11450000	Frequency
	4.37%	27.6%	2.9%	34.8%	Percent
	12.54%	79.1%	8.3%		Row Percent
	16.48%	79.2%	7.5%		Column Percent
outer suburbs	619018	954831	11140000	12720000	Frequency
	1.88%	2.9%	33.9%	38.7%	Percent
	4.87%	7.5%	87.6%		Row Percent
	7.11%	8.3%	87.6%		Column Percent
Total	8710589	11450000	12720000	32880000	
	26.49%	34.8%	38.7%	100%	

Table 3.25. Origin-Destination trip matrix by zone in 2001, Paris Region

Origin	Destination				
	Center	inner suburbs	outer suburbs	Total	
center	6573872	1377205	551539	8502616	Frequency
	19.12%	4.0%	1.6%	24.7%	Percent
	77.32%	16.2%	6.5%	100%	Row Percent
	77.18%	11.4%	4.0%		Column Percent
inner suburbs	1396705	9716017	971934	12080000	Frequency
	4.06%	28.3%	2.8%	35.1%	Percent
	11.56%	80.4%	8.0%	100%	Row Percent
	16.4%	80.5%	7.1%		Column Percent
outer suburbs	546894	984256	12270000	13800000	Frequency
	1.59%	2.9%	35.7%	40.1%	Percent
	3.96%	7.1%	88.9%	100%	Row Percent
	6.42%	8.2%	89.0%		Column Percent
Total	8517471	12080000	13790000	34390000	
	24.77%	35.1%	40.1%	100%	

3.2 Econometric modelling trend analysis

The following cross-sectional analyzes were performed for Household level and Individual level.

3.2.1 Household level: Data description and methodology

Multinomial logistic regression (MLR) was employed using categories of the number of vehicles in the household as the dependent variable and correlating it with the factors as independent/predictor variables. The categorical dependent variable (Vehicles/hh) was grouped into four levels: No cars, one, two, and three or more cars. In all cases, this variable corresponds to the numbers of motorized private vehicles, or cars owned by family members.

The MLR was modeled as an extension of the binary logistic regression [133, 134] by comparing each class of vehicle ownership (1, 2, ≥ 3) with vehicle deprivation (No cars) as the reference level, thus producing three binary logistic regression outputs. Standard interpretation of the relative risk ratios is for a unit change in the predictor variable, the relative risk ratio of outcome m relative to the referent group is expected to change by a factor of the respective parameter estimate given the variables in the model are held constant.

Regarding the independent variables, the table below shows the availability by case study and year (if no specified: variable available for each year).

Table 3.26. Variables per case study

Variables	Juarez	Puebla	Lille	Paris Region
zone of residence	✓	✓	✓	✓
adults per hh	✓	✓	✓	✓
number of rooms	×	✓	×	×
hh surface area	×	×	×	✓
type of hh	×	✓	✓	✓
status at hh	×	×	✓	✓
income	✓	✓ (2011)	✓ (1998, 2006)	✓

*hh: household

Categorical variables: Zone, describing the location of the household in terms of the urban form configuration mentioned before (center, inner suburbs and outer suburbs); Type/hh, describing the type of housing (house unit and apartment); Status at household, referring to whether the occupants of the household are the owners or not (categories differ from case studies).

Continuous variables: Total number of adults living in the same household (adults/hh) from 18 years old and total number of rooms in the household (total_rooms).

Ordinal categorical variables: Household surface area (5 categories from lower than 50 m² up to 150 m² or more) and income per household (income/hh, measured in number of minimum wage for Juarez, based on previously established ranges of total family income, and different income categories for the other case studies).

3.2.2. Household level: Results

In the multinomial logistic regression analysis concerning the explanatory factors of vehicles ownership at household level, income/hh is found to be significantly associated with the numbers of vehicles in the Household, in Juarez (both years), Puebla (2011), Lille (1998 and 2006) and Paris Region (both years) ($p < 0.001$ for each category) with an increase of the Relative Risk Ratio (RRR) from one category to the next one, suggesting that with higher income, the number of vehicle ownership at household increases. The effect is weaker in 1996 (Juarez), 2006 (Lille) and 2001 (Paris Region). (Annex 1)

The number of adults living in the household (adults/hh) is statistically significant in Juarez (1996), Lille (all years) and Paris Region (both years) for every category of motorization rate ($p < 0.001$) and positively related with an increase of the RRR as the number of vehicles increases. In Puebla (1994) and Juarez (2006) adults/hh is only significant for the category three or more vehicles compared to having no cars ($p=0.001$). In France, the main obstacle to more households with 3 or more vehicles is the reduction of households with many adults (working group from ENSAE). In other words, for households with one or two motorized private vehicles, the number of adults living in the same house is not a predictor of vehicle ownership. For the year 2011 (Puebla), adults/hh is significantly associated to motorization for the categories 2 and 3 or more vehicles.

In relation to urban form characteristics mentioned before and its impact on motorization and travel behavior, the results show that the overall effect of the zone as an urban form classification is statistically significant in Juarez (both years) but stronger in 1996 ($p < 0.001$ in 1996 and $p = 0.03$ in 2006), in Puebla (2011: $p < 0.001$), Lille (1987: $p = 0.02$; 1998 and 2006: $p < 0.001$) and Paris Region (both years: $p < 0.001$). The overall effect of the variable is no significant in Puebla (1994: $p = 0.41$). In Juarez (1996), outer suburbs category is not statistically significant for explaining mono-motorization versus vehicle deprivation, as opposed to inner suburbs which has a relative risk ratio (RRR) of 1.22 compared to the center. In fact, in 1996 the outer suburbs class is no significant in predicting the outcome neither for mono-motorization nor the other categories (0 vs 1, 2, 3 or more vehicles). Outer suburbs changed from being not statistically significant in 1996 to being statistically significant and positively related to mono-motorization in 2006 with a RRR of 1.64. Likewise in Lille, the expected risk of having 1 vs. 0 vehicles is higher for households located in the inner and outer suburbs relative to those located in the center, with a gradual increment of the RRR, being only the category of outer suburbs no significant in 1987. As for Puebla (1994), outer suburbs category is the only statistically significant for explaining mono-motorization versus vehicle deprivation, with a RRR of 0.77 with respect to the center. In other words, the expected risk of having 1 vs. 0 vehicles is lower for households located in the outer suburbs relative to those located in the center. However, this category changed from being statistically significant in 1994 to being not statistically significant in 2011.

For two vs. zero cars, the relative risk ratio (RRR) switching from zone = 1 (center) to 3 (outer suburbs) is 1.93 (2006), it is 1.75 when changing from the center to inner suburbs in 1996 and 1.60 in 2006, in Juarez. The ones not mentioned are no significant. In Puebla (2011), the relative risk ratio (RRR) switching from zone = 1 (center) to 2 (inner suburbs) is 0.31 and it is 0.55 when changing from the center to outer suburbs. Thus, the risk of having two vehicles decreases in inner and outer suburbs with respect to the center. As for Lille, the risk increases the most in outer suburbs in all years. Being farther from the center is linked to having two cars compared with car deprivation.

For ≥ 3 cars, in Juarez (1996) the expected risk of having ≥ 3 vs. 0 cars is higher for households located in the inner suburbs (RRR=3.01) than those located in the center. In 2006 zone is no longer significant for inner and outer suburbs with respect to the center, meaning that there is no difference in location of households with ≥ 3 cars. In

Lille (1987 and 1998) the risk increases only in outer suburbs, but in 2006 it increases in inner and outer suburbs, with a greater effect in households located the farthest from the center. The variable is no significant in any of the categories in Puebla (both years).

In brief, an increment of the RRR linked to a higher number of cars in the household, is observed in Juarez (1996: in inner suburbs), in Lille (2006: both “zones”) and in the Paris Region compared to center. For the Paris Region, this pattern is found in both years – that is a higher RRR in outer suburbs and for households with ≥ 3 vehicles.

Regarding the type of household, the overall effect is statistically significant in Puebla (both years: $p < 0.001$), Lille (all years: $p < 0.001$) and the Paris Region (both years: $p < 0.001$). In Puebla (both years) and the Paris Region (1991), living in a multiple dwelling household has lower RRR for explaining the event of having one car vs. no vehicles with respect to a detached or semidetached household. The variable was not significant in 2001 (Paris Region). In Lille, living in a multiple dwelling household has a higher RRR (1.49) with respect to those in a detached or semi-detached house for explaining the event of having one vs. no vehicles, in 1998. The variable is no significant in 1987 and 2006 for explaining this category of motorization. As for the Paris Region, the risk of having 1 vs. 0 vehicles is lower for a multiple dwelling household in 1991.

The RRR of having two vs. zero cars is lower for multiple dwelling type households in Puebla (both years), Lille (2006) and the Paris Region (both years).

For ≥ 3 cars, the variable is only significant in 1994 for Puebla with a RRR of 0.44. In Lille, the RRR of having three vs. zero cars is also lower for a multiple dwelling household (in 2006) as in the Paris Region (both years).

Concerning the residential status, the overall effect is statistically significant in Lille (all years: $p < 0.001$) and the Paris Region (both years: $p < 0.001$). In Lille, being tenant - LRH or other- (all years) or having other type of residential status (1987 and 2006), has lower RR ratios compared to the owner of the property, for explaining the event of having one vs. no vehicles. As for the Paris Region, the risk is lower for tenants (both years) and those having a free lodge (2001) while it is higher for both those lodged by the employer (1991).

The RRR of having two vs. zero cars is lower for tenants (LRH or other in Lille and the Paris Region), other type of residential status in Lille (all years), and for free housings (Lille, 2006 and Paris Region, 2001).

For ≥ 3 cars, the RRR is also lower for tenants (LRH or other) in Lille (all years) and in the Paris Region (both years), compared to the owner.

The variable number of rooms in the household (*total_rooms*) is statistically associated with the number of vehicles owned by the household in Puebla (both years: $p < 0.001$) and Lille (2006, data only available for this year). The RRR increase from one category to the next one in Puebla (1994) and Lille, which may explain that if there is a large number of rooms in the household, there are more vehicles too. However in Puebla (2011) the ascending order of the RRR doesn't exist (1.24 for one car, 1.37 for two cars and 1.36 for three or more cars).

Finally, the "household surface area" variable (*hh_area*), was also statistically associated with the variable household vehicles ownership, in the Paris Region (overall effect: $p < 0.001$). An increment of the RRR linked to a higher number of household vehicles, is observed in both years. (1991: RRR=1.2 for one car, 1.5 for two cars and 1.8 for three or more cars; 2001: RRR=1.5 for one car, 2.1 for two cars and 2.8 for three or more cars).

3.2.3. Household level: Ranking of explanatory variables of vehicle ownership

A log-likelihood test is applied in order to obtain the ranking or order of importance of explanatory variables for vehicles ownership at household level.

Juarez shows the same results in 1996 and 2006 (Table 3.27). Household's monthly income is the most influential factor for explaining the number of private vehicles. The second explanatory factor is the number of adults at household and lastly the location of the household.

The overall results of Puebla for the years 1994 and 2011 are shown in the Table 3.28 below. Household's monthly income is the most influential factor for explaining the number of private vehicles in 2011. The second explanatory factor is the number of rooms, which is the most important determinant in 1994 (household's income, not being known in 1994, the models are not comparable, as well as in Lille, year 1987). The household type follows the number of rooms in both years. The variable "adults

at household” is the last explanatory factor in both years. The location of the household is only significant in 2011, being in the fourth position of importance.

The overall results of Lille for the years 1987, 1998 and 2006 are shown in the Table 3.29. Adults at household is one of the most influential factors for explaining the number of private vehicles in all years with the first or second position. The residential status follows the variable adults at household each year, being at the second or third position. Household’s monthly income is the most significant factor in 1998, although in 2006 it fell to the fourth position. Household income is not available in 1987, therefore models are not comparable. Moreover, the variable zone gains importance, from being the second last determinant in 1987 and 1998, to occupy the 3rd place in 2006. As for the variable type of household, it is the last explanatory factor in all years.

The overall results of the Paris Region for the years 1991 and 2001 are shown in the Table 3.30. The variable “adults at household” is one of the most influential factors for explaining the number of private vehicles in both years with the first or second position. Zone follows the variable adults at household in each year, occupying the second or third position. Household’s monthly income is the most significant factor in 1991, although in 2001 it fell to the fourth position, just after the household surface. Then follow in order of importance the variables zone, status and type of household. In 1991 after the variable zone, follow in importance the type of household, the household surface and the status at household.

Table 3.27. Ranking of explanatory variables for household vehicle ownership in "Juarez"

1996	2006
Income	Income
Adults at household	Adults at household
Zone	Zone

Table 3.28. Ranking of explanatory variables for household vehicle ownership in "Puebla"

1994 *	2011
Total number of rooms	Income
Type of household	Total number of rooms
Adults at Household	Type of household
	Zone
	Adults at household

* Household’s income not known in 1994: models are not comparable.

Table 3.29. Ranking of explanatory variables for household vehicle ownership in "Lille"

1987 *	1998	2006
Adults at household	Income	Adults at household
Status of household	Adults at household	Status of household
Zone	Status of household	Zone
Type of household	Zone	Income
	Type of household	Type of household

* Household's income not known in 1987: model not comparable.

Table 3.30. Ranking of explanatory variables for household vehicle ownership in the "Paris Region", 1991 and 2001.

1991	2001
Income/hh	Adults at household
Adults at household	Zone
Zone	Household area
Type of household	Income/hh
Household area	Status of household
Status of household	Type of household

The main result is, when data are available on income at two points in time for the same city, this factor, which was dominant in the 90's, has lost importance in the 2000's. The erosion of the income factor and the strengthening of the geographical factor for explaining the number of vehicles in the household was observed also at a national level in France [25].

3.2.4 Mobility at individual level: Data description and methodology

The dependent variables of interest are:

- trip made in private vehicle as a driver (VD_trips);
- trip made in private vehicle as a passenger (VP_trips);
- trip made in public transport (PT_trips) and
- "all modes" trip which includes all transportation modes recorded in the survey such as bicycle and walking (Total_trips)

They were coded 0 when the interviewed person did not make any trip on each category and 1 when the person did in fact make at least one trip using one of the transportation mode mentioned above. Multiple logistic regression analyses using a stepwise form were performed to jointly examine the possible influence of the potential explanatory variables on the fact of having made at least one trip on a specific mode category mentioned before. The overall p-value for the categorical variables needed to be <0.05 to be selected in the model.

The potential predictor variables included in the models were:

- residential zone (center, inner and outer suburbs),
- motorization, with 0, 1, 2 or >2 vehicle ownership (vehicle/hh),
- 9 categories for age,
- gender (Male, Female),
- family role (e.g. Head of household, Son/daughter),
- activity (e.g. Retired, full time student),
- profession (e.g. Industry, bank/finance),
- income brackets per person and/or at household level when monthly salaries were included in the surveys (i.e. in terms of minimum monthly wage in the case of Juarez) ; if income is available at household level the variables is income_hh and income_per at individual level ;
- level of education (e.g. Highschool, elementary school),
- possession of driving license and/or of transport card if available (Yes/No).

A likelihood ratio method was used for testing the overall association between the independent variables included in the final model and the dependent variables relative to trips (logistic regression $Y=0/1$).

These Multiple Logistic Regression analyses are important to identify the profile of people who chose a particular transport mode and how this profile is evolving over time. Moreover, it was necessary to deepen the study of the relationship between factors that influence the mode choice, not only in terms of trip frequency, but also in terms of travel distance, which may vary compared to trip models listed above. For this, additional models were created in order to test explanatory variables of kilometers traveled by transport mode. More specifically, Multiple Linear Regression analyses were used to assess the association between each one of the four dependent continuous variables and the potential explanatory variables mentioned above. Dependent variables for multiple linear regressions are: travel distance (kilometers) in Private Vehicle as Driver (PVD_km), Private Vehicle as Passenger (PVP_km), in Public Transport (PT_km) and total number of traveled kilometers (Total_km which includes all modes of transportation such as bicycle and walking). The best subsets of variables were chosen from a stepwise selection procedure, judged by the p-value (<0.05 to be included in the model selection). F-test was used for testing the significance of each categorical predictor in the final models for each one of the dependent variables relative to distance travelled.

An evaluation of multicollinearity among the independent variables was also implemented for each model –number of trips and distance travelled-.

Each analysis at household and individual levels was performed for all case studies in France and Mexico using all available surveys in order to compare the evolution of results.

3.2.5 Mobility at individual level: Results

The results of the stepwise multiple logistic regression for the variables Vehicle Driver (VD_trips) and Vehicle Passenger (VP_trips), in Juarez (1996); for the variable VP_trips, in Puebla (1994); for the variables VP_trips and Public transport (PT_trips), in Lille (1987) and for the variables Total trips in the Paris Region (1991) and VD_trips and PV_trips (2001), showed that the full model, with all the available independent variables together, is statistically significant (Annexes 2 to 5).

The variable zone is no significant for VD trips in Juarez (2006) and Puebla (2011); for VP_trips in Puebla (2011) and Lille (1998); for PT_trips in Juarez (2006); and for All Modes (Total_trips) in Juarez (both years) and Lille (1998).

The variable gender is no significant for VD_trips in Puebla (both years), Lille (all years) and the Paris Region (1991); for PT_trips in Juarez and Puebla (both years), in Lille (1998, 2006) and in the Paris Region (2001); and for Total_trips in Juarez (both years), Puebla (2011) and Lille (all years).

The variable income is no significant for VD_trips in Puebla (2011) (not available in 1994) and Lille (2006) and for VP_trips in Juarez (2006).

The variable family role is no significant for VP_trips in Juarez (2006), and for PT_trips in Juarez (2006), Lille (1998, 2006) and the Paris Region (1991, 2006).

The variable car ownership is no significant for Total_trips in Juarez (2006), Puebla (2011), Lille (all years) and the Paris Region (2001).

The variable activity is no significant for VD_trips in Juarez (both years) and for VP_trips and PT_trips in Lille (1998 and 2006).

The variable profession is no significant for VD_trips and PT_trips in Lille (both years); for VP_trips in Juarez (both years) and Lille (2006); and for Total trips in Lille (1998).

The variable education is no significant for VD_trips and PT_trips in Lille (2006) and for VP_trips in Lille (1998, 2006) and in the Paris Region (1991).

The variable driver license is no significant for Total_trips in Puebla (both years). In 2011 the variable age is no longer significant for VD_trips and neither driving license, for VP_trips, in comparison with the year 1994.

The variable transport card is no significant for VP_trips in Lille (both years).

Multicollinearity was tested after each regression. The results of the analysis showed that some data violate the no multicollinearity assumption. Since the tolerance of each variable must be greater than 0.1, and the variance inflation factor (VIF), lower than 10 [135], when two variables were collinear, the one with the strongest overall p-value was retained in the model. Table 3.31 shows the variables per model not included due to collinearity.

Table 3.31. Variables not included due to collinearity

Case study	Year	Mode	Variable
Juarez	1996	PT_trips	Activity
Juarez	2006	PT_trips	Income/per
Puebla	1994	PVP_km	Education
Lille	1987	All regression (trips, km)	Education
Lille	1998, 2006	PVD_km	Education
Lille	2006	Total_km	Profession
Paris Region	2001	All regressions (trips)	Income/hh
Paris Region	1991, 2001	PT_km	Education

After correction of multicollinearity, the tolerance value of each independent variable was greater than 0.18 which exceeded the suggested criteria of below 0.1 and the VIF values of the variables ranged from 1.23 to 7.65.

Risk analysis of making at least one trip in private vehicle as a driver (Annex 2) is as follows:

- In Juarez (1996), people living in inner suburbs have a higher risk of making at least one VD trip than those living in the center. People who live in outer suburbs are in an intermediate position between the two preceding categories. In Puebla, people living in outer suburbs have a lower risk of making at least one VD trip than those living in the center in 1994, without a significant difference with the inner suburbs category with respect to the center. The variable zone is not significant in 2006 for Juarez and 2011 for Puebla. As for Lille, in 1987 and 1998 the highest risk of making at least one VD trip is for those living in inner suburbs, then outer suburbs, with respect to living in the center. In Lille 2006 and in the Paris Region (both years), a rising risk is found, those living in outer suburbs showing the highest risk.
- The risk of making at least one VD trip in Juarez, Lille and the Paris Region (all years) increases with the number of vehicles in the household. More there are cars at home, more the risk is elevated. In Puebla, the risk is higher when there is one or more vehicle(s) at household in both years (1994, 2011) but with no progressive increment in multi-motorized households.
- Having a driving license increases the risk of making at least one PV trip as a driver in Puebla, Lille and the Paris Region for each year, with a much greater impact in 1994 (Puebla), 1998 (Lille) and 2001 (Paris Region). Additionally in Lille (1998 and 2006) and the Paris Region (2001), being in a supervised driving training also increases the risk of making at least one PV trip as a driver.
- On the other side, having a transport card decreases the risk of making at least one VD trip in Lille (1998, 2006) and the Paris Region (both years). In Lille a lower risk is observed for those who have a free subscription, and in the Paris Region, the lowest risk is for those with a solidarity card (1991) and for those with a regular paid card (2001).
- In Juarez, being aged 18 to 23 years or 44 years and older decreases the risk of making at least one VD trip compared to the reference age bracket which is the individuals from 34 to 43 years old. In 1996 and 2006, the risk is the lowest

among those aged 64 and older. There is no significant difference with respect to the reference bracket for people aged 24 to 33 years in both years. On the contrary, in Puebla being aged 24 to 33 years or 74 years and older decreases the risk of making at least one VD trip compared to the same reference age bracket. In 2011 the variable is no significant. As in Lille (in 1987 and 1998) and the Paris Region (in both years) the risk decreases for people aged 44 years or older. In Lille (2006), besides this range, it also decreases for people aged 24 to 33 years. For each year the lowest risk is for those aged 74 years or older.

- In Juarez being a woman reduces the risk for making at least one VD trip as a driver compared to being a man in 1996 and 2006. The coefficient is weaker in 2006, showing more and more similarity of behavior according to gender. The variable is no significant in Puebla, Lille and the Paris Region (all years).
- Being a wife/husband, daughter/son or other type of relation, decreases the risk of making at least one VD trip in relation to being the head of household in Juarez (1996), Puebla (1994), Lille (1987, 1998 and 2006) and the Paris Region (1991 and 2001). Besides, in Juarez (1996) being the housemaid or a guest decreases the risk of making at least one VD trip and in 2006, only being a daughter/son, other relative or other non relative, decreases that risk. In Puebla (2011), being the mother, daughter/son or other non-relative decreases that risk in relation to being the father. Furthermore in the Paris Region, a housemaid (in 1991) and other non relative (in both years), have a lower risk of making at least one VD trip in relation to the reference person.
- In Puebla, unemployed, stay-at-home housewives and retired people have a lower risk of making at least one VD trip than active workers in 1994 and 2011. In the same year, being a full time student decreases that risk too. Concerning Lille, unemployed, young students (up to high-school), stay-at-home housewives or other have a lower risk of making at least one VD trip in each year as well as those in an internship training (2006), retired people (1998) and students (2006), in relation to those who work full time. In contrast, people in internship have a higher risk in 1998. As for the Paris Region, students, unemployed, retired or other inactive people have also a lower risk compared to active workers in both years. The variable was no significant in Juarez (both years).

- In Juarez, in relation to a person who is currently not working, retired people and people with a freelance profession or other services, have a higher risk of making at least one VD trip in 1996. In 2006, a retired person has the highest risk of making at least one VD trip, followed by people with a freelance profession and people with a profession of trade/commerce. In Lille, the variable is only significant in 1987, where the fact of being at school increases greatly the risk of making at least one VD trip.
- In Puebla, in relation to a person who has no education, people with high-school or higher education have more than twice the risk of making at least one VD trip in 2011, the variable being no significant in 1994. Concerning Lille, in 1998, those who are currently studying have a higher risk of making at least one VD trip. The variable is no significant in 2006. As for the Paris Region, those with secondary or higher school, and those still at school have also a higher risk compared to those without education.
- In Juarez, the risk of making at least one VD trip increases with income in 1996, from the second category (2 minimum salaries). In 2006, only earning 7 to 8 minimum salaries increases the risk. In Lille, only in 1998 earning from 30000F to <60000F (second category) increases the risk compare to those with an income inferior to 30000F. The variable is no longer significant in 2006 (data no available in 1987). As for the Paris Region, the variable was no significant in 1991, and in 2001 only the first income bracket (< 4,573 €) was significant. People belonging to this bracket have a lower risk of making at least one VD trip compared to those with no income. The variable is no significant in Puebla (2011; data on income are no available in 1994)

Risk analysis of making at least one trip in private vehicle as a passenger (Annex 3) is as follows:

- In Juarez, people living in inner suburbs have a higher risk of making at least one VP trip than those living in the center in 1996, with no significant difference with people living in outer suburbs. In contrast, in 2006 people living in outer suburbs have a lower risk of making a VP trip compared to those living in the center as well as Puebla, concerning the year 1994, with no significant difference with people living in inner suburbs. In 2011 the variable is not significant. Regarding Lille, while in 1987 the risk of making at least one

VP trip increases the farther a person lived from the center, in 1998 the variable is no significant, and in 2006 only the category of outer suburbs is significant, with a higher risk for those who live in that area compared to the center. As for the Paris Region, the risk of making at least one VP trip increases the farther a person lived from the center in both years.

- People with one or more vehicles at household have a higher risk of making at least one VP trip in Juarez (1996 and 2006), Puebla (1994 and 2011), Lille (1987, 1998 and 2006) and the Paris Region (1991 and 2001), with a gradual rise of risk in 2011 for Puebla and in 2001 for the Paris Region.
- In Lille and the Paris Region, the risk of making at least one VP trip as a passenger decreases if the person has a driving license in all years. Conversely, in Puebla having a driving license increases slightly the risk in 1994, becoming no significant in 2011.
- On the other side, having a regular or a student transport card decreases the risk of making at least one VP trip in the Paris Region in 1991 and 2001 respectively.
- In Juarez, be aged 5 to 33 years and 54 to 63 years increases the risk of making at least one VP trip compared to people aged 34 to 43 years in 1996. In 2006 being aged 24 to 33 also increases that risk. The higher risk is for children aged 5 to 17 years old in both years. In Puebla, be also aged 5 to 17 years increases the risk of making at least one VP trip compared to people aged 34 to 43 in both years. Furthermore, be aged 24 to 33 decreases that risk in 1994, and be aged 18 to 23 increases the risk in 2011. As for Lille, be aged 5 to 33 years, increases the risk of making at least one VP trip compared to the same reference age bracket in 1987 (besides the range 64 to 73 years) and 1998. In 2006, the risk increases if the person is between 5 and 23 years old. Regarding the Paris Region, the risk increases in the age brackets 5 to 33 and 64 to 73 years in 1991, and in 2001 the risk is higher in every category compared to the reference bracket 34 to 43 years.
- Being a woman increases the risk of making at least one car trip as a passenger compared to being a man in Juarez, Puebla, Lille and the Paris Region in all years.

- Being a daughter or son increases the risk of making at least one VP trip in relation to being the head of household, followed by being a wife or husband in Juarez (1996) and Puebla (1994). The family role variable is not significant in 2006 for Juarez. In Puebla (2011) being the mother or “other type of relationship” increases the risk of making at least one VP trip compared to the father. In Lille (1987, 1998 and 2006) and in the Paris Region (both years), only being the spouse increases the risk of making at least one VP trip in relation to being the reference person (head of the household). Additionally in the Paris Region, other type of relative has a lower risk.
- In Juarez, students have a higher risk of making at least one VP trip than active workers in both years. In Puebla, stay-at-home housewives have a lower risk also in both years. Additionally, in 2011, being unemployed decreases the risk of making at least one VP trip, and in 1994, being in the military service increases five times the risk. Regarding Lille, unemployed, retired and stay-at-home housewives have a lower risk of making at least one VP trip than full time workers only in 1987, the variable being no significant in 1998 and 2006. In the Paris Region unemployed and retired people have a higher risk of making at least one VP trip than active workers in 1991 and 2001 respectively.
- In Lille (1987) while a person in the working class category has a higher risk of making at least one VP trip, in relation to a person who is currently not working or inactive, a person in the category of small-medium business has a lower risk. In 1998, employees and people in the working class category have a higher risk as well. The variable is no significant in Puebla (2006) and Juarez (both years).
- In relation to a person who has no education, people with incomplete elementary school or technical school have higher risk of making at least one VP trip in Puebla (1994), followed by people with higher education. In 2011 only people with high-school have a lower risk of making at least one VP trip compared to people with no education. In the Paris Region, people with elementary or secondary school, or being still at school have a higher risk of making at least one VP trip in 2001. The variable was no significant in 1991.

- Belonging to the first three categories of income (1 to 4 minimum salaries) increases the risk of making at least one VP trip compared to individuals with no income in Juarez (1996). The variable is no significant in 2006. In Puebla, belonging to the three highest categories of monthly income (\$5001 to \$8000 Mexican pesos) increases the risk of making at least one VP trip compared to people belonging to the first category (\$0 to \$2500 Mexican pesos) (2011; data no available in 1994). In Lille, people with an income within the ranges 4 to 10 in 1998 (90000F to 600000F or more) and 3 to 6 in 2006 (30000€ to 60000€ or more), have a higher risk of making at least one VP trip compared to individuals with an income inferior to 30 000F in 1998 and 10 000€ in 2006.

Risk analysis of making at least one trip in Public Transport (Annex 4) is as follows:

- In Juarez (1996), Lille (1987, 1998 and 2006) and the Paris Region (1991 and 2001), people living in inner and outer suburbs have a lower risk of making at least one PT trip than those living in the center. The variable is no significant in 2006 for Juarez. In Puebla, people living in inner suburbs have a higher risk of making at least one PT trip than those living in the center in 1994 and 2011. However, in 1994, people living in outer suburbs have a lower risk with respect to people living in the center.
- People with one or more vehicles at household have a lower risk of making at least one PT trip in Juarez, Puebla, Lille and the Paris Region in all years. In other words, the risk of making a PT trip decreases with a higher number of private motorized vehicles.
- Having a driver license decreases the risk of making at least one PT trip in Puebla, Lille and the Paris Region (all years). In contrast, being in a supervised driving training increases the risk in Lille (1998 and 2006).
- On the other side, having a transport card increases the risk of making at least one PT trip in Lille for both years (1998, 2006). In the Paris Region having a regular, a solidarity card or other type of transport card increases the risk of making at least one PT trip in 1991, and in 2001 having a student transport card also increases the risk.

- In Juarez (1996) and the Paris Region (both years), be aged 5 to 10 years or 74 and older decreases the risk of making at least one PT trip compared to people aged 34 to 43 years. In contrast, be aged 11 to 23 years, increases that risk in Juarez in 1996. In 2006 the risk is lower for children (5 to 10 years old) and higher for people aged 18 to 23 years. In Puebla, be aged 5 to 23 years or 44 and older decreases the risk of making at least one PT trip compared to people aged 34 to 43 years in 1994. The lowest risk is among children aged 5 to 10 years. In 2006, be aged 5 to 17 years or 74 and older also decreases the risk. In contrast, the risk is increased in the age brackets 18 to 33 and 54 to 63. Concerning Lille, the risk of making at least one PT trip compared to the same reference bracket, is lower for children aged 5 to 10 (all years). The risk is also decreased for those aged 11 to 17 (1987), 64 to 74 or older (1998 and 2006) and 54 to 63 (2006). On the contrary, be aged 18 to 23 years increases the risk of making at least one PT trip (all years).
- Being a woman increases the risk of making at least one PT trip compared to being a man in Lille only in 1987 and in the Paris Region in 1991. The variable is no longer significant in 1998 and 2006 (Lille) and in 2001 (Paris Region), which shows once more a weaker and weaker difference between genders in France. The variable is no significant in Juarez and Puebla (both years).
- Being a wife/husband or mother, a daughter/son or other type of relation increases the risk of making at least one PT trip in relation to being the head of household or the father in Juarez (1996) and Puebla (1994 and 2011). This variable is not significant in 2006 for Juarez. Concerning Lille, the variable is only significant in 1987, where being daughter or son increases the risk of making at least one PT trip in relation to the reference person.
- In Juarez, students (working and full time) have a higher risk of making at least one PT trip than active workers in 2006. In 1996 is no significant. In Puebla, unemployed, stay-at-home housewives, retired people or other have a lower risk of making at least one PT trip in both years. In contrast, students have a higher risk. As for Lille, people with a reduced risk of making at least one PT trip are the stay-at-home housewives (in all years) and retired people (1987). On the contrary, those with a greater risk are students (all years), and part-time workers (in 1998). Regarding the Paris Region, the risk is higher for

students and lower for other inactive people compared to active workers, in both years.

- In Juarez, a person working in the industry sector or belonging to the categories other services or other, have a higher risk of making at least one PT trip in 1996, in relation to a person who is currently not working. In 2006, the risk is much higher for a person working in a bank or in the finance sector, and for people with a profession of trade or commerce. In Lille, the variable is only significant in 1987, being employee who has a higher risk of making at least one PT trip compared to unemployed or inactive people.
- In Puebla, belonging to any category of education, with the exception of “elementary school not completed”, increases the risk of making at least one PT trip compared to individuals with no education in 1994. In 2011, having only kinder garden decreases the risk of making at least one PT trip, but having other type of education increases that risk, with the higher risk for the category of higher education. In Lille, individuals still at school have a higher risk than those with no education in 1998. The variable is no significant in 2006. In the Paris Region, those with higher education have a higher risk than those with no education (both years), and those being still at school have also a higher risk, only in 1991.
- In Juarez, belonging to the first two categories of income (1 and 2 minimum salaries) increases the risk of making at least one PT trip compared to individuals with no income in 1996. In contrast, individuals earning from 7 to 14 minimum salaries, have a lower risk. In Puebla, belonging to the three highest categories of monthly income (\$5001 to \$8000 Mexican pesos) decreases the risk of making at least one PT trip compared to people belonging to the first category (\$0 to \$2500 Mexican pesos) (2011; data no available in 1994). In Lille (1998), people with an income within the ranges 6, 7, 8 and 10 (150000F to <360000F and 600000F or more), have a higher risk compared to people with an income inferior to 30000F. The variable is no longer significant in 2006 (Juarez) and 2011 (Lille). In the Paris Region, people belonging to the five highest ranges of income (150000 Francs or more) have a higher risk compared to the first range (<30000 francs) in 1991.

Risk analysis of making at least one trip (All Modes) (Annex 5) is as follows:

- People living in inner and outer suburbs have a lower risk of making at least one trip regardless the mode of transportation (all modes) than those living in the center in Puebla (1994 and 2011), Lille (2006) and the Paris Region (both years). In Lille in 1987, only the category outer suburbs is significant, with a lower risk compared to the center and in 1998 the variable is not significant.
- People with two vehicles have a higher risk of making at least one trip than those with no cars, in Juarez (1996), Puebla (1994) and the Paris Region (1991). In 2006, the variable is no significant in Juarez. As for Puebla, the variable is no longer significant in 2011.
- Having a driver license increases the risk of making at least one trip in Lille and the Paris Region (all years). The variable is no significant in Puebla (both years).
- Having a transport card (paid subscription) increases the risk of making at least one trip in Lille for both years (1998, 2006), and having a free subscription increases the risk only in 1998. As for the Paris Region, having a transport card (regular or other) increases the risk of making at least one in 1991. In 2001 having a student transport card also increases the risk.
- In Juarez, be aged 11 to 17 years increases the risk of making at least one trip compared to the reference bracket (34 to 43 years) in 1996, and 5 to 10 years increases the risk in 2006. In contrast, be 44 to 74 years and older decreases the risk in both years, as well as in Puebla in 1994. In 2011 individuals aged 11 to 33 years have a higher risk, differently from those aged 54 to 74 and older, who have a lower risk of making at least one trip. Regarding Lille and the Paris Region, be aged 5 to 17 years increases the risk, whereas be aged 54 to 74 years or older, decreases the risk (all years). Moreover, be aged 44 to 53 years decreases the risk in the Paris Region and in Lille (in 1987 and 1998). Also in 1998 be aged 18 to 23 years increases the risk too.
- In Puebla (1994) and the Paris Region (both years), being a woman increases the risk of making at least one trip compared to being a man. The variable is no significant in Puebla (2011).

- Being a daughter or son, other type of relative or a housemaid, decreases the risk of making at least one trip in relation to being the head of household in Juarez (both years) and Puebla (1994). In 2011, being a daughter, son or other person no relative to the family decreases the risk too in relation to being the father. On the contrary, having other type of relationship increases that risk. As for Lille, the risk decreases for the son, daughter or other relatives in every year. Regarding the Paris Region, the children (daughter, son, grandchild or other) and other type of relative have a lower risk of making at least one trip compared to the reference person in both years. Additionally, the spouse and the housemaid have also a lower risk in 1991, and other no relative have a lower risk in 2001.
- Stay-at-home housewives, retired and unemployed people have a lower risk of making at least one trip than active workers in Juarez (1996) and Lille (1987 and 2006). For the year 1998 (Lille), only stay-at-home housewives and unemployed people have a lower risk. Regarding Puebla, for each category of activity but military service and student, the risk of making at least one trip decreases compared to active workers in both years. Conversely, students have a higher risk in Juarez (2006) and Puebla (both years), and part-time workers, in Lille (1998). As for the Paris Region, retired, unemployed or other inactive people have a lower risk of making at least one trip compared to active workers in both years.
- In relation to a person who is currently not working, a person working in the industry sector has a higher risk of making at least one trip in Juarez (1996). In 2006, the risk is three times higher. Similarly, for a retired person the risk is higher than for a person not currently working in 1996, and it is five times higher in 2006. In Lille, employees have a higher risk of making at least one trip compared to an unemployed or inactive person in 1987. The variable is no significant in 1998, but in 2006, employees, technicians and people of the working class category have a higher risk of making at least one trip.
- Belonging to any category of education increases the risk of making at least one trip compared to individuals with no education in Puebla (1994 and 2011) and Lille (1998), with the exception of those who are still at school. The greatest risk is for individuals with technical education in 1994, for those with higher school in 2011 (Puebla), and for people with high-school in Lille. In the

Paris Region those with elementary, secondary or higher school, or those still at school have a higher risk of making at least one trip in 1991. In 2001 only those with higher education have a higher risk compared to those with no education. In contrast, people with elementary education or being still at school, have a lower risk of making at least one trip in Lille (2006).

- In Juarez, belonging to the first four categories of income (1 to 6 minimum salaries) increases the risk of making at least one trip compared to individuals with no income in 1996. In 2006, individuals earning 3 to 4 minimum salaries and 7 to 8 minimum salaries, have also a higher risk. In Puebla, people belonging to any category of income (\$2501 to \$10000 or more Mexican pesos), have a lower risk of making at least one trip “all modes” compare to people with the first income category (\$0 to \$2500) (2011; data no available in 1994). As for Lille, belonging to the income ranges 3 to 9 (60000F to <60000F), increases the risk of making at least one trip compared to individuals with an income inferior to 30000F (1998).

Linear regression analyses were performed for each travel outcome variable of interest relative to the number of kilometers travelled by mode.

Regression analysis of travel distance (kilometers) in private vehicle as a driver (Annex 6) is as follows:

- The number of kilometers in private vehicle (being a driver) is higher in inner and outer suburbs compared to the center in Juarez (both years), Puebla (1994), Lille (all years) and the Paris Region (both years). The farther the person lives from the center, the greater the number of kilometers. In Puebla (2011), it is higher only in outer suburbs.
- The number of kilometers in PVD is higher when the person has one or more vehicles at household in Juarez, Puebla, Lille and the Paris Region (all years).
- The fact of having a driving license also makes higher the number of kilometers in PVD in Puebla, Lille and the Paris Region (all years).
- Having a transport card (paid subscription) makes the number of kilometers in PVD higher in Lille (1998 and 2006) and the Paris Region (1991 and 2001).

Additionally in this city, having a solidarity transport card (in 1991), a student transport card (in 2001) or other type of transport card (in both years) makes the number of kilometers in PVD higher.

- Be aged 18 to 33 years, and 44 to 74 or older makes lower the number of kilometers traveled in Juarez (both years) and Lille (1998). The effect is stronger for people aged 64 and older. In Lille (1987 and 2006) and the Paris Region (1991 and 2001) be aged 44 to 74 or older makes lower the number of kilometers. Additionally in the Paris Region, the number of kilometers traveled in PVD is lower in the age bracket 18 to 23 years in both years. In Puebla, be aged 24 to 33 years makes lower the number of kilometers traveled, in 1994. The variable is no significant in 2011.
- Women travel fewer distances as a driver in Juarez (1996). In 2006 gender is no longer significant for being a driver, suggesting an equality or convergence trend between males and females. In the Paris Region women travel also fewer distances, in both years. However, the effect is stronger in 1991, with a bigger difference between men and women than in 2001. The variable is no significant in Puebla (both years) and Lille (all years).
- In Juarez, the number of kilometers is lower if the member of the family is the wife or husband, compared to the Head of Household, followed by the housemaid who has the strongest effect in 1996. In 2006 it is lower if the member of the family is the wife, husband, son or daughter, with a major effect for other relatives or non relatives. In Puebla (1994) and the Paris Region (2001), the number of kilometers is lower compared to the Head of Household, excluding being the housemaid, which isn't significant. It is also lower with any family member in Puebla (2006), in Lille (all years) and the Paris Region (1991), compared to the reference person.
- In Juarez, stay-at-home housewives, unemployed and full time students travel fewer kilometers than active workers in 1996, and working students travel more kilometers, in 2006. In Puebla, full time students and retired people travel fewer kilometers than active workers in 2011. The variable is no significant in 1994. Regarding Lille, part-time workers, unemployed, retired, stay-at-home wives or other, make lower the number of kilometers traveled as a driver in PV in all years. Additionally, being at school makes lower the

kilometers in 1987 and 2006. In this same year, students and individuals in an internship decrease the kilometers too. As for the Paris Region, belonging to any category of activity makes lower the number of kilometers in PVD, having a greater effect the retired or other inactive people in both years.

- In Juarez, in relation to a person who is currently not working, retired people travel more kilometers in 1996 but also in 2006, where people working in a bank or in the finance sector travel also more kilometers. Concerning Lille, farmers and people with a small-medium business travel less kilometers in 1987, whereas those with a free lance profession or technicians, travel more kilometers (1987 and 2006). In 1998, having a small-medium business, a free lance profession or technicians increases the number of kilometers.
- In Puebla, people with high school or higher education travel more kilometers than those with no education at all, in 1994. In 2006, people with higher school, travel more too. As for the Paris Region, people with secondary or higher education travel more kilometers than those with no education, in 1991. In 2001, only those with higher education travel more kilometers. The variable is no significant in Lille.
- In Juarez, people belonging to the five last highest categories of income (5 to 14 salaries) travel more kilometers than those with no salary, in 1996. In 2006, people earning 7 to 10 salaries and 13 to 14 salaries, travel more. In Lille, people with an income belonging to the categories 8 and 9 in 1998, and the categories 3 and 6 in 2006, make higher the number of kilometers traveled (data no available in 1987). As for the Paris Region, belonging to the 4th or 6th income range (in 1991) or the 7th range (in 2001) make higher the number of kilometers traveled in PVD. The variable is no significant in Puebla (2011; data no available in 1994).

Regression analysis of travel distance (kilometers) in private vehicle as a passenger (Annex 7) is as follows:

- The number of kilometers in private vehicle (being a passenger) is higher in inner and outer suburbs compared to the center in Juarez (1996) and Lille (1998 and 2006). In contrast, the kilometers are significantly higher only in

outer suburbs in Juarez (2006), Lille (1987), Puebla (both years) and the Paris Region (both years).

- The number of kilometers in PVP is higher when the person belongs to a household with one or more vehicles in Juarez, Lille and the Paris Region (in all years) and in Puebla (1994). In Puebla (2011) only people with one or two vehicles in the household make higher the number of kilometers in PVP.
- In Puebla, having a driving license makes slightly higher the number of kilometers in PV as a passenger in 1994. However, in 2011 the fact of having a driving license makes it lower, as well as in Lille and the Paris Region (all years). On the contrary, being in a supervised driving training makes lower the number of kilometers in PVP in the Paris Region in 2001.
- Having a transport card makes slightly higher the number of kilometers in PVP in Lille (1998; data no available in 1987). As for the Paris Region, having a regular paid transport card make the number of kilometers in PVP lower in 1991. The variable is no significant in Lille (2006) and the Paris Region (2001).
- In Juarez (1996), Lille (all years) and the Paris Region (2001), be aged 5 to 33 years, makes higher the number of traveled distance as a passenger. Besides this, in Lille (1987) the traveled distance is also higher for those aged 64 to 73 years, and in the Paris Region (2001) it is also higher for those aged 54 to 63 years. In the Paris Region (1991), be aged 18 to 23 or 64 to 73 years, makes higher the number of kilometers in PVP. In Puebla, be aged 5 to 17 years, makes it higher, in 1994. The variable is no significant in 2006 (Juarez) and 2011 (Puebla). In the three cities, the major effect is in the category 5 to 10 years.
- In Juarez, Puebla, Lille and the Paris Region (all years), women travel longer distances as passengers than men.
- The number of kilometers as passenger is lower if the member of the family is the housemaid in Juarez, but it is higher if it is the wife, husband or the mother, compared to the reference person in Juarez (1996) and Lille (all years). The variable is no significant in 2006 (Juarez) and Puebla (both years). As for the Paris Region, the spouse travels longer distances than the reference person

in both years. Additionally in 2001, other non relatives travel longer distances too.

- In Juarez, students travel more kilometers as passengers than active workers in both years. In Puebla, housemaids and unemployed people travel less kilometers as passengers than active workers in 2011. The variable is no significant in 1994. In Lille, stay-at-home housewives and students travel fewer kilometers than full-time workers in 1987. The variable is no longer significant in 1998 and 2006. As for the Paris Region, while the variable was no significant in 1991, it is in 2001, being the retired people who travel longer distances than active workers.
- In Juarez, in relation to a person who is currently not working, retired people travel more kilometers as passengers in 2006. The variable is no significant in 1996. In Lille young students (up to high-school) travel less kilometers than unemployed or inactive people in 1998. The variable is no longer significant in 2006.
- In relation to a person who has no education, individuals with high-school, teacher training or higher education travel more kilometers as passengers in Puebla in 1994. In the Paris Region, those with secondary education travel more kilometers than those with no education in 2001. In 1991 the variable was no significant. The variable education is no significant in Lille (1998 and 2006).
- In Juarez, people earning 1 to 4 salaries travel more kilometers as passenger than those with no salary, in 1996. In 2006, people earning 5 to 10 salaries travel more. In Lille, people with an income within the ranges 4, 5 and 8 (1998) and 3, 5 and 6 (2006) travel more kilometers as passengers than those with the first income range. As for the Paris Region, a person belonging to the income ranges 4 to 6, in 1991, travel more kilometers than those belonging to the first income range. In 2001, the variable is no longer significant. In Puebla the variable is no significant (2011; data no available in 1994).

Regression analysis of travel distance (kilometers) in public transport (Annex 8) is as follows:

- The number of kilometers by public transport (PT) is higher in inner and outer suburbs compared to the center in Juarez (2006), Puebla (both years) and the Paris Region (both years). The farther from the center, the number of kilometers increases. In contrast, the number of kilometers is significantly higher only in outer suburbs in Juarez (1996) and Lille (1998 and 2006; no significant in 1987).
- In Juarez (both years), Puebla (both years) and Lille (1987 and 2006), the number of kilometers in PT is lower when there is one or more vehicles at the household, meaning that more number of vehicles in the household is linked to fewer kilometers in Public Transport. In Lille (1998) and the Paris Region (1991) the kilometers traveled by PT are lower only for multi-car households (≥ 2 cars). The variable is no longer significant in the Paris Region in 2001.
- In Puebla and Lille, having a driving license makes lower the number of kilometers in PT, with a larger effect in 1994 and 1998 respectively. In contrast, if the person is under a supervised driving program, the number of kilometers in PT is higher in Lille (1998 and 2006).
- Having a transport card (regular, solidarity or other type) makes higher the number of kilometers in PT in the Paris Region in both years. Besides, in 2001, having a student transport card Lille makes it higher too.
- In Juarez, be aged 5 to 10 years, makes lower the traveled distance in PT, in both years. Additionally, in 2006, the kilometers are lower in the age bracket of 64 to 74 or older. On the contrary, the kilometers are higher in the age brackets of 18 to 23 (both years), and 44 to 53 years (1996). In Puebla, be aged 5 to 23 years or 44 and older, makes lower the traveled distance in PT, in 1994, with a major effect in children aged 5 to 10 years. In 2011 be aged 5 to 17 years, makes lower the PT kilometers as well, with a strong effect. On the contrary, be aged 24 to 33 increases traveled distance in PT. Regarding Lille, the number of kilometers is lower with the age brackets of 5 to 17, in 1987, and 5 to 17 and 64 to 74 or older, in 1998 and 2006. As for the Paris Region, be aged 5 to 17

years makes the number of kilometers in PT lower in both years, and in 1991, be aged 74 or older makes it lower too.

- Gender is no statistically significant in Juarez (both years), Puebla (both years) and Lille (1987 and 1998). However, in Lille (2006) and the Paris Region (both years), being a woman makes lower the number of kilometers in PT.
- In Juarez, the number of PT kilometers is higher if the member of the family is “other type of relative”, in 1996. The variable is no significant in 2006. The number of PT kilometers is higher if the member of the family is the son or daughter in Lille (1987 and 2006) and Puebla (1996). In contrast, in 2011(Puebla) it is lower if the member is other type of relative. The variable is no significant in 1998 in Lille. As for the Paris Region (both years), the variable is no significant.
- In Juarez (1996), Puebla (2011) and Lille (1987 and 2006), stay-at-home housewives, unemployed and retired people travel fewer kilometers by PT than active workers. Unemployed and stay-at-home housewives; unemployed, retired people and those in military service; and stay-at-home housewives, make lower the travel distances respectively in Juarez (2006), Puebla (1994) and Lille (1998). In contrast, a stay-at-home housewife makes higher the number of kilometers traveled by PT in Puebla (1994). Furthermore, working students travel more kilometers in Juarez (2006), and in Lille, part-time workers and students travel more kilometers than full-time workers, in 1987 and 1998/2006 respectively. As for the Paris Region, unemployed and other inactive people make lower the number of kilometers in PT than active workers, in 1991. In 2001, retired or other inactive people make it lower. In contrast, students make it higher, in 2001.
- In relation to a person who is currently not working, people in the industry sector travel more kilometers in Juarez (1996). In 2006, the people working in a bank or finance sector, in commerce or retired people, are the ones who travel more by PT. In Lille, students and employees, and young students traveled more kilometers in 1987 and 1998 respectively. The variable is no significant in 2006.

- In Puebla, the number of kilometers increases in relation to a person who has no education or incomplete elementary school. A stronger effect is found for individual with high-school followed by those with technical education (5 years), in 1994. In 2011, people belonging to the last three categories of education travel more kilometers than those with no education with a major effect for individuals with higher education. In the Paris Region, the variable education was no included because of multicollinearity.
- People earning 1 or 2 salaries travel more kilometers in Public Transport than those with no salary, in Juarez in 1996. On the contrary, people earning 7 to 14 salaries, travel fewer kilometers by Public Transport. In 2006, people earning at least one salary, travel fewer kilometers than those with no salary, with the stronger effects from 11 to 14 salaries. In Lille (1998) people belonging to the income ranges 2 to 8 travel more kilometers than those belonging to the first range, being those earning from 180000F to <240000F who travel more kilometers in PT. The variable was no longer significant in 2001. The variable is no significant in Puebla (2011; data no available in 1994).

Regression analysis of “All modes” travel distance kilometers (Annex 9) is as follows:

- The number of kilometers traveled is higher in inner and outer suburbs compared to the center in Juarez, Puebla, Lille and the Paris Region in all years, with a major effect in 2006 (Juarez), 1994 (Puebla) and 2006 (Lille).
- In Juarez, people with three or more cars in their household travel longer distances in 1996. In 2006, people with two or more vehicles in their household, travel more than those with no car. In Puebla (1994), Lille (all years) and the Paris Region (both years), people with one or more cars in their household travel longer distances than those with no vehicles. The variable is no significant in Puebla (2011).
- The fact of having a driving license makes higher the number of total kilometers in Puebla, Lille and the Paris Region in all years. (Variable not available in Juarez).

- Having a transport card (regular, solidarity or other type) makes higher the number of total kilometers (all modes of transport) in the Paris Region in both years. Besides, in 2001, having a student transport card in Lille makes it higher too. The major effect is for those with a regular paid transport card.
- In Juarez and the Paris Region, people aged 5 to 17 years and 44 to 74 or older travel less kilometers than people aged 34 to 43 years. Those aged 5 to 10 years, and 64 to 74 or older travel the fewest number of kilometers in Juarez, and those aged 5 to 10, in the Paris Region. Besides, in 2001 (Paris Region) those aged 18 to 23 years also travel less kilometers. In Puebla, people aged 5 to 33 years or 54 to 74 or older travel fewer kilometers, being those aged 5 to 10 years who do the fewest number of kilometers in 1994. In 2011 individuals aged 5 to 17 years or 74 or older travel fewer kilometers as well. However, people aged 24 to 33, traveled more kilometers than those aged 34 to 43 years. As for Lille, the age brackets that have a lower number of total kilometers are: 5 to 10 and 44 to 74 or older in 1987 and 1998, and 5 to 17 and 54 to 74 or older in 2006. In 1987, be aged 18 to 23 increase the number of total kilometers with respect to those aged 34 to 43 years.
- Gender is not statistically significant in Juarez (both years), Puebla (both years) and Lille (1987), although in 1998 and 2006, and in the Paris Region (both years), being a woman makes lower the number of total kilometers.
- In Juarez, Puebla and the Paris Region, the number of total kilometers is lower in each category of the family member (excluding other type of relationship for Puebla in both years and stay-at-home housewife for the Paris Region in 2001) in relation to the reference person, being the stay-at-home housewife who makes lowest the number of kilometers travelled. In Lille, being the wife or husband makes lower the number of total kilometers in all years, and being the son or daughter, in 1987 and 1998.
- Stay-at-home house wives, unemployed and retired people or other travel less than active workers, in Juarez (1996), Puebla (both years) and Lille (all years). Additionally in Lille, part-time workers make lower the number of total kilometers in 1998 and 2006 (besides young students in the last year). On the other side, working students travel far more kilometers in Juarez (2006), and in Puebla (1994), students also travel longer distances. As for the Paris Region,

belonging to any category of activity makes lower the number of total kilometers, in both years compared to active workers.

- In relation to a person who is currently not working, retired people and people in the industry sector travel more kilometers in Juarez (1996). In 2006, people working in a bank or in the finance sector have the strongest effect, traveling more than people in commerce or a freelance profession or other. In Lille, people with small-medium business decrease the total number of kilometers, while employees, technicians and people with a freelance profession make higher the total number of kilometers in 1987. In 1998, those with a freelance profession or a small-medium business also make higher the total number of kilometers. The variable is no significant in 2006.
- In Puebla, people belonging to the seven highest categories of education (in 1994) or the three highest categories (in 2011), travel more kilometers than those with no education, being the individuals with 5 years-technical school (1994) and higher education (2011) who travel more. Regarding Lille, people belonging to the two highest categories (high school and higher education) in 1998, and those with higher education in 2006, travel more kilometers than those with no education. In the Paris Region, having secondary or higher education makes higher the number of total kilometers, in both years.
- In Juarez, people earning 2 to 6 salaries travel more kilometers than those with no salary, in 1996. In 2006, people earning 5 to 6 salaries travel more too. In Puebla earning from \$2501 to \$8000 Mexican pesos travel less kilometers than those with an income of \$0 to \$2500 Mexican pesos (2011; data no available in 1994). Regarding Lille, belonging to the fourth or the three highest income ranges (in 1998) or the four highest income ranges (in 2006), increases the total number of traveled kilometers. As for the Paris Region, people earning from 60000F to 180000F travel more kilometers than those earning less than 30000F, in 1991. In 2001, only belonging to the 7th range (30490 to <36588) travel more than those with no income.

3.2.6 Mobility at individual level: Ranking of explanatory variables of travel behavior

The explanatory variables included in the models are listed in separate tables (3.32 to 3.35) for each one of the cities. Variables are sorted in order of importance in the explanation of each independent variable (according to F-statistics for the significance of the variables in the model).

Table 3.32. Ranking of explanatory variables of travel behavior at an individual level "Juarez"

TRIPS IN:	1996	2006	KILOMETERS IN:	1996	2006
Private Vehicle Driver	Vehicles/hh Family role Age Income Gender Profession Zone	Vehicles/hh Family role Age Income Gender Profession	Private Vehicle Driver	Vehicles/hh Family role Income Zone Age Gender Profession Activity	Vehicles/hh Income Profession Age Family role Activity Zone
Private Vehicle Passenger	Vehicles/hh Age Activity Income Family role Gender Zone	Vehicles/hh Activity Gender Age Zone	Private Vehicle Passenger	Vehicles/hh Zone Activity Age Gender Family role Income	Vehicles/hh Gender Activity Profession Income Zone
Public Transport	Vehicles/hh Age Income Profession Family role Zone	Vehicles /hh Age Activity Profession	Public Transport	Vehicles/hh Income Age Profession Zone Family role Activity	Vehicles/hh Age Activity Income Profession Zone
All modes	Age Family role Profession Income Activity Vehicles/hh	Activity Age Profession Family role Income	All modes	Zone Age Vehicles/hh Family role Activity Profession Income /per	Profession Age Zone Activity Family role Vehicles/hh Income/per

Findings of Juarez from present Chapter (Table 3.32) show that the determinants of Private Vehicle Driver at an individual level are quite stable, the availability of a vehicle in the household being the strongest predictor for making at least one trip and traveling more kilometers in a motorized vehicle as a driver. Then followed, in order of importance, by family role, age, income, gender and profession for both

years, in terms of making at least one trip. The influence of the variable related to urban form “zone” is in fact weak compared to other variables. Actually, in 1996 the zone of residence was the last statistically significant factor for making at least one trip as a Driver, while in 2006 the same variable is not longer statistically significant. The same shifts happens in terms of traveled kilometers, for the urban form factor, having the 4th ranking in 1996 and down to the 7th position in 2006. This results regarding zone was in fact expected since Juarez has a very strong inclination towards private vehicle ownership and use, and general analysis from first section show that vehicle use is not a behavior linked to a specific geographic area. Moreover, “Income” and “age” factors gain importance in 2006 compared to 1996 for traveling kilometers as a Driver. Like many trends around the world concerning gender differences in transportation, “gender” factor is no longer statistically significant in 2006 meaning that, statistically speaking there is no difference (in 2006) between being a male or a female for traveling the same distance as a driver. Thus, travel behaviors by gender for vehicle driver mode tend to converge in Juarez.

Private Vehicle Passenger is also determined by the number of vehicles in the household in both years. Age as an explanatory factor loses strength for both, making at least one trip as passenger and travelling more kilometers as a passenger in a private vehicle. In fact in 2006 for travel distance, age is no longer statistically significant. Family role is statistically significant in 1996 for trips and kilometers while in 2006 it is not longer an explanatory factor for making at least one trip and kilometers travelled as a passenger in 2006. The profession of the individual gained importance on explaining vehicle passenger mode; in terms of making at least one trip the shift was from rank 8th to the 4th. In addition, in terms of number of kilometers, in 1996 the profession was not statistically significant, while in 2006 it has the 4th rank for explaining kilometers travelled as passenger. As for the zone variable, the greatest shift was the downward trend of its importance in the vehicle passenger distance model in 2006.

In the case of Public Transport, the results show that vehicle ownership (negative related) at the household is also the primary determinant and age is the second most important in most cases. The most important shifts were the trend of the variable family role, which is no longer significant in 2006 for both trips and kilometers, and zone of residence, which is not significant for the trip model in 2006 having less impact in the distance model in the most recent survey. Lastly, income and profession, are both significant for explaining Public Transport mode, but tend to be less important over time.

In the case of “All modes”, age is a primary determinant for trip and kilometers models. Vehicle ownership and income are no longer significant for the trip and kilometer models respectively. Profession and activity are predominant factors and gained importance in both models. Indeed, what emerges from the National Transport Surveys in France [25] is an attenuation of the role of income and a strengthening of the geographical factor.

Table 3.33. Ranking of explanatory variables of travel behavior at individual level “Puebla”

TRIPS IN:	1994	2011	KILOMETERS IN:	1994	2011
Private Vehicle Driver	Dr. license Vehicles/hh Education Family role Age Activity Zone	Vehicles/hh Dr. license Family role Activity Education	Private Vehicle Driver	Dr. license Vehicles/hh Education Family role Zone Age	Dr. license Vehicles/hh Education Family role Zone Activity
Private Vehicle Passenger	Vehicles/hh Age Family role Zone Dr. license Education Gender Activity	Vehicles/hh Income/hh Age Education Family role Gender Activity	Private Vehicle Passenger	Vehicles/hh Age Dr. license Gender Zone	Vehicles/hh Income/hh Zone Gender Activity Education Dr. license
Public Transport	Activity Age Dr. license Vehicles/hh Zone Education Family role	Age Vehicles/hh Activity Education Dr. license Income/hh Family role Zone	Public Transport	Activity Zone Age Education Dr. license Vehicles/hh Family role	Age Zone Activity Vehicles/hh Dr. license Education Family role
All modes	Activity Zone Age Family role Education Vehicles/hh Gender	Activity Education Family role Age Zone Income/hh	All modes	Zone Activity Education Age Vehicles/hh Dr. license Family role	Zone Age Activity Education Family role Income/hh Dr. license

Findings of Puebla show that the determinants of Private Vehicle Driver at an individual level are quite stable, being the availability of a vehicle in the household and having a driving license the strongest predictors for making at least one trip and traveling more kilometers in a motorized vehicle as a driver. The influence of the variable related to urban form “zone” and “age” are weak compared to other

variables. In fact, in 1994 the zone of residence is the last statistically significant factor for making at least one trip as a Driver and age has the 5th position, while in 2011 the same variables are not longer statistically significant. In terms of number of kilometers a similar pattern is observed, zone being almost in last position and age only being significant in 1994. The variables “activity” and “family role” factors gain importance in 2011 compared to 1994 for traveling at least one trip as a driver. As for kilometers travelled, “family role” preserves the same position, whereas “activity”, being no significant in 1994, it is in 2011.

Private Vehicle Passenger is also determined by the number of vehicles in the household in both years. Driving license as an explanatory factor loses strength for both, making at least one trip as passenger, being no longer statistically significant in 2011, and travel more kilometers as a passenger in a private vehicle. Activity and education gain importance. While they aren't statistically significant in 1994 for travel distances, in 2011 they occupy the fifth and sixth position of importance. For its part, the variable zone, is not longer an explanatory factor for making at least one trip as a passenger in 2011. Age loses strength in both models, trips and kilometers. As for the variable zone regarding kilometers, it gains importance.

In the case of Public Transport, the results show age and activity as the primary determinant for both, trips and kilometers. Vehicle ownership (negative related) at the household and driving license are the next variables more important concerning the fact of making at least one trip. Regarding the number of kilometers, the variable zone occupied the second position of importance, whereas regarding the trips it occupies the 5th position in 1994 to become the last significant variable in 2011. Lastly, the variable education gains importance regarding the trips, while it loses position regarding the kilometers travelled.

In the case of “All modes”, activity is a primary determinant for trips and zone, for kilometers model. Gender and vehicle ownership are no longer significant in 2011 for trips and kilometers models respectively. Family role gained importance in both models. While age loses strength concerning trips, it gains strength concerning kilometers. On the contrary, education gains strength concerning trips, and loses it, concerning kilometers. As for household income, the variable was no significant in 1994, but it is in 2011 for both models, trips and kilometers. Conversely, the variable vehicles at household is no longer significant in 2011 for both models. Driving license also loses strength concerning kilometers travelled.

Table 3.34. Ranking of explanatory variables of travel behavior at individual level “Lille”

TRIPS IN:	1987	1998	2006	KM IN:	1987	1998	2006
Private Vehicle Driver	Dr. license Vehicles/hh Family role Age Activity Profession Zone	Dr. license Vehicles/hh Family role TC Activity Zone Income/hh Age Education	Dr. license Vehicles/hh TC Family role Activity Age Zone	Private Vehicle Driver	Vehicles/hh Dr. license Family role Zone Profession Activity Age	Vehicles/hh Dr. license Family role Zone Activity Age Profession TC Income/hh	Dr. license Vehicles/hh Zone Activity Family role Profession TC Age Income/hh
Private Vehicle Passenger	Vehicles/hh Family role Dr. license Age Profession Activity Gender Zone	Age Dr. license Vehicles/hh Family role Gender Income/hh Profession	Dr. license Age Vehicles/hh Gender Income/hh Family role Zone	Private Vehicle Passenger	Zone Vehicles/hh Family role Dr. license Activity Age Gender Profession	Age Zone Dr. license Vehicles/hh Family role Income/hh Profession Gender TC	Dr. license Zone Vehicles/hh Gender Age Income/hh Family role
Public Transport	Age Vehicles/hh Activity Dr. license Profession Zone Family role Gender	TC Age Dr. license Vehicles/hh Zone Income/hh Education	TC Age Vehicles/hh Dr. license Activity Zone	Public Transport	Family role Vehicles/hh Dr. license Activity Age Profession	TC Age Dr. license Zone Activity Profession Vehicles/hh	TC Age Activity Dr. license Vehicles/hh Gender Family role Zone
All modes	Activity Age Dr. license Profession Family role Zone	Age Activity TC Dr. license Family role Education Income/hh	Age Activity Dr. license Education Family role TC Profession Zone	All modes	Zone Activity Dr. license Vehicles/hh Age Profession Family role	Zone Vehicles/hh Age Activity TC Dr. license Income/hh Education Profession Family role Gender	Zone Activity Age Vehicles/hh Income/hh Dr. license Education TC Gender Family role

* TC: Public Transport Card

Findings of Lille for the determinants of Private Vehicle Driver at an individual level show that the household number of vehicles and having a driving license are the strongest predictors for making at least one trip and traveling more kilometers in a motorized vehicle as a driver. Family role is another important variable for explaining PVD trips, occupying the 3rd or 4th position. Regarding the kilometers it occupies the 3th position in 1987 and 1998, losing strength in 2006 (5th position).

Education and income are no longer significant in 2006 regarding trips, and occupying the last positions in 1998, along with age. Profession is only significant in 1987 regarding trips, just before zone, which is the last explanatory variable in these years, as in 2006. Regarding the kilometers mode, zone occupies the 4th position in 1987 and 1998, while in 2006, it occupies the 3rd one.

In the case of Private Vehicle Passenger, results show that the variable driving license gains importance, becoming the main predictor in trips and kilometers models in 2006. On the contrary, the variable family role becomes gradually less important in both models. Age gains importance in 1998, being the principal explanatory variable in both models, but it loses strength in 2006. Gender gradually gains importance with respect to trips, and regarding kilometers, it passes from the second last position, to the 4th one. Finally, the variable zone is the last important variable for trips. However, it is one of the most important determinants in traveled distance.

In the case of Public Transport, the variable transport card (TC) is the primary determinant for both, trips and kilometers in 1998 and 2006. In 1987, age and family role are the first explanatory variables for trips and kilometers, respectively. Household vehicle ownership (negative related), age and driving license are the next variables more important concerning trips. The variables profession, family role and gender are no longer significant in 1998 and 2006. Activity becomes no significant in 1998, but it is significant in 2006 (the second last position). As for the variable zone, it occupies the 3rd last position in 1987 and 1998, becoming the last explanatory variable in 2006. Regarding the number of kilometers, the variable age gains importance occupying the second position in 1998 and 2006. Profession becomes no significant in 2006. On the contrary, gender is only significant in 2006. Zone loses strength becoming the last determinant in 2006. As for the variables activity and vehicles at household, they lose strength in 1998, ascending two positions in 2006.

In the case of "All modes", age and activity are the primary determinants for trips, whereas zone is the most important determinant for kilometers model. Regarding trips, profession and zone are the last explanatory variables in 2006, being no significant in 1998. Education gains importance, from being no significant in 1987 to occupy the 4th position in 2006. Gender and age gain importance regarding kilometers. Family role is the last or second last explanatory variable regarding kilometers, while in trips, it occupies the 5th position each year. The variable income/hh is only significant in 1998 for trips model, and for kilometers model, it

gains importance. The variable driving license remains quite stable concerning trips model, but it loses strength concerning kilometers model. The variable transport card loses strength in both models. As for the variables activity and vehicles/hh, they also remain quite stable, with a slight change in 1998.

Table 3.35. Ranking of explanatory variables of travel behavior at individual level "Paris Region"

TRIPS IN:	1991	2001	KM IN:	1991	2001
Private Vehicle Driver	Driving license Vehicles/hh Transport card Family role Zone Activity Age Education Income	Driving license Vehicles/hh Transport card Family role Zone Activity Age	Private Vehicle Driver	Transport card Vehicles/hh Zone Family role Activity Dr. license Age Gender Education Income/hh	Transport card Vehicles/hh Zone Family role Activity Dr. license Education Age Gender Income/hh
Private Vehicle Passenger	Age Vehicles/hh Driving license Family role Zone Gender Income/hh Transport card Activity	Vehicles/hh Age Driving license Family role Zone Gender Transport card Activity Education	Private Vehicle Passenger	Zone Age Family role Dr. license Vehicles/hh Gender Transport card Income/hh	Zone Family role Vehicles/hh Age Dr. license Gender Activity Education
Public Transport	Transport card Age Vehicles/hh Zone Education Activity Driving license Income/hh Gender	Transport card Zone Vehicles/hh Age Education Driving license Activity	Public Transport	Transport card Zone Age Gender Income/hh Vehicles/hh Dr. license Activity	Transport card Zone Age Activity Gender Dr. license
All modes	Age Family role Transport card Activity Income/hh Driving license Gender Zone Vehicles/hh Education	Age Family role Transport card Activity Zone Driving license Education Gender	All modes	Zone Transport card Age Vehicles/hh Activity Family role Dr. license Gender Education Income/hh	Zone Transport card Vehicles/hh Activity Age Family role Dr. license Gender Education Income/hh

Findings of the Paris Region show that the determinants of Private Vehicle Driver at an individual level are considerably uniform. Having a driving license is the strongest predictor for making at least one trip, and having a transport card is it for traveling more kilometers in a motorized vehicle as a driver in both years. "Vehicles in the household" is the second predictor for both, trips and kilometers. Then transport card, family role, zone, activity and age followed in order of importance, in terms of making at least one trip in both years. The influence of the variables education, income/hh and age is weaker compared to the other variables. In terms of number of kilometers the order of the variables is similar in both years. The most notable changes are those of the variables age, gender and education. While age and gender lose significance, education gains importance.

Trips in Private Vehicle as Passenger is largely determined by the availability of vehicles in the household, age and driving license in both years, while the zone is the most important explanatory factor for kilometers in both years. Education gains importance in terms of making at least one trip in PVP, becoming significant in 2001. In terms of kilometers, the variables age, driving license, transport card and income lose strength, whereas the variables family role, vehicles/hh, activity and education gain significance. Indeed, the variables transport card and income/hh are no longer significant in 2001, and the variables activity and education become significant in 2001.

In the case of Public Transport, the results show that the most important determinant is the variable transport card for both models, trips and kilometers, in both years. Concerning the fact of making at least one trip, the variables age, activity and gender lose strength, and the variables zone and driving license gain importance. In terms of kilometers, the variables income/hh and vehicles/hh are no longer significant in 2001.

In the case of "All modes", age is the primary determinant for trips and zone, for kilometers model. Concerning making at least one trip, the next variables in order of importance are family role, transport card and activity in both years. Vehicles ownership at household is no longer significant in 2001, and gender loses strength. On the other hand, the variable zone gains importance. As for the number of kilometers, age loses importance, whereas vehicles/hh and activity gains significance.

3.3 Chapter Summary

In Juarez, household's monthly income is the most influential factor for explaining the number of private vehicles in both years (1996 and 2006), followed by the number of adults, then the zone of residence. In Puebla, the income of the household, not being known in 1994, the models are not comparable, as well as in Lille, year 1987. Comparing only 1998 and 2006 (Lille), as well as 1991 and 2001 in Paris, the results show that the income, which was dominant in the 90's, has lost importance in the 2000's, and the number of adults take over. Also, household's location becomes more important than income.

French National Transport Surveys have also shown an attenuation of the role of income and a strengthening of the geographical factor for explaining the number of vehicles in the household. According to [25], the factor that explained the most the fact of having at least one car in France was the zone of residence in 1981 and 2007. On the one hand, income and gender of the reference person played less important roles in 2007 compared to 1981. On the other hand, household type and total number of active people in the household increased their impact in the same period. Similarly, the factors that explained the most the fact of having one vehicle instead of two or more was the total number of adults in the household for both years (1981 and 2007). In 2007, the zone of residence and gender of the reference person played more important roles compared to 1981. In contrast, household income, total number of children in the household, age and education level of the reference person decreased their impact.

According to the risk analysis of making at least one trip (in private vehicle as a driver, passenger, or by public transport), at an individual level, results show that income is more important than the zone in private vehicle trips as a driver in Juarez (both years); in private vehicle trips as passenger in Juarez (both years), Puebla (2011) and Lille (1998 and 2006); and in public transport trips in Juarez (1996). In terms of traveled kilometers, income is more important than zone in the following cases: private vehicle as a driver in Juarez (both years); private vehicle as passenger in Juarez (2006) and Puebla (2011); and in public transport in Juarez (both years).

The results of the logistic regression analyses show a convergence male/female in the Paris Region in the case of trips in private vehicle as passenger. However, in Juarez, Puebla and Lille, there is a major difference between the risk of a woman to make at least one trip as passenger and a man in the 2000's compared to the 90's. In Lille, this difference increases progressively over the years (1987, 1998 and 2006). As for the trips by public transport, the variable was no longer significant in the 2000's for all case studies, neither in 1998 in the case of Lille. In terms of trips in private vehicle as a driver, since the variable gender was not significant in the cases of Puebla, Lille and Paris, the variable family role was taken into account. Comparing the head of the household (reference) and the spouse, there is no convergence in Puebla and the Paris Region. As for Lille, the difference between both of them decreases progressively. Regarding the distance traveled, there is convergence of head of the household/spouse in all the case studies with respect to the number of kilometers in private vehicle as a driver. Nevertheless, a convergence male/female is only observed in Puebla and the Paris Region with respect to the number of kilometers in private vehicle as passenger and and for public transport kilometers in the Paris Region.

Chapter 4. AGE-COHORT MOBILITY FORECASTS

Chapter 4: Age-cohort mobility forecasts

Introduction

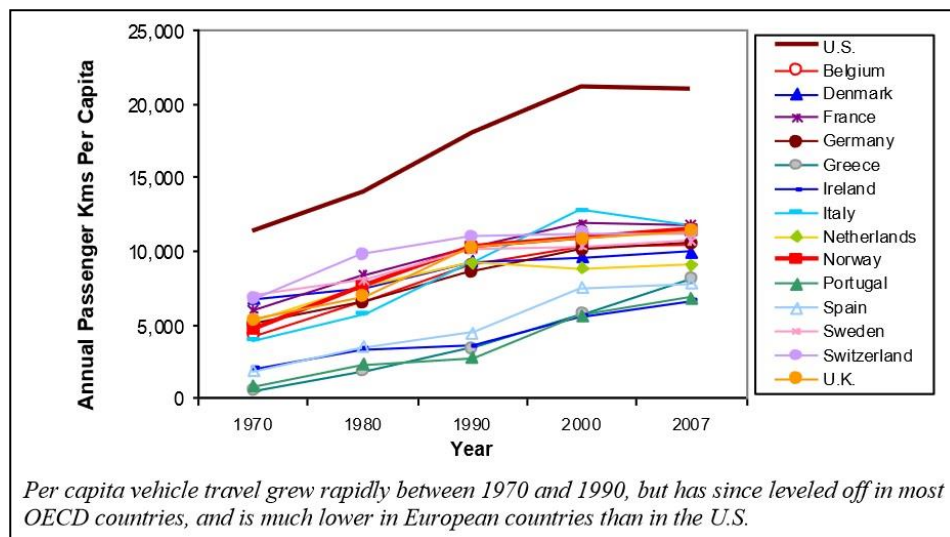
In most developed countries urban mobility and car traffic have stagnated since the early 2000s. In France, various data sources show that the trend can be attributed primarily to people living in large urban areas: trips have become less frequent (with unbroken workdays) and less exclusively taken by car (as more young adults adopt multimodal behaviors), and car ownership is decreasing in the most densely populated areas, then to a lesser extent, in suburbs. Does this levelling-off of traffic suggest that the saturation point is near? Is this a structural phenomenon (population ageing, etc.) or a cyclical one linked to rising and volatile fuel prices and the recession? We shall explore these issues in the light of data collected in the Urban Areas of Lille and Paris; and then move on to a comparison with two Mexican cities, Juarez on the northern border of Mexico where the level of motorization is high compared to Puebla, our second Mexican case study, where motorization is still low. Chapter 1 mentioned the limits of cross-sectional approach for long term forecasting. It is widely known that long-term elasticities cannot be drawn from transversal analysis. Therefore, cross-sectional models cannot identify the dynamics of long-term travel behavior [26, 27, 31, 61, 63-67] [69, 136]. Chapter 2 presented data availability, in particular it showed that the variables included in the surveys were the same or very similar from one year to another, thus enabling comparability between them. This benefits especially the application of the method applied in this chapter. Chapter 3, described the comparison of travel behavior of cohorts interviewed at a given date for each case study showing the differences of travel activity by transportation mode at the same age, thus reflecting the generation effect from one Household Travel Survey to another. This enforces the necessity of a longitudinal approach for long-term travel demand forecasting. In this Chapter each case study will be analyzed under demographic based travel demand long-term projections, taking into account age and cohort effects, decoupling the effects of changes in transport behavior and of population structure, in order to consider the extent to which, and in what time frame, the trends observed in developed cities could occur in the emerging economies. Will peak travel observed in cities from developed countries occur in the developing ones? Case studies from France and Mexico will help to respond to this question.

4.1 Urban travel trends in developed countries

After expanding rapidly in the 1960s and 1970s, growth in road traffic of persons (as a per capita average) slowed in the early 2000s and seemed to approach the saturation point in a number of industrialized countries [21, 22, 137] [138] (Figure 4.1). Data from the Transport Outlook 2013/ITF (Figure 1.7 from Chapter 1), also show that the growth of passenger-kilometres by private car has stopped or even decreased since 2003-2005 in rich countries. The Australian Bureau of Infrastructure, Transport and Regional Economics, which has compiled long time-series for 25 countries, explains this trend as a reflection of fuel prices and economic activity, as well as a time-related saturation effect [139]. A comprehensive analysis of global transport demand trends over the next 40 years was presented by the JTRC/ITF in May 2011 in Leipzig [140]. Having noted an apparent saturation in the developed countries, this working group nonetheless took a critical view of extrapolating demand on the basis of this assumption alone, stressing the need to take account of such other factors as rising fuel prices and the distribution of wealth, as well as the scope of future transport demand trends in the emerging economies. A round table on Peak Travel of the International Transport Forum in November 2012 concluded that while some explanatory factors are fairly well understood, others are more uncertain. In most developed countries, the proportion of people holding driving licenses at any given age had always been on the rise as compared with previous generations, and the increase had been greater for women than for men, thus indicating that their respective behavior patterns were becoming more similar. It has now been found that the license-holding percentage among young people has started to decline in some 10 countries [28], in parallel with the development of the Internet, and that this is especially perceptible in the case of young males; these countries are located in North America (Canada and the USA), where the spread of the automobile began in the 1930s, in the Nordic regions (Norway and Sweden, but not Finland), in western Europe (United Kingdom, France and Germany, but neither Switzerland nor the Netherlands), and in the most densely populated areas of the Far East (Japan and South Korea); the flourishing of car ownership is too recent in Central Europe (Poland, Latvia), and to a lesser extent the Mediterranean countries (Spain, Israel), for such a phenomenon to be observable yet. In France, the decline in the number of license-holders could be attributed to the abolition in 1997 of compulsory military service, which had enabled young men to start driving at virtually no cost to themselves [141].

According to a comparative study of young adults (aged 20 to 29) in six industrialized countries (Germany, United Kingdom, France, Japan, Norway and the United States), between 1975 and 2010, in most countries, the average distance travelled peaked around the end of the 1990s, or at the beginning of the 2000s in the United States, and subsequently declined. Thus, young people are less likely to have a driving license and to travel exclusively by car than youth in the previous generation [142]. There are a number of possible explanations for this phenomenon: the fact that a growing proportion of young people pursue higher education, which postpones their entry into the labor market; the tendency to start a family at a later age; rising fuel prices; the introduction of demand- management measures to reduce car traffic in cities; and lastly, a change in mentalities.

Figure 4.1. International Vehicle Travel Trends



Source: Litman, Todd (2009).

For the United Kingdom [143] observes that over the past 30 years the average travel time has remained stable at about 1 hour per day (375 hours per person per year), as has the average number of trips (1000 trips per person per year). Car ownership has more than doubled, as have the average speeds, which in combination with rising income prompted a substantial increase in distances travelled, until a certain levelling-off as from the mid-1990s. Metz puts forward a number of explanations for the levelling-off of traffic: fewer local trips due to longer absences from home [144], worsening congestion, fewer trips as a result of strides in telecommunications, and structural saturation of the demand for travel. Do the trends being observed reflect the approach of the saturation point via a decoupling of the growth rates for traffic and income? [21]. Is this decoupling manifesting itself first in the most densely populated regions and/or over a certain standard of living? Or does the levelling-off

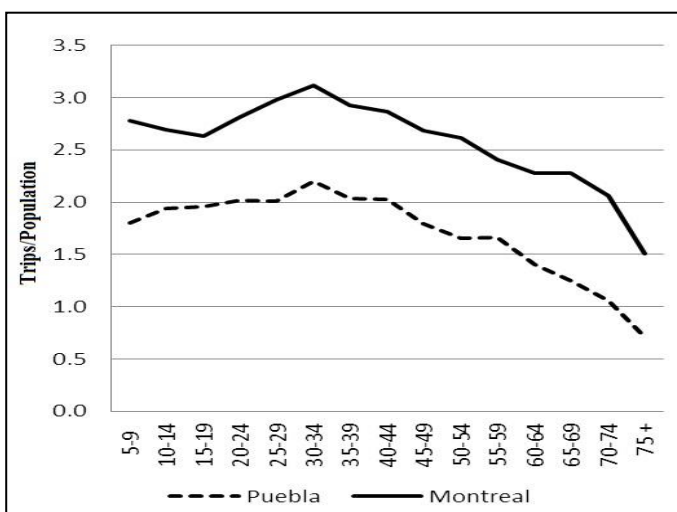
of traffic result rather from a cancelling out of opposite trends (continued growth in rural and suburban areas and decline amongst residents of the most densely populated areas) [145]. Some authors even make the assumption that reduction in travel in the developed world is attributable to a variety of socio-economic factors such as population ageing, rising fuel prices, increasing urbanization, more travel options, increase of environmental concerns and change of consumer preferences [30]. One could well ask whether this is a socio-demographic phenomenon (population ageing, re-densification of large center-city areas, fewer but more-intensive workdays, without returning to home for lunch, etc.) or an economic one linked to rising and volatile fuel prices and the recession [146, 147].

An initial simple approach for measuring the impact on mobility of the shifting age pyramid is to apply constant transport behaviors to population projections with an age pyramid that is changing over the long term. The meaning of ageing here is not so much the presence of elderly people, but the gradual change in the age pyramids, which leads, in the long term to more elderly people, but also, when the age pyramid is young, to more people in the age of driving. Chapter 3 described that the linkages between socio-demographic characteristics and mobility are well established.

For instance, as can be observed in the figures 4.2 and 4.3, general mobility by age is bell-shaped. In Montreal Canada, data of 1993 shows that it peaks at around age 35, and declines regularly thereafter until advanced ages. In Puebla Mexico, a virtually identical curve can be observed but with a lower overall level of mobility. With regard to modal choice, car driver mobility is bell-shaped, peaking in Montreal at about age 40. The form of the curve in Puebla is also similar, peaking somewhat later, at about age 45 albeit at a lower level. Public transport being in direct competition with cars, the observed curve is U-shaped in the case of Montreal and adopts a similar form in the case of Puebla (Figures 4.2, 4.3 and 4.15). The combined result of these trends will inevitably yield high individual private vehicle use in active age groups, translating into vehicle-kilometers such as can be noted in the United States for the period 1995-2001-2009, where a decrease in vehicle kilometers traveled can be seen in youngest drivers, but an increase for the over-65 age groups (Figure 4.4). Bussière & Fortin [148], applied a travel demand forecast on Montreal extrapolating traffic flows based on a straightforward demographic data, which considers mobility for 5 years age groups as constant over time, multiplied by long term population time-series in the future as well as for the past in the form of a retrofit. This projection was made over a 40-year time span (1971-2011) in order to measure the effect of population growth and ageing on mobility through time.

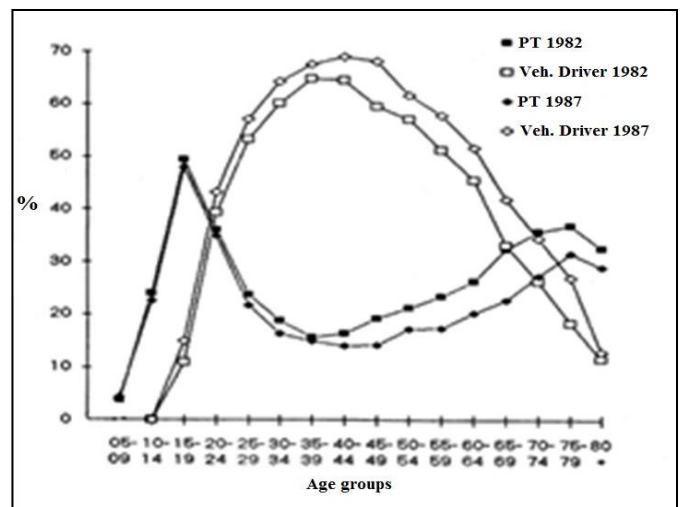
This forecast was based on constant travel behavior observed in the 1982 O-D survey and applying it to demographic projections. In this simulation all other factors are kept constant, namely travel behavior based on 1982 O-D Survey and urban form. They found 25 years ago that peak car and peak travel could be observed at the beginning of the 21st century in this city (Figure 4.5). This simplified model has the advantage of measuring the impact of population growth and ageing on a very long period but the Age-Cohort model gives a more realistic projection taking into account behavioral characteristics of each generation.

Figure 4.3. Daily trips by age, Montreal and Puebla (1994)



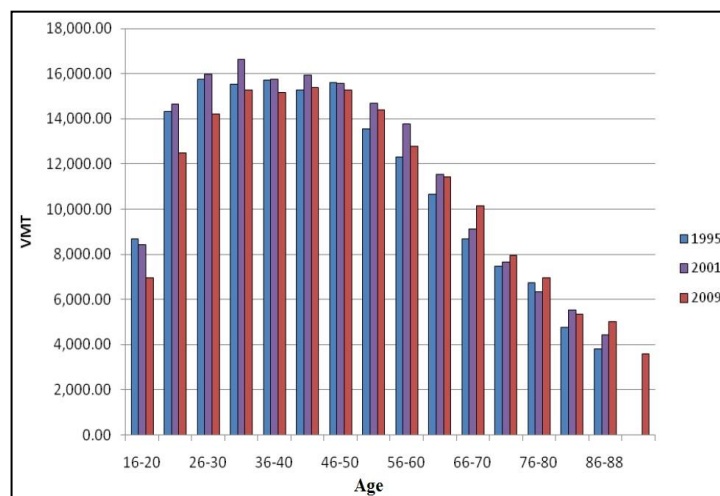
Sources: OD Surveys 1994, [138]

Figure 4.2. Modal share by age, Montreal, 1982 and 1987



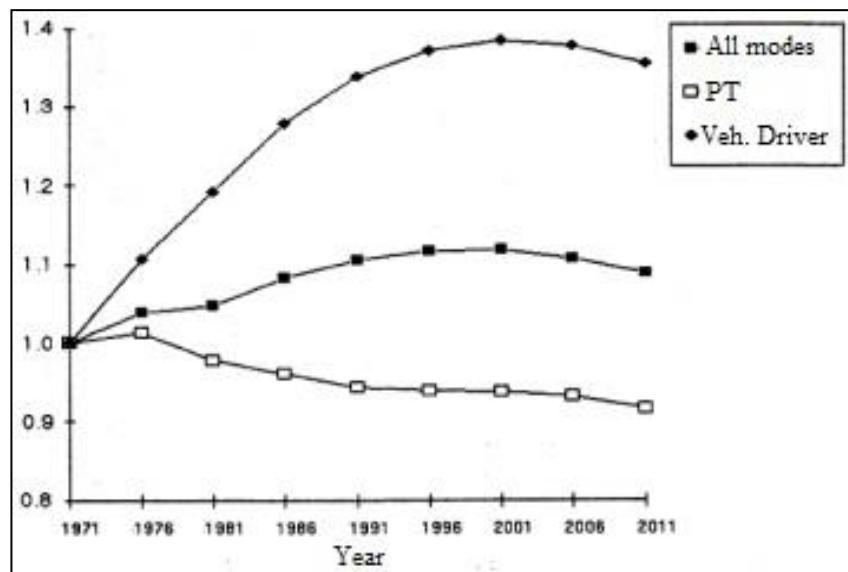
Sources: STCUM OD Surveys 1982 and 1987, [138]

Figure 4.4. Annual vehicle-miles per driver by age USA, 1995, 2001, 2009



Source: OECD/ITF, Transport Outlook (2011) , [149]

Figure 4.5. Transport demand trends measuring population impact (All modes, Public Transport, Vehicle Driver) Montreal 1971-2011 (1971 = 1) - At fixed 1982 behavior



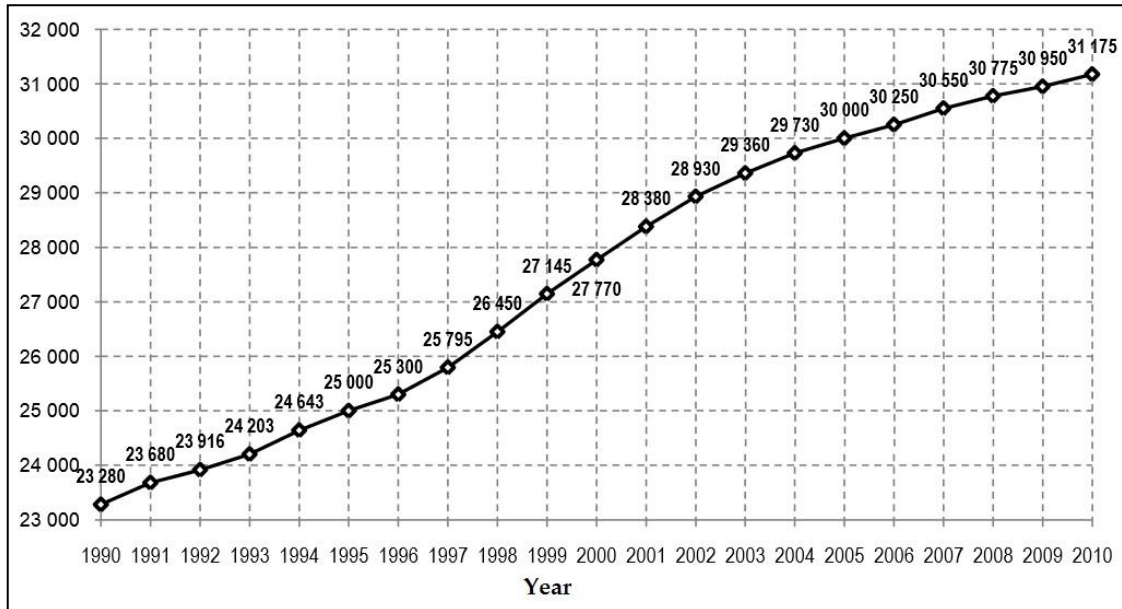
Source: [148]

In the case of Montreal, the baby boom had been very substantial and followed by a sharp drop in birth rates, from the 1970s until the late 1990s there was an exponential increase in pressures towards individual car ownership and a decline in public transport, the period when freeways and urban freeways were built, then, individual car ownership reaches an inflection point in 2001, followed by a decline. This was a similar trend as was observed in the great majority of developed cities. Without prejudice to other factors (population growth, urban contours, access to cars, lifestyle), it can therefore be concluded that the demographic impact on trends in individual car ownership is substantial, and that we are currently witnessing a saturation effect in respect of that impact. According to Bussière [148], ageing would explain 35% of the growth in vehicle travel trends in Montreal and its impact is certainly significant, probably more important in Montreal than in the U.S. due to a higher baby boom.

With respect to travel trends in France, a stabilization of vehicle ownership and vehicle use has been observed exactly at the same time showing signs of peak car. In fact, total vehicle kilometers traveled between 1990 and 2010 grew by 28%. However, this growth is attributable only to the 20th century (Figure 4.7). After 21st century, the vehicle kilometers traveled have remained stable. In France, there has been an ageing of the private vehicles on the road, the average age increased from 6.2 years in 1993 to 8.2 years in 2007, one of the main reasons is the greater number of second vehicles in the household, which are driven less and last for longer [150]. According to recent

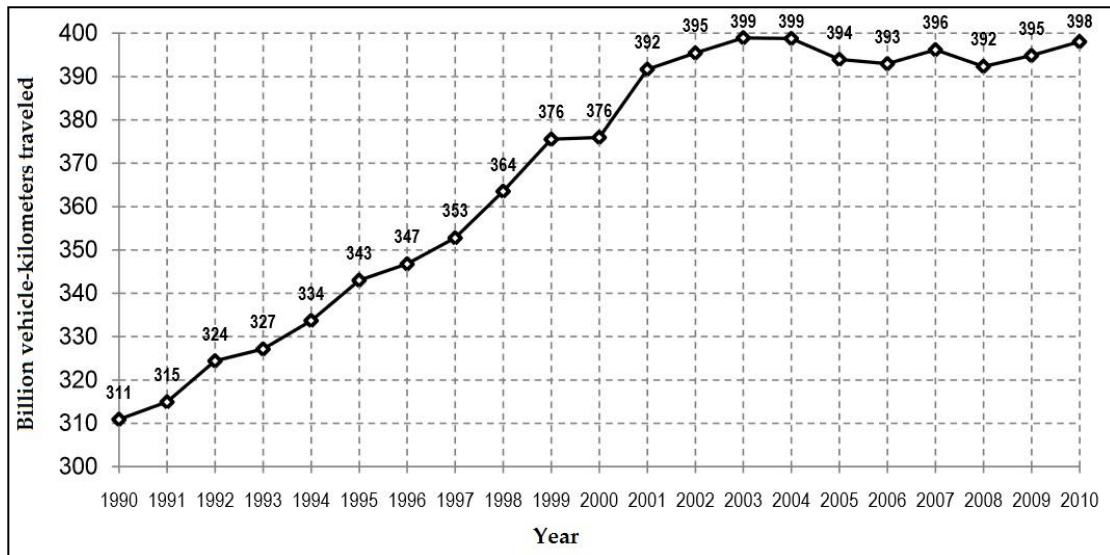
publications from the Mobility Observatory of the Paris Region (OMNIL⁸⁸), the individual travel intensity by car has decreased in 2010 compared to 2001. The only question that remains is whether peak-car is a temporary or permanent phenomenon.

Figure 4.6. Annual number of registered vehicles in France for the period 1990-2010



Source: (CCTN, 2010 and [150])

Figure 4.7. Total Vehicle Kilometers Traveled, France, 1990-2010



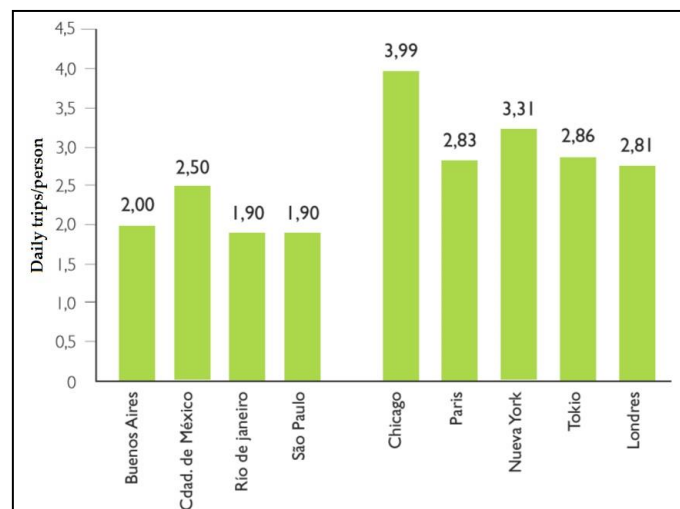
Source: (Traffic assessment CCTN, 2010; and [150])

⁸⁸ <http://www.omnil.fr/>

4.2 Urban travel trends in Mexico

Is Mexico following the peak travel and/or peak car trends observed in the developed world? Figure 8 from Chapter 1 made it clear that developed countries have stabilized the motorization rates in the last decade, while there was still significant growth in all developing regions including Latin America, which had an increase of 1.25 in the same period. On the one hand, motorization rates are higher and tend to stabilize in the developed world. As well as per capita Passenger-Kilometers by private vehicle, which seems to have reached its peak. On the other hand, motorization rates are slower but increasing in developing countries. Travel activity, measured in daily trips per person is in general higher in Metropolitan areas from rich countries. For example 3.99 trips/person in Chicago vs 1.9 trips/person in Sao Paulo in the same year (Figure 4.8). The question now is focused on the evolution of travel intensity in urban region from developing countries. Are travel activity, and vehicle use growing, stabilizing or declining in Latin American cities?

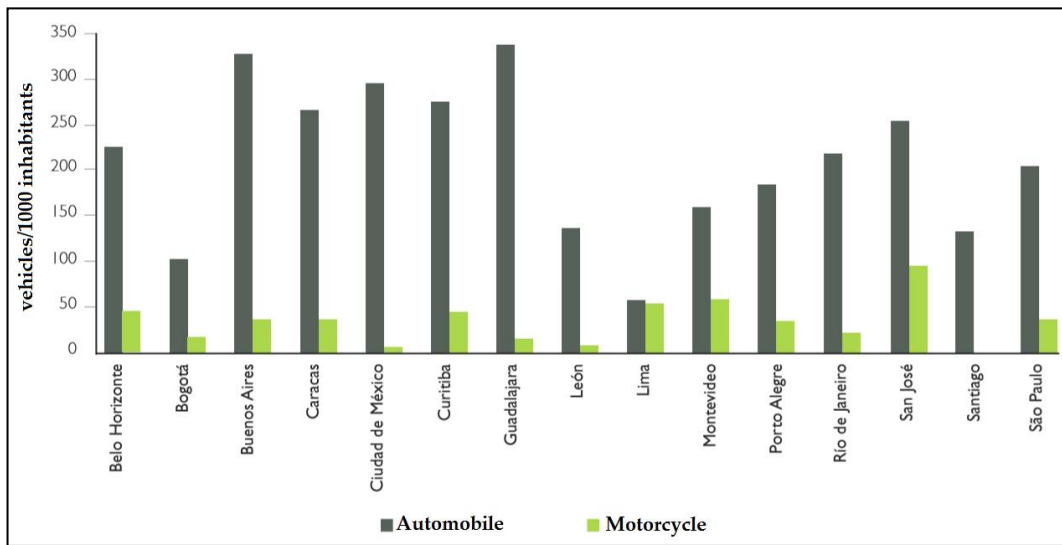
Figure 4.8. Mobility comparison between metropolitan areas from Latinoamerica and developed countries



Source: [151]

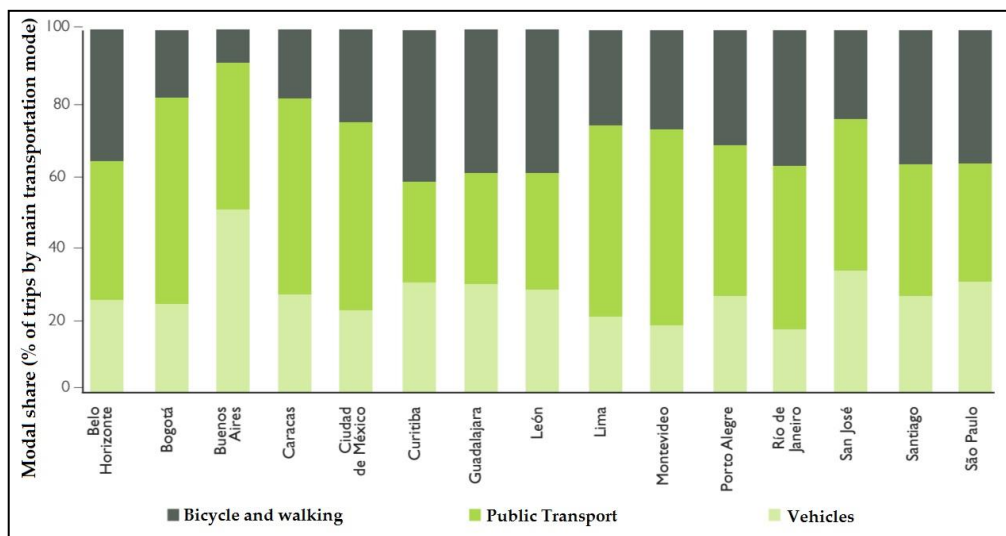
Data collected from Latin American countries by the Development Bank of Latin America [151] shows that motorization rates are higher in Buenos Aires, Mexico City and Guadalajara, and the lowest are in Lima and Bogota (Figure 4.9). The public transport predominates and their share is more than 50% in Bogota, Caracas, Mexico City, Lima and Montevideo. Individual motorized transport is predominant in Buenos Aires. Non-motorized transport is important in Curitiba, Guadalajara, Leon, Santiago and São Paulo. The average mobility of all metropolitan areas is close to two trips per day per capita. The highest rates of public transport use per capita correspond to Mexico City, Santiago and Lima (Figure 4.10).

Figure 4.9. Motorization rate in Latinoamerican cities, automobiles and motorcycles



Source: [151]

Figure 4.10. Modal share in Latinoamerican cities

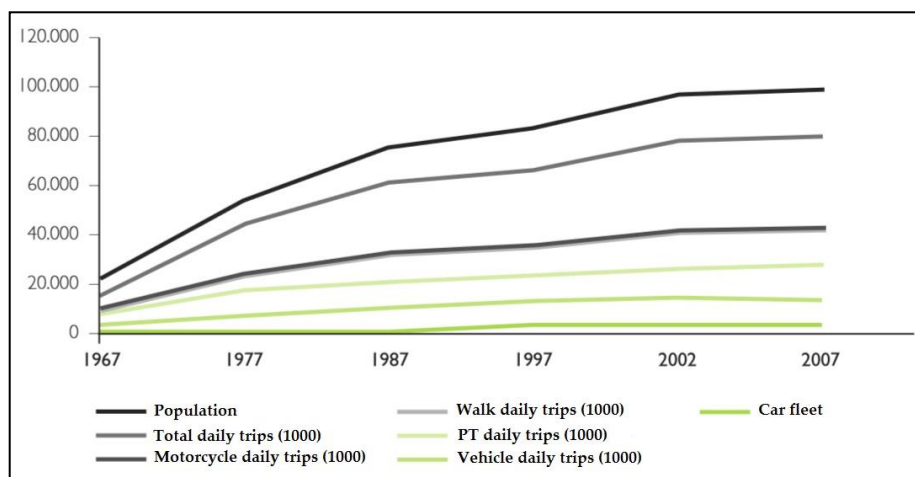


Source: [151]

Analyzing mobility from an evolutionary perspective we have observed that in Buenos Aires Argentina, the percentage of trips made by private vehicle was 15% from a total number of trips of 17.4 million in 1971, rising up to 42% out of 26.3 million trips in 2007. Belo Horizonte in Brazil show also increases in both, total number of trips and share of private vehicle. In 1995, Belo Horizonte reported 5.3 million trips in which 16% were traveled by car. In 2002 the total number of trips increased to 6.3 million and the share of private vehicle was 21.8%. Per capita travel activity in Santiago Metropolitan Region in Chile had increases in both private vehicle and total daily trips. Per capita motorized trips went from .87 in 1977, 1.29 in 1991 and up to 1.75 in 2001. With respect to global mobility, which takes into account

all modes of transportation, the evolution was 1.04 in 1977, 1.69 in 1991 and 2.39 in 2001. All Latin American cities mentioned before experienced increases in travel intensity and vehicle use. However, peak travel could be in fact possible in developing cities. Per capita motorized mobility in Sao Paulo increased by 50% between 1967 and 1977; and reached 1.27 in 2002, rising to 1.30 in 2007. Share of private vehicle in Sao Paulo was 29% in 1977 and 28% in 1987, then increased up to 32% in 1997 and remained stable in 2002 with 32%, then went down again to 27% in 2007. Per capita general mobility (including walking trips) in the same city remains unchanged between 1977 and 1987, and subsequently decreases about 10%, and increase in 2002 and going down to 1.96 in 2007. Observed mobility trends in Sao Paulo show fluctuations in both general mobility and per capita mobility that could be signs that peak travel and/or peak car could in fact occur also in Latin American cities (Figure 4.11). According to the Development Bank of Latin America [151] the main reasons for this stabilization in mobility in Sao Paulo were ageing of the population; the number of elderly increases having an impact on global mobility. In addition, the trading and services sectors increased their share of total employment. These changes are directly related to those in mobility behavior due to the different rates associated with each economic activity. Another reason was that there were new trip attraction facilities distributed in the sub-centers, which allowed the reduction of travel distances between homes and workplaces, replacing in some cases motorized travel by non-motorized modes.

Figure 4.11. Mobility indicators, Sao Paulo, evolution 1967-2007



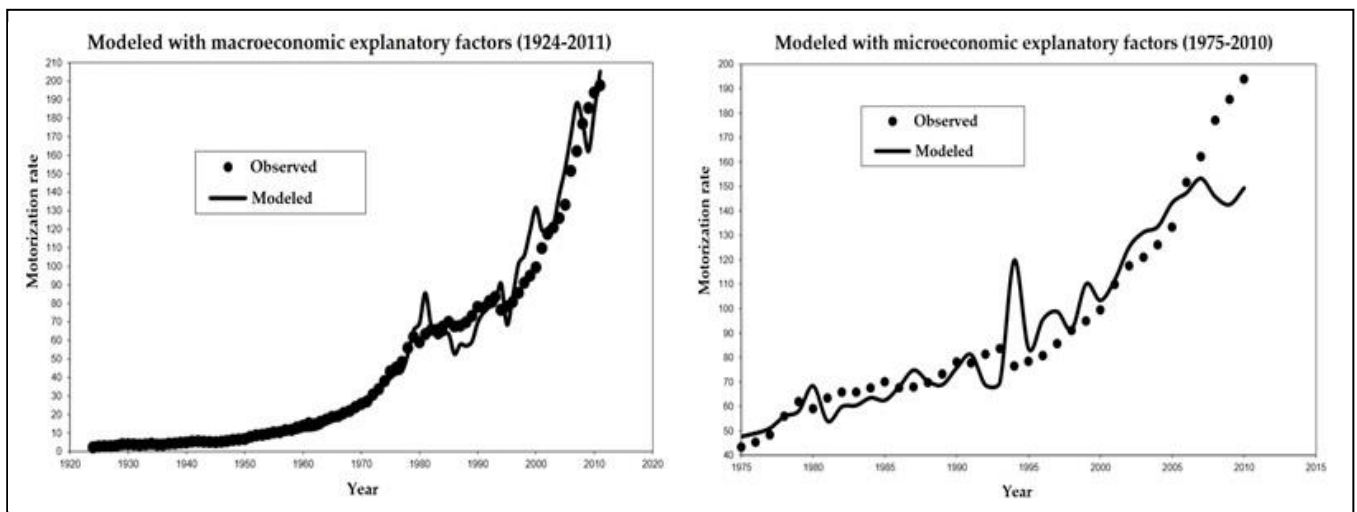
Source: [151]

Aggregated data for Mexico at a national level shows that the motorization rate (vehicles per 1000 inhabitants) has been growing significantly and is far to show signs of stabilization (Figure 4.12) going from 78 in 1991 up to 198 in 2011 [152].

In 2012 the growth of motorization rate in Mexico was 6.32% per year, which was higher than the growth rate of the population (2.41%) [153].

[152] applied a sigmoidal model to vehicular possession in Mexico from 1924 to 2011 (Figure 4.12) finding that if the same trend continues, Mexico is predicted to reach saturation level of 150 million passenger cars in circulation. Regarding the motorization rate, the saturation level predicted by the corresponding model is 856 cars per thousand inhabitants. Both values are in the range of the figures reported for other countries, particularly in developed nations [152], and very close to the U.S. which is estimated to be 852 vehicles per person. Projections published by [153] estimates 500 vehicles per 1000 people would be achieved by the year 2030, which means that there would be still room for the motorization to continue to rise in Mexico.

Figure 4.12. Observed and modeled motorization rates in Mexico, Macroeconomic model (1924-2011), microeconomic model (1975-2010)



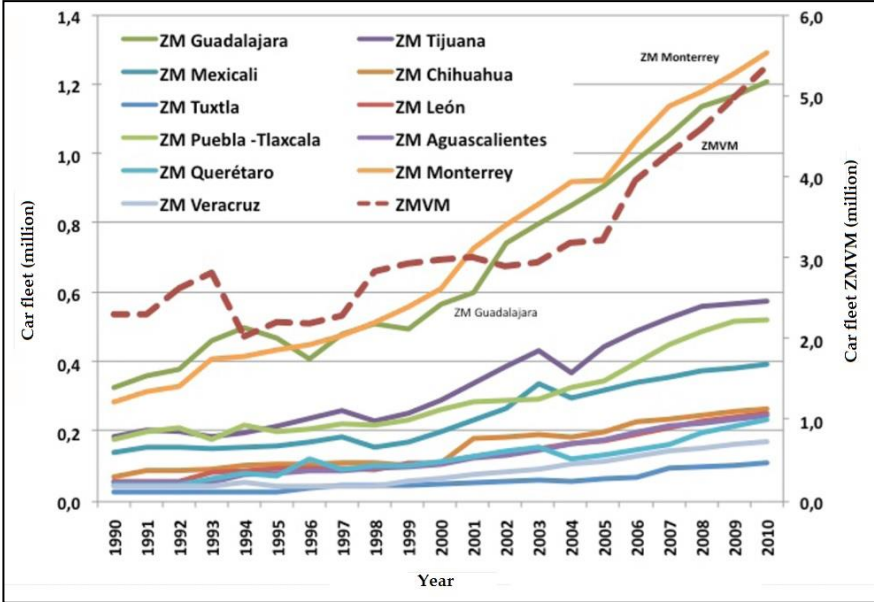
Source: [152]

Levels of car ownership (total vehicle fleet) disaggregated by urban region show great increase trends in all cities (Figure 4.13).

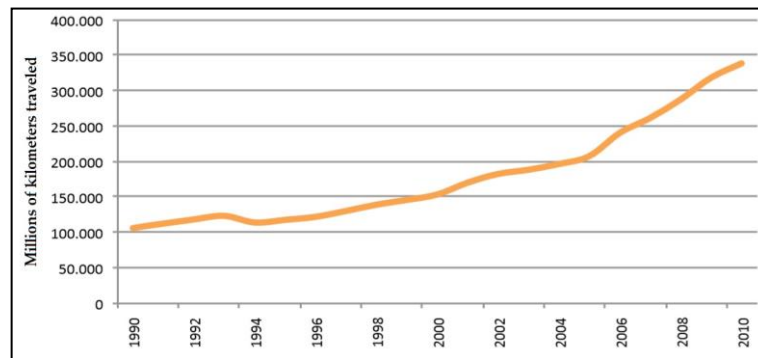
There are no official annual historical statistics with respect to vehicle use (measured as vehicle kilometers traveled) in Mexico at a national level or even at the level of the major metropolitan areas, such as the estimates reported by developed nations such as the vehicle kilometers traveled in France, which are shown in the previous section.

Most of these estimates are based on gas sales. In Mexico, state-owned petroleum company PEMEX reported increase in total automobile gasoline sales from 2000 to 2008, then stabilized from 2008 to 2013 at 1.48% compared to base year 2000, even with significant increases in gas price (PEMEX, 2014). It is difficult to estimate historical travel intensity from total gas sales in particular due to the influence of gas price evolution, emission standards for passenger cars and commercial vehicles in recent years, the actual implementation of these norms in a developing-world context and lastly, to good quality time-series data unavailability. However, [153] integrated dispersed or incomplete information in order to obtain an unprecedented estimate of the intensity of private vehicle use in Mexico at a national level from 1990 to 2010. Contrary to the peak car observed in France (Figure 4.7) this estimates show a great increase trend in the intensity of private vehicle use of more than three times in just two decades (Figure 4.14). It seems then that based on data shown in figures 4.12 to 4.14, that vehicle use in Mexico is still in the growing phase, and no peak car can be observed or predicted, at least from these results. To address the question of future urban travel trends in Mexican cities, in particular the case studies of Juarez and Puebla, long-term travel demand forecasts will be estimated with the Age-cohort methodology, which is described in section 4.3.1.

Figure 4.13. Car fleet evolution in mexican cities, 1990-2010



Source: (ITDPauto_2012)

Figure 4.14. Total Vehicle Kilometers Traveled, Mexico, 1990-2010

Source:[153]

With respect to our case studies, the percentage of private vehicle use in the modal choice seems to be almost the same in Juarez Mexico and Lille France. As for the number of daily trips per person, we observe almost the double in Lille compared to Juarez. The main difference between these contrasted urban areas could be in fact a result of the important gap in terms of income between developed and developing countries which has been observed in Figure 4.8. Nevertheless in Juarez the private car share (50%) appears to be stabilized between 1996 and 2006 showing a strong automobile dependency for a Mexican city (for example only 27% in the Guadalajara Metropolitan Area in 2007). In contrast to Lille, this is due mostly as mentioned before to poor public transportation infrastructure, sprawled urban form and the availability of cheap used cars imported from the U.S. On the other hand the public transport share decreased from 24.2% to 22.3%⁸⁹ between 1996 and 2006 showing that in Juarez private auto users could be seen as captive users who are generally unable to change to shared passenger transport modes due to structural reasons⁹⁰. According to the latest Urban Observatory of Security and Safety, the total amount of private vehicles in Juarez was approximately 750,000 which, considering the 1,332,131 inhabitants reported in the population census of 2010, results in a rate of 0.56 this result in a rate of 0.6 vehicles per capita [154]. In 1996 Juarez had a vehicle fleet with an average age of 12.7 years, which increased to 13.8 years in 2006, due possibly to multiple ownership, the persistence of relative poverty and the proximity of the US border, which facilitates lightly taxed imports of vehicles aged ten years or more. Puebla is much less motorized, representative of a more traditional life-style.

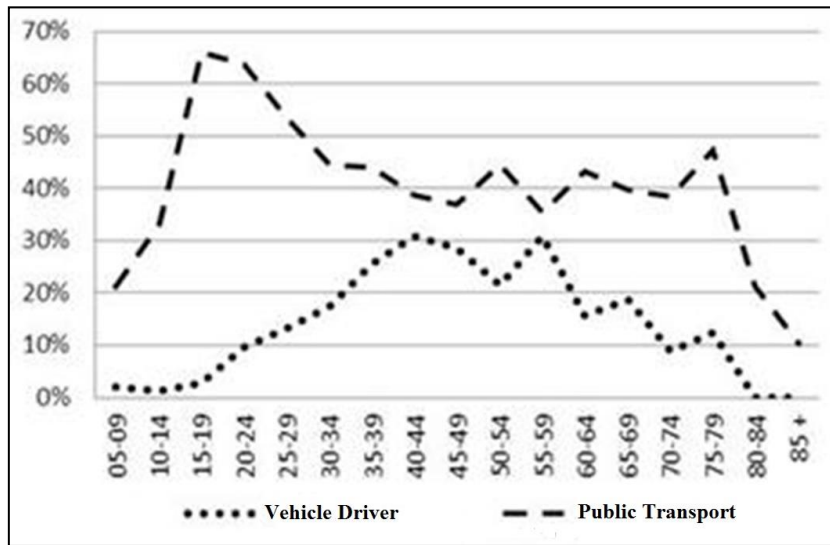
⁸⁹ Taking into account taxi, public transport, company and school buses.

⁹⁰ Only walking and bicycle modes increased from 25.6% to 28.1% in the same period.

In 2011 the private car share was down to 14% from 21% in 1994 and public transit use rose from 46% to 53%, a surprising result according to the 2011 O-D Survey, which may be explained by persistent poverty and a possible underestimation of motorization due to the difficulty to survey gated communities and cyclical economic crisis phenomena. A recent household origin destination transport survey in Puebla (2011) gives us interesting input with which to complete the picture. Between 1994 and 2011, per capita mobility remained stable (at 1.75 trip per day per person), as did individual car ownership, which followed population growth (+50%), but persistent poverty did not allow household car ownership to increase. On the contrary, the proportion of households with cars fell to 33% in 2011, as compared to 39% in 1994, and the proportion of households with more than one car was only 3.8% in 2011 versus 10.3% in 1994. To a large extent, this trend reflects the persistence of poverty. While in 1994 19.0% of households suffered from food poverty, the rate did not change in 2008, with 19.5% [155]. In addition, over the same period, the average age of cars on the road increased from 9.4 to 13.0 years. A 2012 O-D survey in the city of Colima on the west coast of Mexico indicated also an average age of household cars of 13 years.

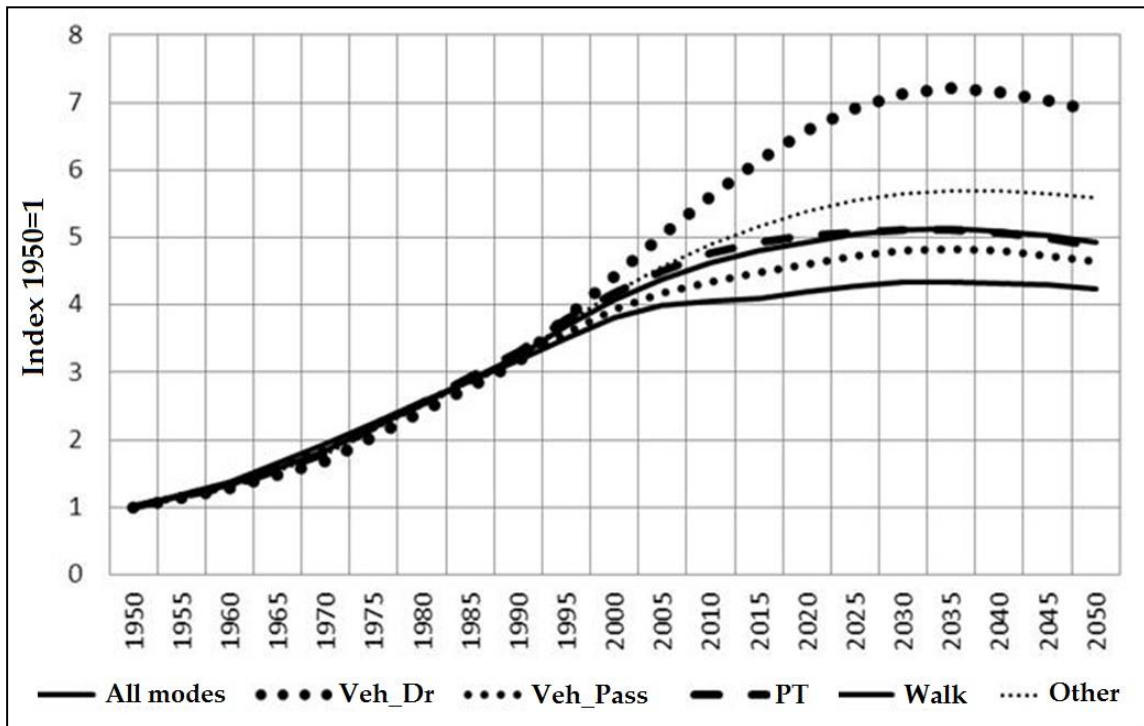
In an intent to predict travel demand trends in the city of Puebla, Bussière [81] applied constant behavior by age and transportation mode observed in the 1994 O-D Survey (Figure 4.15) to past and future populations over a 100-year period (1950-2050). This simulation was made with the simple model with retrofit to measure the impact of demographic changes from 1950 to 2050. Puebla's demographic projections used in this simulation were based on long series forecasts developed for Mexico by the National Population Council of Mexico (CONAPO) assuming the fact that the ageing process of Puebla and at the National level tend to be similar. The results shows the beginnings of demographic pressures conducive to individual car ownership around the year 2000 (Figure 4.16), at the same time that a slowdown was being observed in developed cities and apparently also in Sao Paulo. In Puebla we should assist to two decades of heavy demographic pressure conducive to individual car ownership and a slowdown in Public Transit. Bussière [81] obtained very similar results to the case of Montreal. In fact, according to this simulation based on 1994 data the inflection point is to come at around 2035, after which there should be a slowdown in individual driving and a virtual levelling-off for Public Transport. This simulation represents a minimalist scenario because it assumes a continued low level of car ownership. If the growth in living standards and household car ownership factor is added in, the result would be explosive for at least another 20 years.

Figure 4.15. Modal choice by age, Vehicle Driver and Public Transport, Puebla (1994)



Source: Household Origin-Destination Surveys.

Figure 4.16. Transport demand trends in Puebla measuring the impact of population fixed behavior in 1994, 1950-2050 by mode defined as total daily trips (index 1950=1)



Source: [156].

4.3 The travel demand forecast models used

We apply a demographic modelling approach, namely the Age-Cohort model, for the analysis of travel behavior. As mentioned in Chapter 1, this methodology for the travel demand forecasts was developed by researchers of the French National Institute for Transport and Safety Research (INRETS) currently the French Institute of Science and Technology for Transport, Development and Networks (IFSTTAR). Cohorts are constructed using data from cross-sectional Household Travel Surveys of each case study (described in Chapter 2). Estimates are made for age and generation effects (Figure 23 from Chapter 1) which are subsequently applied to demographic projections. Having as a result the extrapolation of per capita and total travel demand, measured in daily number of trips and daily traveled distance for each main transportation mode: All modes (including walking, etc.), Vehicle Driver, Vehicle Passenger and Public Transport.

*Table 4.1. Description of the Age-Cohort Travel Demand Forecast Model*⁹¹

The model, based on demographic trends in a longitudinal analysis reveals the complex role of the age factor which, in a dated temporal context, consists of a combination of three interlinked dimensions:

- the stage in the life cycle, which expresses the influence of age on travel behavior. By evaluating the effects of the stage in the life cycle, it is possible to obtain a characteristic curve for those changes which can be related to age (we shall refer to this as the standard life profile);

- the generation (or cohort), which takes into account travel behavior on the basis of membership of a group of individuals born during the same period, who therefore share a common "life experience". Introducing this generation gap effect (which can be measured by means of differentials) allows us to place this profile in a long term perspective;

- the Age-Cohort model supposes age and generation behaviors stable through time;

- a more complete Age-Cohort-Period model, which is not considered here, would take into account the period effect, which expresses the influence of the overall economic context on behavioral changes. In such a model the period effect expresses the importance of socio-economic factors which affect all individuals and households simultaneously (e.g. changes in legislations, cost of fuel).

⁹¹ Description of the Age-Cohort Travel Demand Forecast Model is taken from Dejoux et. al. [155].

Presentation of the age-cohort model

The model used is essentially based on an age-cohort approach taking into account the impact of the life-cycle and generation effects through time on travel behavior, which permits to outline the impact of age and generation combined with various structural variables: gender, spatial distribution, motorization of the households ...

We used a variance analysis model which is written as follows:

$$\pi_{a,k} = \sum_{a \in A} \alpha_a I_a + \sum_{k \in K} \gamma_k I_k + \varepsilon_{a,k}$$

Where:

- $\pi_{a,k}$: measures a characteristic or behavior (daily kilometers, number of trips per day, ...); "a" is the age band of the individual reflecting the life-cycle and "k" his generation, defined by his date of birth;
- α_a : measures the behavior of a generation of reference at the age band "a". This allows us to calculate a « Standard Profile » of the life cycle;
- I_a : are the dummy variable of the age band "a".
- γ_k : measures the gap between the cohort "k" and the generation of reference k0 g ;
- I_k : are the dummy variable of the cohort "k".
- $\varepsilon_{a,k}$: is the residual of the model (which includes all other factors).

The unit of measurement used is the standard five years cohort used in demographic analysis. Mobility is measured by two variables:

- global mobility or frequency of trips (average number of trips per person for a typical week day);
- distance travelled (number of kilometres travelled per person for a typical week day).

The model for Projection of Mobility

The projection of mobility (daily kilometres, number of trips per day...) for an individual of zone of residence (z), level of motorization (v) and gender (s) at the date (t) is given by:

$$\pi_{a,k}^{z,v,s} = \alpha_a^{z,v,s} + \gamma_k^{z,v,s}$$

Where:

- $t=a+k$ (a is the age of the individual reflecting the life-cycle and k his generation, defined by his date of birth);
 - α_a : measures the behavior of a generation of reference at the age a . This allows us to calculate a « Standard Profile » of the life cycle;
 - γ_k : measures the gap between the cohort k and the generation of reference γ_k^0 ;
- Since the gaps in cohorts for recent generations tend to disappear we took the last observed cohorts gap for future generation (Madre & al., 1995).

The mobility for the population at the date t is estimated as follow:

$$M_t = \frac{\sum_{z=1}^3 \sum_{v=0}^2 \sum_{s=1}^2 (P_{a,t}^{z,v,s} * \pi_{a,k=t-a}^{z,v,s})}{\sum_{z=1}^3 \sum_{v=0}^2 \sum_{s=1}^2 P_{a,t}^{z,v,s}}$$

Where:

- $P_{a,t}^{z,v,s}$ is the population projection of zone of residence z , level of motorization v and gender s at the date t .

Source: [157].

For clarification it should be emphasized that we considered in all models travel activity and population forecasts exclusively within the same area of study over the years in order to mitigate geographic selection bias [32] [116]. In fact, we decided to control for geography since the models could be sensitive to the changing geographies over two time periods [158]. Another reason is that despite the possibility in developed countries to know a couple of decades in advance where new developments are going to be built and with a good approximation of the total population living in these new areas; in developing countries it is very difficult to predict it due to lack of systematic urban planning and strong political power over existing urban master plans. Therefore all results shown take into account homogeneous zones excluding urban sprawl. We would probably expect greater travel distances if urban sprawl was included in forecasted years. In fact, a promising path of research could be taking into account different levels of urban sprawl and

population densities. In our research we chose to better understand transportation trends in constant/homogeneous geographic areas. With respect to population forecasts, in developed economies population is ageing but in emerging economies, with few exceptions, populations are still young, but the ageing phenomenon will arrive there as well. Emerging economies present very diverse situations. For example, in China ageing is important, due to the one child policy, but India has still very strong population growth rates.

Demographic projections from France were based on the OMPHALE⁹² model provided by the French National Institute for Statistics and Economic Research (INSEE). In Mexico, population growth is still very rapid (averaging 1.58% per year between 1990 and 2010) but can be expected to slow down. According to the National Population Council of Mexico (CONAPO) national projections of the annual growth rate should average roughly 0.67% between 2010 and 2030, with rapid and substantial ageing (the proportion of people aged 65 or over was 3.4% in 1950, 4.2% in 1990, 6.4% in 2010 and is forecasted to be 12.5% in 2030 and 22.0% in 2050). In the cities, growth should be slightly more rapid because of a continuing rural exodus and urbanization described in Chapter 1. There are no official demographic projections disaggregated at city level for Mexican case studies (see section 2.4.1.3). Since the age-pyramid evolution tend to be similar at a state and city levels, the demographic projections used in the Age-Cohort models were constructed in part based on CONAPO's statewide projections, from which age-pyramid evolutions were obtained. In fact, demographic projections by 5 age cohorts are available only at a national and statewide level. Thus, demographic projections were developed starting with observed data from Household Travel Surveys for each city by 5 year age cohorts, and then adjusting it to projections at the statewide level assuming that the lag between statewide data for each cohort and local data remain stable through time. This gives us a fair enough estimation of the ageing process and serves as an input of the model. This approach was applied in Puebla and Juarez, with the only difference of slow demographic growth scenario in Juarez given the current social context mentioned in Chapter 1.

⁹² Outil Méthodologique de Projection d'Habitants, d'Actifs, de Logements et d'Élèves

Multiple perspectives in relation to travel indicators and model application are needed to better draw future travel changes and to identify the impact of age pyramid evolution, travel behavior changes and population growth on individual and global mobility. In summary, the travel demand forecasts are estimated through a diversity of model implementation in order to assess the role played by the main components of the Age-Cohort model when estimated jointly and separately. Approaches of model application are described below:

Model 1: This model consists of the **Full Age-Cohort model**, which considers the main components of the model: the effect of an ageing population through the deformation of the age pyramid and the effect of travel behavior changes over time. This model is identified as AC model in the results. In addition, in an intent to isolate structural factors in the trends of an apparent saturation of urban mobility the Age-Cohort model is also applied as described below focusing in the decoupling of population ageing changes (model 2) and travel behavior changes (model 3) in order to assess the role played by these components.

Model 2: In this model future travel behavior by age and generation is arbitrarily set and fixed in the year 2000, therefore only changes in the age structure of the population are taken into account and subsequently shown in the results. In other words, the distances and number of trips remain as estimated in 2000 showing only the effect of an ageing population through the deformation of the pyramid. This model is identified as **Ageing AC model** in the results.

Model 3: In this model the age structure of future population is arbitrarily set and fixed in the year 2000 and therefore only travel behavior is allowed to change over time. In other words, this model show only the effect of travel behavior keeping the structure of the population in 2000, to which is attributed to each year mobility (per capita daily km or trips). This model is identified as **Behavior AC** model in the results. The mobility variables measured in models 1, 2 and 3 are (km/day/person) and (trips/day/person).

Model 4: In addition to per capita projections from models 1, 2 and 3 and in order to decouple the magnitude of contribution of population growth and age pyramid evolution over global mobility, the Full Age-Cohort model was also applied to estimate global travel volumes at city level based on two different demographic projections. The first scenario considers an increasing population and age pyramid

changes year after year (model 4a). This scenario better recreates demographic projections that are more likely to be observed in the future. The second demographic scenario (model 4b) has a total population fixed at year 2000 but changing age pyramid over the years. In other words, it shows only the influence of the modification of the age structure of the population, not the influence of the total number of inhabitants. Having these two demographic forecasts models allows us to better identify the contribution of population growth in global travel demand by making the following subtraction: [model 4a] – [model 4b]. The global mobility variables measured in models 4a and 4b are total traveled distance (km/day) and total number of trips (trips/day) in each city.

4.4 Results

4.4.1 Has Urban Mobility Reached a Maximum? Behavior Shifts or Structural Effects? Case Study of Lille⁹³.

⁹³ This section is a reprint of: TAPIA-VILLARREAL, Irving; MADRE, Jean-Loup; BUSSIERE, Yves. pp. 117-134. 2013. Espace Populations Sociétés, Volume: 2012 .Issue Number: 3. <http://eps.revues.org/5143>



Le plafonnement de la mobilité des citoyens : Changements de comportement ou effets de structure? Le cas de Lille.

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Résumé :

La tendance observée en France et dans d'autres pays industrialisés montre une désaffection des jeunes pour le permis de conduire et une stagnation de la mobilité quotidienne des citoyens. S'agit-il de changements de comportements liés à la conjoncture ou d'effets de structure ? Pour tenter de répondre à cette question nous avons analysé le cas des habitants de la Communauté Urbaine de Lille (LMCU) en ajustant un modèle de projection démographique Age-Cohorte calé sur trois enquêtes ménages déplacements (1987, 1998, 2006) qui permet d'isoler des effets structurels d'âge et de génération liés au cycle de vie.

Le vieillissement de la population n'explique cependant qu'une part des évolutions observées et on assiste à des changements de comportement significatifs. À l'horizon 2030, la proportion d'adultes titulaires du permis de conduire devrait stagner. En calant le modèle successivement sur 1987 et 1998, puis sur 1998 et 2006 pour la distance journalière parcourue par habitant, nous obtenons des projections très contrastées : d'une croissance ralentie dans le premier cas au prolongement de la diminution amorcée en 2006 dans le second. L'analyse par mode de transport montre, au-delà de la renaissance des transports en commun observée dans les années 2000, que la croissance de leur utilisation entre 2000 et 2030 pourrait aller de +18% d'après le calage 1987-1998, à +38% en calant le modèle sur les deux dernières enquêtes.

Le modèle Age-Cohorte, sur l'exemple de Lille, permet de montrer que le vieillissement de la population ne rend compte que partiellement du plafonnement de la mobilité observée dans les années 2000. Cependant le vieillissement qui donne moins de poids aux jeunes, amplifie le phénomène de plafonnement. Les différences significatives observées entre les comportements prévalant jusqu'aux années 90 et dans les années 2000 expliquent bien le retournement de tendance observé, et conduisent à des projections divergentes.

Mots-clés : saturation, permis de conduire, modèle Age-Cohorte, Enquêtes Ménages Déplacements, projection à long terme.

Has Urban Mobility Reached a Maximum? Behavior Shifts or Structural Effects? Case Study of Lille.

Abstract :

Recent trends in France and other developed countries such as a reduction in drivers' license ownership and stagnation of daily urban mobility suggest that " peak travel " within urban areas may have been reached. Are we assisting to cyclical or structural changes? We tried to answer to this question by applying a prospective demographic Age-Cohort model to the Metropolitan Area of Lille, calibrated from household travel surveys conducted in 1987, 1998 and 2006. The model permits to isolate age and generation effects linked to the life cycle.

Population ageing explains only partially the decline of daily traveled distance per person. Indeed there are significant changes in behavior. According to the model the proportion of adults with a driver's license should remain almost constant till 2030. Forecasts derived from the Age-Cohort model show a slowdown of travel distance increase, when the model is calibrated on 1987 and 1998 surveys, while it shows a slow decline from 2000 to 2030 when calibrated on the two most recent surveys. Concerning the revival of public transport observed around the year 2000, calibrated with the 1987-1998 surveys, the model shows an increase by 18% between 2000 and 2030, and it could reach +38% when calibrated with the 1998 and 2006 surveys.

The Age-Cohort model, based on the case study of Lille, shows that population ageing explains only partially the saturation in daily mobility observed in the 2000's. However, ageing, which gives less weight to the younger generations, amplifies the phenomenon. The significant differences observed in the behaviors until the 90's and in the 2000's, explain well the reversal of tendency observed which leads to diverging projections.

Key-words : Peak Travel, driving licence, Age-Cohort model, Household Travel Survey, Travel Forecast.

JEL : R00, R41, D01, C53.

1. Introduction

Depuis plusieurs décennies, la mobilité individuelle ne cesse de croître. Cependant, au cours des dix dernières années on observe dans divers pays industrialisés un ralentissement de la mobilité des citoyens et un plafonnement de l'usage de l'automobile [BITRE, 2012] : depuis 2003 en France, on ne mesure pas d'évolution significative du volume de trafic total [CCTN, 2012]. La question posée ici est de savoir s'il s'agit d'un phénomène conjoncturel ou structurel, d'après des données essentiellement françaises, portant particulièrement sur Lille.

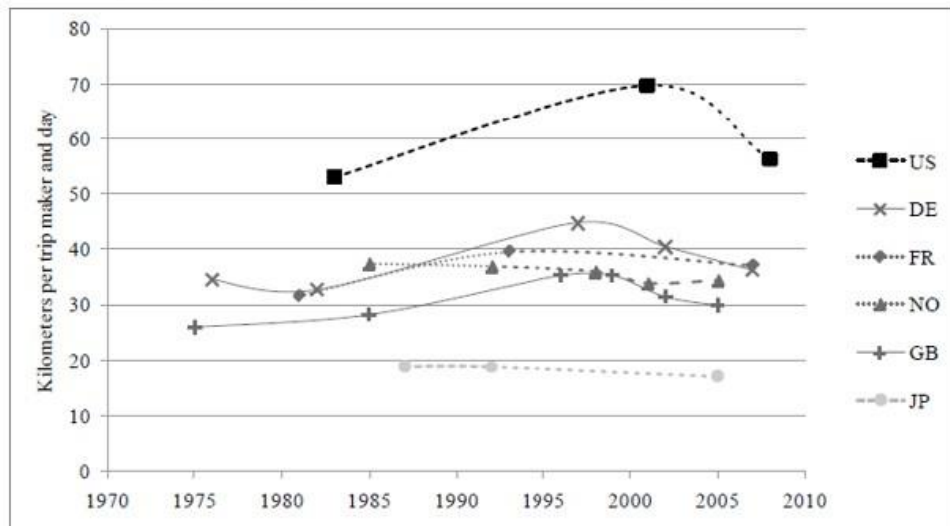
Nous présenterons d'abord, à partir d'une revue rapide de la littérature, un constat des changements de tendance observés dans les années 2000 et différentes pistes d'explication du phénomène (section 2); nous décrirons ensuite l'approche démographique qui vise à expliquer au moins en partie ces tendances récentes (section 3). Nous concentrerons ensuite l'attention sur les habitants de Lille Métropole Communauté Urbaine (LMCU) en analysant les évolutions de la possession du permis de conduire (section 4) et des distances parcourues selon le mode de transport utilisé, avec quelques éléments de projection à l'horizon 2030 (section 5).

2. Le constat

En France, depuis le milieu des années 2000, le Bilan de la Circulation établi par la Commission des Comptes Transport de la Nation montre une stagnation des trafics automobiles [CCTN, 2011]. Cette rupture par rapport à la croissance antérieure a été confirmée et illustrée par les Enquêtes Ménage Déplacements (EMD) à Lyon, Lille, Rouen,

Reims, Rennes, Strasbourg, etc. puis par l'Enquête Nationale Transport et Déplacements (ENTD) qui permet de l'imputer essentiellement aux habitants des grands pôles urbains [Hubert, 2009] et de la resituer dans une vision d'ensemble de la mobilité : les déplacements des actifs et des étudiants-élèves sont moins fréquents avec l'augmentation de la journée continue [Hubert et al., 2010] et moins exclusivement automobiles. La motorisation des ménages décroît au cœur de l'agglomération parisienne comme d'ailleurs de celles de Londres, de Bruxelles,..... Selon une étude comparative auprès des jeunes adultes (20-29 ans) dans six pays industrialisés (Allemagne, Grande Bretagne, France, Japon, Norvège et Etats-Unis) entre 1974 et 2010, la distance moyenne parcourue a connu un maximum entre 1995 et 2000 pour ensuite diminuer (graphique 1). Aussi, les jeunes ont moins souvent le permis de conduire et sont moins exclusivement automobilistes que ceux de la génération précédente [Kuhnimof et al., 2012]. Pour expliquer ce phénomène, plusieurs pistes sont proposées : l'accroissement du taux de scolarisation supérieure des jeunes, ce qui retarde leur entrée sur le marché du travail, l'augmentation de l'âge pour former une famille, la hausse du prix du carburant, l'introduction de mesures de gestion de la demande pour diminuer l'usage de l'automobile en ville, et finalement, un changement dans les mentalités.

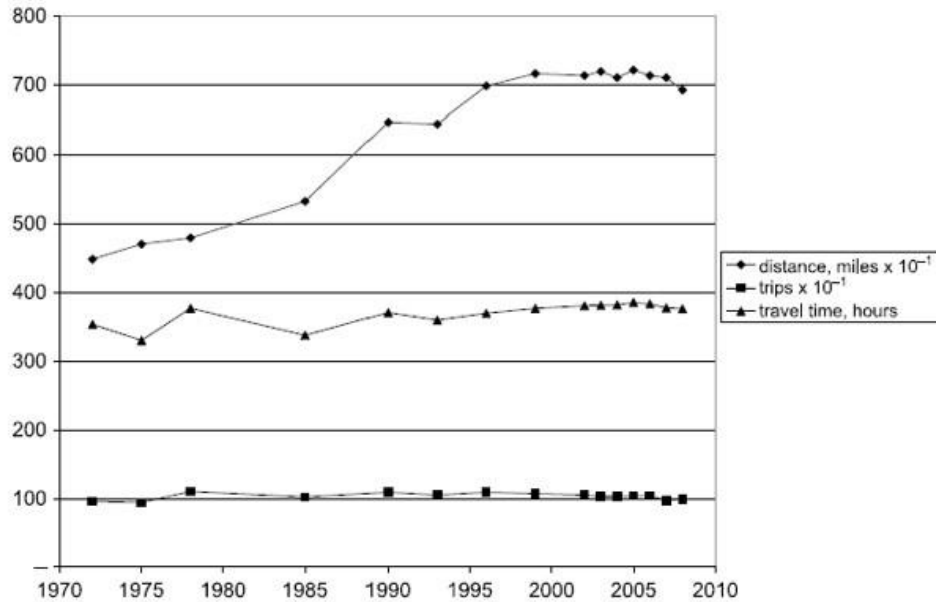
Graphique 1 : Evolution des véhicules-km (auto-conducteur et auto-passager) par voyageur et par jour pour les jeunes adultes de 20-29 ans (6 pays).



Source : Kuhnimof et al. (2012).

Pour la Grande-Bretagne, Metz [2010] observe que, au cours des 30 dernières années le temps moyen voyagé est resté stable à environ 1 heure par jour (375 heures par personne par année) ainsi que le nombre moyen de déplacements (1000 déplacements par personne par année). La possession d'automobile a plus que doublé ainsi que les vitesses, ce qui avec la hausse des revenus a induit une augmentation importante des distances parcourues, vers une certaine saturation à partir du milieu des années '90 (graphique 2).

Graphique 2 : Temps de déplacement (heures par personne par an), distance (milles par personne par an) en Grande Bretagne.



Source : NTS 2008, Tableau 2.1, [Metz, 2010], p. 661.

Metz avance quelques explications possibles de ce plafonnement de la circulation : une diminution des déplacements locaux due à une augmentation des voyages aériens donc à davantage d'absences du domicile [Madre et Armoogum, 1997] ; l'augmentation de la congestion ; la diminution des déplacements due aux progrès dans les télécommunications ; ou encore une saturation structurelle de la demande de déplacements.

Les tendances observées traduisent-elles l'approche de la saturation via le découplage entre croissance des trafics et des revenus? Ce découplage se manifeste-t-il d'abord dans les régions les plus denses et/ou au-delà d'un certain niveau de vie [Millard-Ball et Schipper, 2010] ? Ou le plafonnement de la circulation résulte-t-il de la superposition d'évolutions contraires [Goodwin, 2010-2011] ? Il semble néanmoins que les kilométrages parcourus par les habitants des zones peu denses aient eux aussi tendance à plafonner, mais plus tard et à des niveaux plus élevés qu'au cœur des agglomérations.

Certains auteurs avancent même l'hypothèse d'une diminution des déplacements à court et moyen terme dans les pays développés, attribuable à une série de facteurs socio-économiques [Litman, 2011]. On peut donc se demander s'il s'agit d'un phénomène structurel (vieillesse de la population, arrêt de l'exode rural,...) ou conjoncturel lié à l'augmentation et à la volatilité du prix des carburants, à la récession...?

L'ERA-MOB (Equipe de Recherche sur la mobilité Associée au laboratoire "Dynamiques Economiques et Sociales des Transports" (DEST) de l'IFSTTAR) a entrepris l'analyse de ces changements de comportement [Quételard, 2011] constatés par exemple lors des déménagements [Meissonier, 2011]. Ils constituent notamment un enjeu évident en matière de prospective énergétique et environnementale.

Au niveau international, une analyse globale des tendances des 40 prochaines années de la demande mondiale de transport a été présentée par le JTRC/ITF en mai 2011 à Leipzig «Perspectives des transports - Répondre aux besoins de 9 milliards de personnes » [OECD/ITF, 2011]. L'hypothèse de la saturation y est considérée d'un œil critique, car le point de vue est mondial, et elle ne semble pas proche notamment dans les pays émergents.

Dans la plupart des pays développés jusqu'aux années 90, la proportion de titulaires du permis de conduire à un âge donné était toujours en progression par rapport aux générations antérieures, et cette augmentation était plus rapide chez les femmes que chez les hommes, rapprochant ainsi leurs comportements. On constate désormais dans plusieurs pays (USA, Norvège, Suède,...) un décrochement des taux de permis chez les jeunes, particulièrement sensible pour les hommes. En France, la baisse de titulaires de permis pourrait être attribuée à la disparition en 1997 du service militaire obligatoire qui permettait aux jeunes hommes un accès quasi-gratuit à la conduite [Avrillier et al., 2010]. D'après les Enquêtes Nationales Transport, le tableau 1 montre que c'est seulement dans la tranche d'âge 18-24 ans que l'on observe un repli du taux de permis, particulièrement sensible dans les zones sous influence urbaine (notamment en Ile-de-France) ; il n'apparaît plus dans la tranche 25-35 ans mais trop de temps s'est écoulé entre les ENT de 1993-94 et 2007-08 pour qu'on puisse affirmer qu'il s'agit d'un rattrapage, puisque la cohorte qui a 18-24 ans en 1994, a 32-38 ans en 2008 [Roux, 2012]. Grâce à des enquêtes moins éloignées dans le temps, nous pouvons constater qu'il n'y a pas de rattrapage à Lille, ville sur laquelle porte l'essentiel de cet article, car le taux de permis des habitants de 25 à 34 ans est aussi en retrait en 2006 par rapport à 1998. Ailleurs, par exemple en Grande Bretagne, la désaffection pour le permis de conduire est attribuée à d'autres facteurs, comme l'introduction d'une épreuve théorique mi-1996, même si le repli est observable dès 1993 [Noble, 2005]. De même aux Etats-Unis, on voit comment le recul du permis coïncide avec le durcissement de l'examen dans les différents Etats [Davis et al., 2012].

Tableau 1. Evolution des taux de permis chez les jeunes adultes selon leur zone de résidence en France (en %).

Date	18-24 ans				
	Commune de l'espace à dominante rurale hors Ile-de-France	Commune de l'espace à dominante urbaine hors Ile-de-France	dont : Lille	IDF*	France entière
Années 80	75,7	59,9	58,7	59,7	62,3
Années 90	69,5	69,6	64,5	56,8	66,9
Années 2000	78,6	67,8	54,0	48,7	65,7

Date	25-34 ans				
	Commune de l'espace à dominante rurale hors Ile-de-France	Commune de l'espace à dominante urbaine hors Ile-de-France	dont : Lille	IDF*	France entière
Années 80	87,8	81,2	81,9	78,2	81,9
Années 90	91,7	87,6	85,7	78,9	86,7
Années 2000	95,8	88,3	80,1	81,6	88,5

*IdF = Ile-de-France

Source : Enquêtes Nationales Transport (ENT) de 1981, 1993 et 2007, et Enquêtes Ménages Déplacements de Lille (EMD) de 1987, 1998 et 2006.

Depuis le milieu du 20ème siècle, l'usage de la voiture en ville comme ailleurs ne faisait que croître à un rythme soutenu et régulier et aucun ralentissement de cette croissance n'était perceptible. Mais à partir de 2006, toutes les EMD montrent une stabilisation et souvent une baisse de l'usage de la voiture, dont l'évolution de la structure de la population (notamment son vieillissement) n'explique qu'une faible part [Quételard, 2011] :

- à Lille, les évolutions dans la structure de la population auraient dû entraîner une légère croissance de la mobilité (4,02 déplacements par personne et par jour en 2006 contre 4,00 en 1998), mais on en a observé 3,76 ;
- à Lyon, les évolutions de structure auraient dû entraîner effectivement une baisse de la mobilité mais la baisse observée est bien plus forte, de 3,63 en 1995 à 3,36 en 2006 (3,60 à structure constante) ;
- à Strasbourg, " 10 % de la baisse de la mobilité des habitants de la Communauté Urbaine (CUS) est exclusivement lié au phénomène de vieillissement démographique " et " l'augmentation de la part des actifs, scolaires et étudiants pratiquant la journée continue explique mécaniquement 20 % de la baisse de la mobilité " [ADEUS, 2010].

Quel cadre définir afin de formaliser ces évolutions et de les analyser pour différentes catégories de population et de modes utilisés ?

3. L'approche démographique

Parmi les Sciences de l'Homme et de la Société, c'est la démographie qui fournit les données les plus fiables sur les tendances de long terme. Elle décrit une population d'individus ou de ménages (voire même de véhicules [Kolli, 2012]) au cours de leur cycle de vie, dans un champ donné (en général une zone géographique).

3.1 Le modèle

Il traduit l'influence au cours du temps, du cycle de vie et de la succession des générations sur les comportements [Masson et Kessler, 1985]. Nous l'avons adapté à l'analyse des évolutions et aux projections de la motorisation des ménages [Bussière et al., 1996], et de la mobilité quotidienne [Dejoux et al., 2009]. Il peut rendre compte d'autres facteurs structurels en distinguant différentes catégories de population selon leur sexe, leur lieu de résidence,....

Le modèle " Age-Cohorte " développé par Jean-Loup Madre et collaborateurs au DEST de l'INRETS (maintenant l'IFSTTAR) peut s'exprimer comme un modèle d'analyse de la variance à deux facteurs (l'âge et la génération) :

$$\pi_{ak} = \sum_{a \in A} \alpha_a I_a + \sum_{k \in K} \gamma_k I_k + \varepsilon_{ak} \quad (1)$$

où :

- π_{ak} : mesure une caractéristique des comportements (distance parcourue ou nombre de déplacements par jour et par personne,...); " a " est la classe d'âge dans laquelle se situe l'individu qui reflète sa position dans le cycle de vie, et " k " est la génération à laquelle il appartient définie par son année de naissance ;
- α_a : mesure le comportement de la génération de référence à l'âge "a". Ceci permet d'estimer un " profil-type" de cette génération au cours de son cycle de vie ; comme celui des autres cohortes s'en déduit par translation, le choix de cette cohorte de référence est arbitraire ; pour plus de clarté dans la présentation des résultats, nous avons choisi des cohortes différentes selon les exercices présentés ici ;
- I_a : est l'indicatrice de la classe d'âge " a " ;
- γ_k : mesure l'écart entre la cohorte " k " et la génération de référence γ_{10} ;
- I_k : est l'indicatrice de la cohorte " k " ;
- ε_{ak} : est le résidu du modèle, qui rend compte de tous les autres facteurs.

Cette forme additive simple du modèle maintient constant l'écart entre les générations successives, ce qui ne permet pas de rendre compte de phénomènes de " rattrapage ". C'est une contrainte forte, notamment pour des projections, mais le petit nombre d'enquêtes disponibles sur Lille n'autorise pas l'estimation de formulations plus complexes, car il faut au moins deux points d'observation éloignés dans le temps pour estimer les paramètres du modèle.

Plutôt que de regrouper classiquement les âges en tranches quinquennales, nous avons adapté le découpage aux questions posées : par exemple, identification de chaque âge de 18 à 25 ans pour l'analyse du permis de conduire. Par contre, les générations ont été groupées en décennies selon les années de naissance. Quand les échantillons étaient trop petits, nous avons opéré des regroupements plus vastes.

3.2 Données et hypothèses

Afin d'observer l'évolution de comportements au cours du cycle de vie, l'idéal est de disposer d'un panel. Mais ce type de données est rare et affecté par des biais d'attrition (abandons différents selon les catégories de population). On doit donc constituer un pseudo-panel en suivant dans les enquêtes successives, ici les Enquêtes Ménages Déplacements (EMD) des groupes qui ont des caractéristiques stables au cours du temps (sexe, année de naissance,...) [Deaton, 1985]. Vu la difficulté de raisonner à "géographie évolutive" [Julien, 2000], nous avons fait le choix de travailler à périmètre constant, c'est-à-

dire sur les habitants de la Communauté Urbaine de Lille, qui ont été interrogés de la même manière (tous les membres du ménage, face-à-face) lors des enquêtes de 1987, 1998 et 2006 ; et nous utiliserons naturellement des données pondérées. Si la population n'est pas stable, on doit faire l'hypothèse que les nouveaux arrivants (par exemple emménageant dans la zone considérée) et ceux qui l'ont quittée ont le même comportement que ceux qui n'ont pas déménagé, c'est-à-dire les « anciens habitants » ; on constate que leur proportion est d'autant moins importante que l'on se rapproche du centre-ville (elle a même diminué de 51% en 1987 à 35% en 2006 dans la commune de Lille). Sur l'exemple de la motorisation des habitants de la Communauté Urbaine de Lille, le tableau 2 permet de se rendre compte de la validité de cette hypothèse "d'espace clos" : partout en 1987 et seulement dans les zones extérieures en 2006, les nouveaux arrivants sont plus motorisés que les anciens habitants, c'est l'inverse au centre-ville et en proche banlieue en 2006, mais les différences entre ces deux groupes restent faibles.

Tableau 2. Evolution de la motorisation 1987-2006. Communauté Urbaine de Lille. Hypothèse "d'espace clos".

	Centre Lille		Banlieue		Périphérie		Reste		Ensemble	
	87	06	87	06	87	06	87	06	87	06
% de ménages :										
Anciens habitants : 5 ans et plus dans le logement	51	35	59	58	69	66	72	65	61	56
Nouveaux arrivants : ancienneté 0-5 ans dans le logement	49	65	41	42	31	34	28	35	39	44
Ensemble	100	100	100	100	100	100	100	100	100	100
Voitures pour 100 adultes :										
Anciens habitants : 5 ans et plus dans le logement	33	61	38	84	39	96	37	101	37	87
Nouveaux arrivants : ancienneté 0-5 ans dans le logement	38	55	40	79	42	104	44	110	40	80
Ensemble	35	57	39	82	40	99	38	104	38	84

Source : EMD Lille 1987 et 2006

3.3. Méthodologie

Pour distinguer les effets d'âge et de génération, il faut disposer de données collectées à au moins deux dates suffisamment distantes. Afin de considérer dans quelle mesure les inflexions importantes observées sur la mobilité urbaine dans les années 2000 sont liées à des effets de structure (évolution de la part de différentes catégories, notamment vieillissement de la population) ou à des changements de comportement significatifs à certaines étapes du cycle de vie, nous allons, à partir du cas Lillois, conduire plusieurs simulations sur la base du modèle Age-Cohorte, estimé successivement sur les couples d'enquêtes 1987-1998 et 1998-2006, ainsi que sur les trois années d'enquêtes (1987, 1998 et 2006). Nous pourrions ainsi tester la stabilité des coefficients d'âge (mobilité aux différentes phases du cycle de vie) et de génération (décalages entre les cohortes successives). Dans le cas présent, nous distinguerons des caractéristiques stables au cours du temps (le sexe, par exemple). Etant donnée l'influence de l'automobile sur la mobilité et le choix modal, nous estimerons tout d'abord des modèles Age-Cohorte calibrés pour la proportion de titulaires du permis de conduire, visant notamment à élucider le comportement des jeunes adultes.

Ensuite, parmi les trois mesures classiques de la mobilité :

- fréquence des déplacements (nombre moyen de déplacements par jour et par personne),
 - distance parcourue,
 - budget-temps (temps consacré à se déplacer en moyenne par jour et par personne),
- nous privilégierons la distance parcourue, car c'est la mieux corrélée aux consommations énergétiques.

4. Moins de titulaires du permis de conduire chez les jeunes adultes

Comme, sauf en cas de retrait, le permis de conduire est acquis pour la vie en France, nous focalisons l'attention sur les premières années à partir de 18 ans, âge minimum pour passer l'examen. Le cycle de vie est donc représenté par 8 indicatrices (de 18 à 25 ans), une autour de la trentaine (26-35 ans) et une pour la suite du cycle de vie (plus de 35 ans), soit 10 indicatrices au total (tableau 3).

Tableau 3. Taux de permis, Communauté Urbaine de Lille : modèle Age-Cohorte, génération de référence née dans les années 40 ou 50.

Profil au cours du cycle de vie			
Age	Ensemble	Homme	Femme
18	17%	26%	9%
19	43%	49%	36%
20	53%	62%	46%
21	65%	74%	57%
22	70%	85%	58%
23	74%	85%	64%
24	79%	88%	70%
25	79%	90%	68%
26-35	80%	90%	71%
36 ou plus	79%	90%	70%
Décalage avec la cohorte née dans les années 40 ou 50			
Cohorte née dans les années			
10	-38%	-17%	-47%
20	-25%	-8%	-34%
30	-9%	-3%	-14%
40	0%	0%	0%
50	0%	0%	0%
60	+5%	0%	+10%
70	+3%	0%	+7%
80	-2%	-8%	+3%
R² ajusté	0,756	0,861	0,676

Source : calculs IFSTTAR sur les EMD réalisées à Lille en 1987, 1998 et 2006.

Guide de lecture du tableau 3 : Les paramètres sont ceux de l'équation de la section 3.1 ajustée sur les 3 enquêtes. Les coefficients d'âge (partie supérieure du tableau) correspondent aux taux de permis au cours du cycle de vie, pour la génération de référence (née dans les années 40 ou 50). Les effets de génération (bloc suivant) sont représentés par les écarts avec la cohorte née dans les années 40 ou 50, les comportements n'étant pas significativement différents entre ces deux décennies de naissance.

Pour ceux qui sont nés dans les années 40 ou 50 (cohorte de référence), la part des titulaires du permis croît jusqu'à 80%, niveau pratiquement atteint à 24 ans. Les cohortes nées au début du siècle dernier, avant l'essor de l'automobile, ont bien moins souvent le permis, surtout chez les femmes. La cohorte comptant la plus forte proportion de titulaires est née dans les années 60 et, à âge égal, nous constatons un repli chez les générations ultérieures.

A tous âges, les femmes nées dans les années 40 ou 50 ont moins souvent le permis que les hommes : le taux de titulaires plafonne pour elles à 70% contre 90% pour les hommes. Toutefois, les femmes nées dans les années 60 gagnent 10 points par rapport à la génération précédente, signe d'homogénéisation des comportements déjà maintes fois rencontré [Prédali, 2004 ; Dupont-Kieffer et Krakutovski, 2011]. Le repli est général pour les générations suivantes, plus brutal chez les hommes avec la disparition du service militaire obligatoire comme nous l'avons signalé plus haut.

Quand le modèle est calé séparément sur les enquêtes de 1987 et 1998 d'une part, 1998 et 2006 d'autre part, peu de différences entre les coefficients sont significatives. Seul le repli de la cohorte des années 80 est franchement plus net d'après les données les plus récentes, et un peu celle des années 70 ; par ailleurs, le taux de permis semble se stabiliser un peu plus haut après 35 ans d'après les dernières enquêtes.

5. Les distances parcourues

La distance parcourue constitue l'indicateur de mobilité le plus significatif quant aux enjeux du développement durable, car il est très lié aux consommations d'énergie.

Tableau 4 : Le plafonnement de la mobilité à Lille. Distance (km) parcourue par personne par jour : 1987, 1998, 2006.

	1987		1998		2006	
	LMCU	dont: Lille	LMCU	dont: Lille	LMCU	dont: Lille
Tous modes	10,4	6,6	12,6	8,4	12,6	8,9
Voiture conducteur	5,0	3,2	6,4	4,2	6,5	3,9
Voiture passager	1,7	1,0	2,0	1,2	1,8	0,9
Transports en commun	1,0	1,2	1,3	1,8	1,7	2,6

Source : EMD 1987, 1998 et 2006.

Le tableau 4 montre que le plafonnement de la mobilité en voiture est tout-à-fait perceptible chez les habitants de la Communauté Urbaine de Lille, et encore plus net chez ceux du centre (commune de Lille) ; les kilomètres parcourus en tant que passagers sont

même clairement en recul, vu la baisse du taux d'occupation des voitures. La forte croissance des transports en commun, surtout chez les Lillois, compense cette baisse, conduisant à une certaine stabilité des kilomètres parcourus " tous modes ". L'arrêt de la croissance des distances parcourues est donc bien imputable à l'automobile.

5.1 Femmes et Hommes

Le cycle de vie est découpé en 10 tranches d'âge de 9 ans d'amplitude environ, soit l'intervalle de temps moyen entre deux enquêtes ; étant donnée la spécificité des rythmes scolaires à chaque degré d'enseignement, les tranches sont un peu plus étroites pour les enfants. Ici encore, les cohortes sont définies par la décennie de naissance, avec la génération née dans les années 50 comme cohorte de référence.

Tableau 5. Distance parcourue, Communauté Urbaine de Lille : modèle Age-Cohorte (km par jour), génération de référence née dans les années 50.

Profil au cours du cycle de vie			
Age	Ensemble	Homme	Femme
5-11 ans	4,0	4,2	3,7
12-17 ans	6,5	6,5	6,4
18-26 ans	11,7	12,9	10,5
27-35 ans	12,6	14,2	11,1
36-44 ans	13,6	15,2	12,1
45-53 ans	12,4	14,0	11,0
54-62 ans	10,7	12,4	9,3
63-71 ans	8,3	9,0	7,9
72-80 ans	6,6	7,4	6,1
>80 ans	3,6	4,5	3,1
Décalage avec la cohorte née dans les années 50			
Cohorte née dans les années			
10	-3,2	-3,5	-3,1
20	-2,6	-2,0	-3,1
30	-2,0	-1,0	-3,0
40	-0,9	-0,8	-1,2
50	0	0	0
60	0,9	0,8	1,1
70	0,8	0,8	0,9
80	0,7	0,4	1,1
90	0,5	0,4	0,7
R² ajusté	0,480	0,497	0,473

Source : calculs IFSTTAR sur les EMD réalisées à Lille pour 1987, 1998 et 2006.

Guide de lecture du tableau 5 : Les paramètres sont ceux de l'équation de la section 3.1 ajustée sur les 3 enquêtes. Les coefficients d'âge (partie supérieure du tableau) correspondent aux distances parcourues par la génération de référence au cours de son cycle de vie. Les effets de génération (bloc suivant) sont représentés par les écarts avec la génération de référence (cohorte née dans les années 50).

Les distances parcourues augmentent en début de cycle de vie, culminent à la quarantaine, et diminuent ensuite (tableau 5). Elles sont un peu plus fortes chez les hommes que chez les femmes, à tous âges sauf aux âges de l'enseignement secondaire.

Les habitants de la Communauté Urbaine de Lille nés au début du XXème siècle (jusqu'aux années 30 pour les femmes) parcourent des distances relativement faibles. Les hommes les plus mobiles sont nés dans les années 60 ou 70 (jusqu'aux années 80 pour les femmes) ; et on retrouve un repli pour les générations plus récentes.

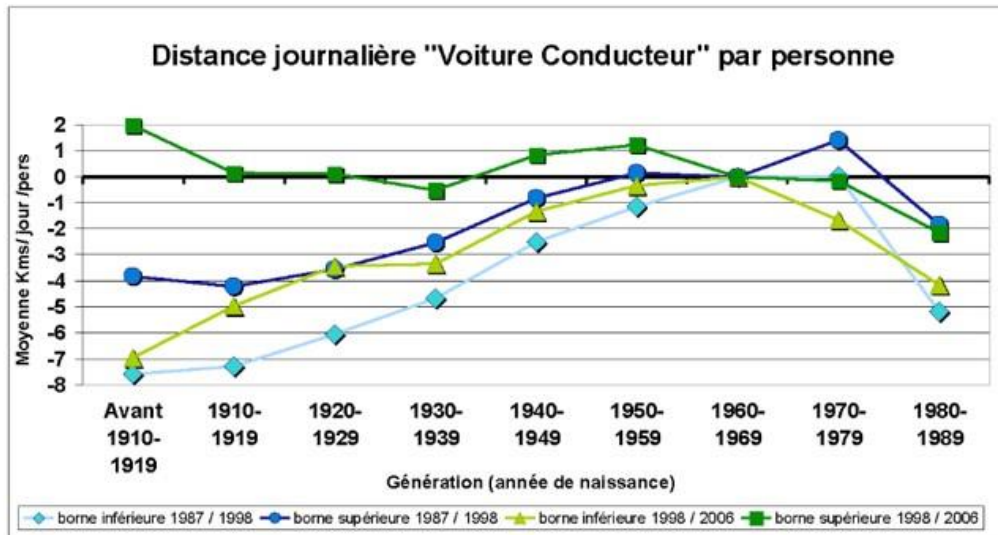
5.2 Y a-t-il une rupture de tendance au tournant du siècle ?

Quand le modèle est calé séparément sur les deux premières et sur les deux dernières enquêtes, nous observons que :

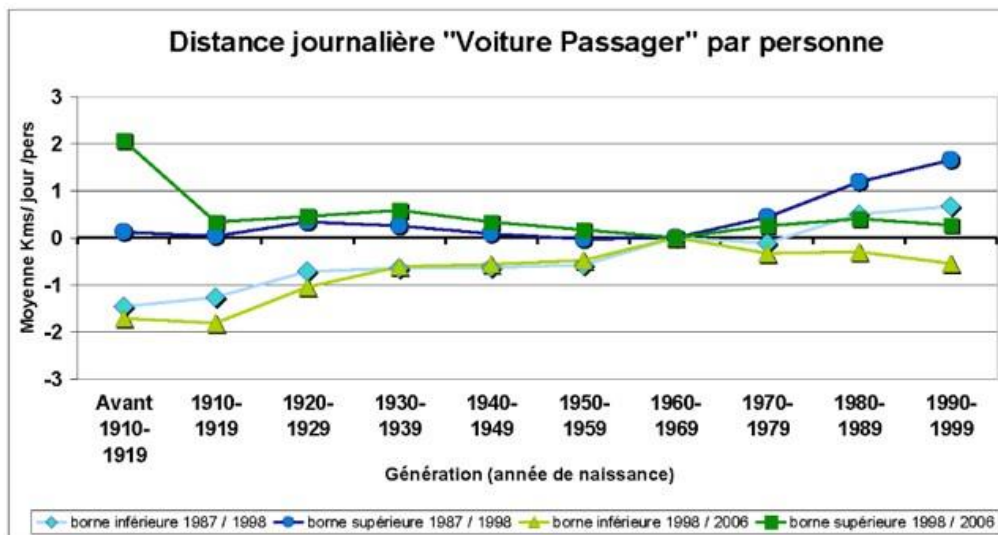
- la mobilité des jeunes (jusqu'à une vingtaine d'années) apparaît plus forte d'après les enquêtes les plus récentes, mais celle des personnes de 50 à 80 ans semble plus faible ;
- il y a significativement moins de différences entre les cohortes: au début des années 2000, les personnes nées des années 20 aux années 50 parcourent toujours des distances plus faibles que la cohorte de référence (née dans les années 50), mais l'écart qui les sépare est significativement plus faible que dans les années 90.

Analysons maintenant la mobilité assurée par les différents modes de transport. Pour les conducteurs de voitures (graphique 3), les écarts entre les cohortes successives tendent aussi à diminuer avec la disparition des générations nées au début du siècle dernier [Pochet, 1995 et 1997]. Du côté des passagers (graphique 4), la seule évolution significative du profil d'âge est un accroissement des distances parcourues par les enfants transportés par leur "maman-taxi" ; et il n'y a plus de différences significatives entre les cohortes dans les années 2000. L'utilisation des transports en commun (graphique 5) est significativement plus forte dans les années 2000 avant 45 ans, surtout autour de la vingtaine. Les bornes inférieure et supérieure des intervalles de confiance pour les coefficients du modèle montrent s'ils sont significativement différents avant et après 1998 (graphiques 3 à 5).

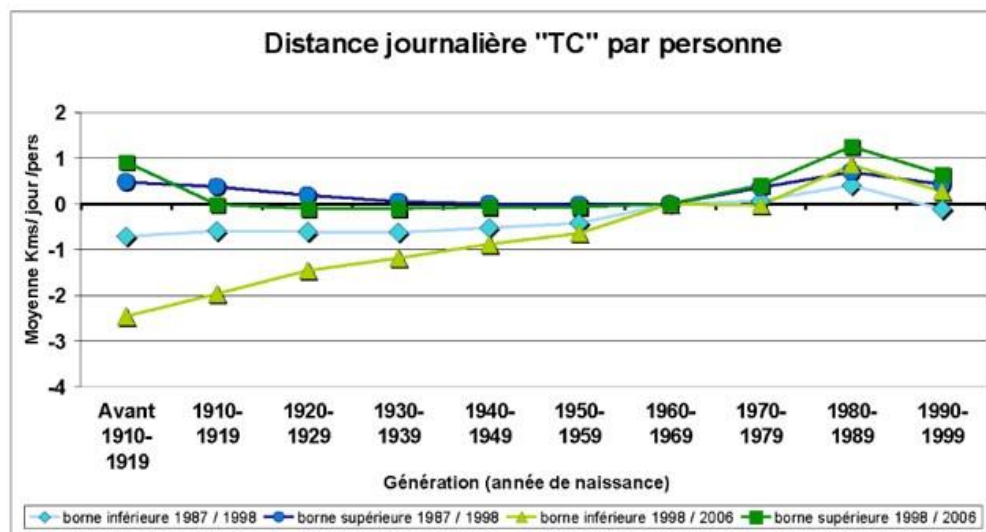
Graphique 3 : Distance moyenne journalière par personne «Voiture Conducteur» pour la cohorte de référence, Communauté Urbaine de Lille.



Graphique 4 : Distance moyenne journalière par personne «Voiture Passager» pour la cohorte de référence, Communauté Urbaine de Lille.



Graphique 5 : Distance moyenne journalière par personne en Transports en Commun pour la cohorte de référence. Communauté Urbaine de Lille.

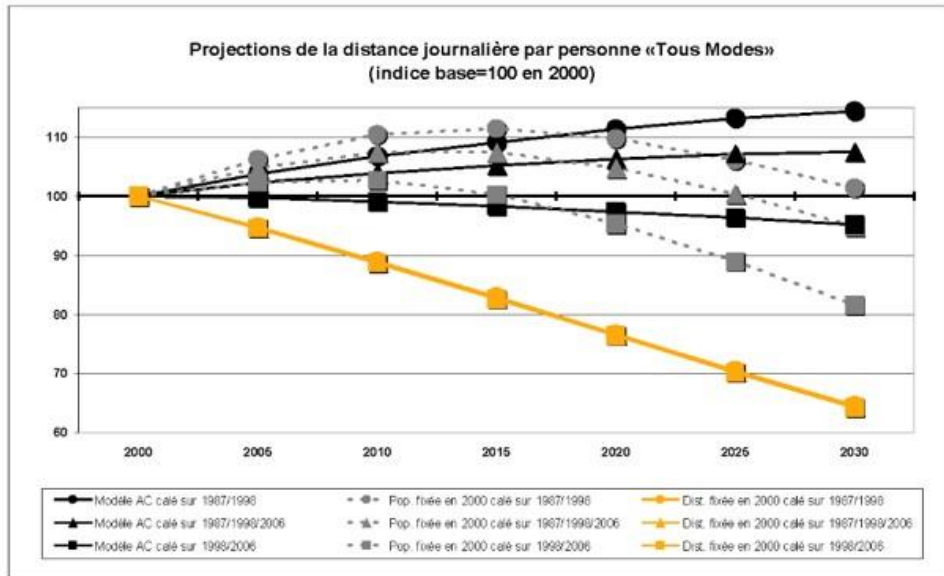


5.3 Et pour le futur ?

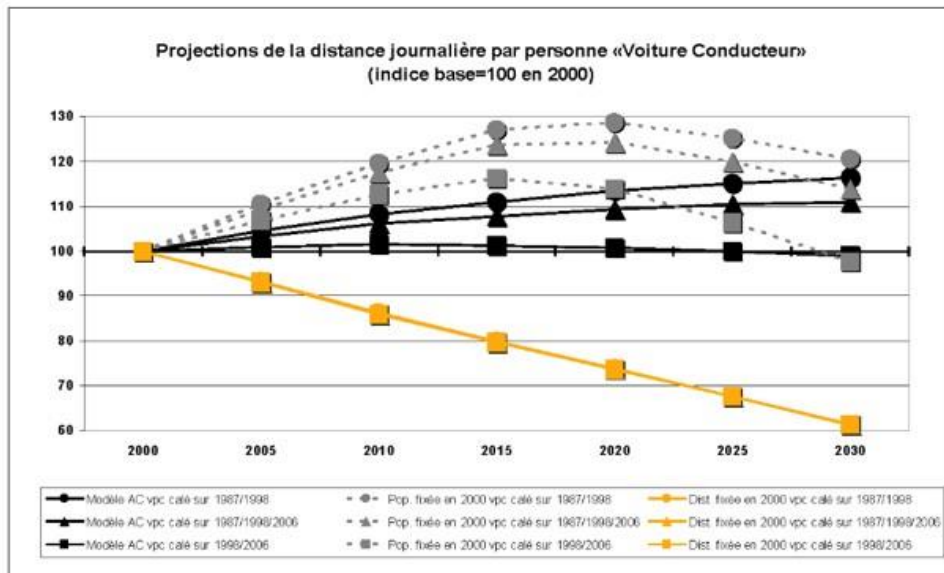
En s'appuyant sur les projections de population de l'INSEE, cette approche débouche aisément sur des exercices de projection à long terme. A L'horizon 2030, il en ressort que la part des adultes titulaires du permis de conduire devrait plafonner vers 75% dans la Communauté Urbaine de Lille. Quant aux distances parcourues, des différentes périodes de calage du modèle Age-Cohorte résultent des projections très contrastées :

- entre 2000 et 2030, la distance parcourue tous modes (graphique 6) se serait accrue de 15% d'après les enquêtes de 1987 et 1998, et devrait diminuer de 5% quand le modèle est calé sur 1998 et 2006,
- pour les conducteurs de voitures, donc en véhicules*km (graphique 7), on va de +18% à -1%,
- pour les passagers (graphique 8), les évolutions seraient similaires en calant le modèle sur les périodes 1987-1998 et 1998-2006, indiquant une stabilisation probable du taux d'occupation des véhicules, alors qu'il avait diminué de 10% entre 1998 et 2006,
- pour les transports en commun (graphique 9), on passe d'une progression de +18% en calant le modèle sur 1987 et 1998, à +38% en le calant sur 1998 et 2006.

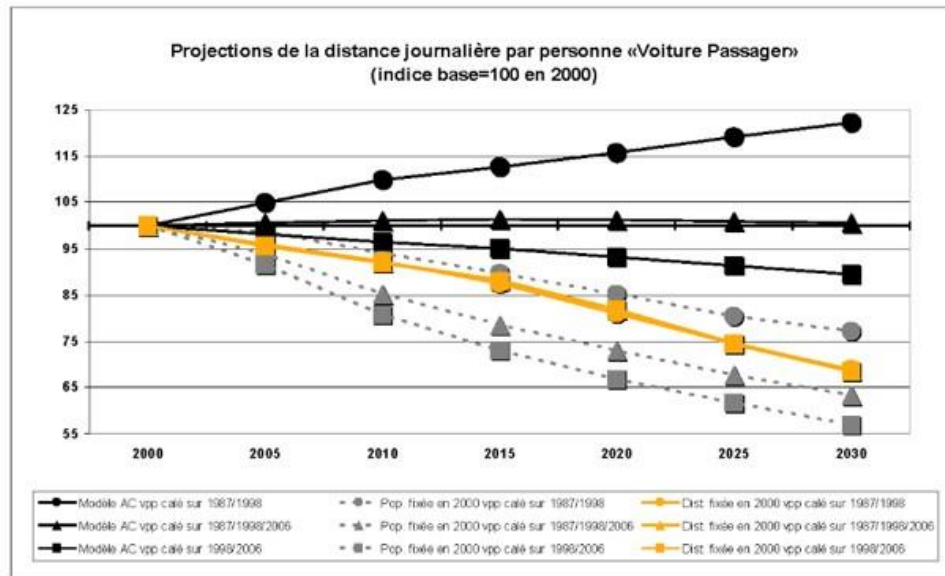
Graphique 6 : Projections de la distance parcourue (kms) moyenne journalière par personne «Tous Modes» (indice base =100 en 2000), Communauté Urbaine de Lille.



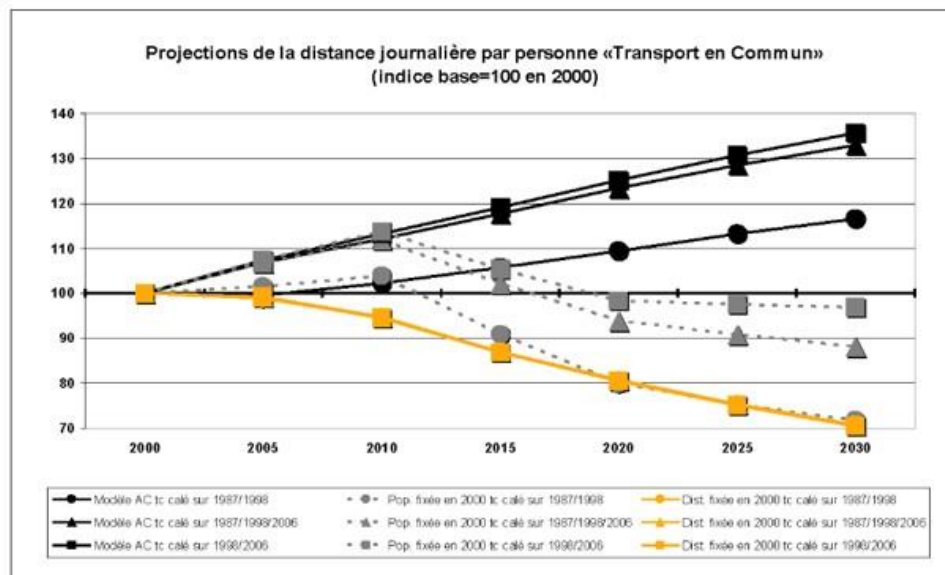
Graphique 7 : Projections de la distance parcourue (kms) moyenne journalière par personne «Voiture Conducteur» (indice base=100 en 2000), Communauté Urbaine de Lille.



Graphique 8 : Projections de la distance parcourue (kms) moyenne journalière par personne «Voiture Passager» (indice base=100 en 2000), Communauté Urbaine de Lille.



Graphique 9 : Projections de la distance parcourue (kms) moyenne journalière par personne «Transport en Commun» (indice base=100 en 2000), Communauté Urbaine de Lille.



Faute de pouvoir introduire des effets de période en raison du trop faible nombre de points d'observation, le modèle lisse les évolutions et ne fait apparaître le retournement de tendance dans les années 2000 que s'il est calé sur les deux dernières enquêtes ; le caler sur les trois enquêtes ne fait apparaître qu'un ralentissement de la croissance.

Afin d'évaluer le rôle joué par les différentes composantes du modèle Age-Cohorte, nous avons effectué deux simulations :

- l'une conservant les distances parcourues telles qu'estimées en 2000 et montrant uniquement l'effet du vieillissement de la population à travers la déformation de la pyramide des âges,

- l'autre pour montrer uniquement l'effet de comportement en conservant la structure de la population de 2000 à laquelle est affectée à chaque époque la mobilité (km/jour/pers.) calculée par le modèle Age-Cohorte.

Faire jouer seulement le vieillissement de la population à mobilité constante conduit à un mouvement monotone à la baisse (graphiques 6 à 9). Maintenir la structure d'âge de 2000 retarde le retournement de tendance pour " voiture conducteur " et " tous modes ", et casse l'essor des TC qui stagneraient à partir de 2015. Pour les " passagers voiture ", la projection " à population constante " est en-dessous de celle " à distances constantes ", contrairement à ce qui est observé pour les autres modes. On remarquera enfin que ces deux simulations conduisent à des projections de mobilité inférieures au modèle Age-Cohorte complet à l'horizon 2030.

6. Conclusion - discussion

Le modèle Age-Cohorte et la simulation "à population constante" ont permis de montrer, sur l'exemple de Lille, que le vieillissement de la population ne peut rendre compte seul du plafonnement de la mobilité observé dans les années 2000. Par rapport aux années 90, les distances parcourues par les jeunes se sont accrues malgré une certaine désaffection pour le permis de conduire, alors qu'on observe un tassement de la mobilité au cours du cycle de vie, une fois corrigés les effets de cohorte. La disparition des générations nées au début du siècle dernier, qui avaient eu peu accès à l'automobile, constitue un facteur notable d'homogénéisation entre les comportements des cohortes successives. Le vieillissement de la population, qui donne moins de poids aux jeunes, amplifie donc le phénomène de plafonnement : il orienterait les distances parcourues par tous les modes à la baisse s'il jouait seul. Ces différences significatives entre les comportements prévalant jusqu'aux années 90 et dans les années 2000 expliquent bien le retournement de tendance observé, et conduisent à des projections divergentes selon qu'on cale le modèle sur les enquêtes de 1987 et 1998 ou de 1998 et 2006.

La convergence entre la mobilité des hommes et des femmes devrait se poursuivre, mais à un rythme de plus en plus lent [Prédali, 2004 ; Dupont-Kieffer et Krakutovski, 2011] ; l'écart entre les distances journalières qu'ils parcourent devrait rester de l'ordre de 30% à Lille et de 20% en banlieue à l'horizon 2030. Lors de travaux futurs, l'analyse des distances parcourues par les détenteurs de permis serait utile pour considérer les influences respectives du « tassement de l'accès au permis » et d'autres effets comme le développement de la journée continue, un éventuel arrêt de la croissance des distances unitaires (ce qui supposerait de faire tourner le modèle sur le nombre de déplacements). Mais il faut être conscient que ces approches démographiques sont gourmandes en données.

Dans le cadre d'une prospective à plus long terme (par exemple sur l'atteinte du " facteur 4 " à l'horizon 2050, soit diviser les émissions de gaz à effet de serre par 4 en France à cet horizon), on pourrait jouer sur les hypothèses concernant principalement les phénomènes démographiques : natalité, mortalité, migrations internationales et intérieures (métropolisation et étalement urbain),... Il faudrait alors analyser les comportements selon le statut (étudiant, actif, retraité,...), et nous pourrions tester l'impact d'évolutions dans l'allongement des études ou le recul de l'âge de la retraite. Quant à l'effet des facteurs économiques (revenu et prix, notamment des carburants) il ne peut être estimé, en introduisant des effets de période, que quand on dispose de séries continues et non d'enquêtes isolées dans le temps [Berri et al., 2005]. Ce n'est qu'en suivant des cohortes d'individus, ce que nous allons entreprendre sur la base du panel Parc-Auto, que l'on pourra tirer des conclusions claires sur la contrainte financière quant aux comportements des jeunes générations (moindre accès au permis et moindre usage de l'automobile).

Le champ d'application de ces méthodes est toujours limité par les hypothèses sur lesquelles elles reposent. L'hypothèse d'espace clos impose de travailler sur des zones suffisamment vastes où le comportement des nouveaux arrivants ne diffère pas trop de celui des anciens habitants ; il en est de même pour la disponibilité des projections démographiques ainsi que pour les hypothèses sur les évolutions des revenus et des prix. De plus, il faut disposer d'observations en continu pour estimer l'effet des politiques de transport (influence des prix et de l'offre que pourraient prendre en compte des effets de période).

En conclusion, une bonne nouvelle : la saturation de la mobilité urbaine paraît réelle dans plusieurs villes du Nord, bien que certainement accentuée ou diminuée selon le cycle économique. Les efforts importants des autorités en faveur des transports collectifs menés dans le cadre des PDU (Plans de Déplacement Urbain) commencent à porter leurs fruits; la circulation automobile atteint ses limites, même si le taux d'occupation des véhicules reste faible. Il serait intéressant de comparer ces résultats avec des pays émergents où, dans la majorité des cas, le faible niveau d'équipement actuel, la pression démographique et la faible volonté politique sont plutôt défavorables pour une mobilité durable [Madre et al., 2012]. Pour combien de temps ?

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4.4.2 Per capita travel demand forecasts

4.4.2.1 Mobility forecasts in absolute numbers, 1 calibration

Per capita mobility forecasts are presented in Figures 4.17 to 4.20 describing average travel activity per person, in absolute numbers (traveled kilometers and number of trips). Regressions were tested with one calibration only considering all surveys available simultaneously in order to test the trend adjusted to all available data at once. Different calibration scenarios are tested further in Figures 1 to 6 from Annexes 10 and 11. Age-Cohort model was applied to a period covering from the year the period 2000 to 2030.

Results for “All modes” and in all case studies⁹⁴ (Figure 4.17) show a stabilization of trips per person and barely noticeable growth of traveled distance per person meaning that in all case studies, the average distance per trip is expected to increase.

Figure 4.18 shows results for Vehicle Driver mode, which had different results for each case study⁹⁵: Puebla had significant decrease in both kilometers traveled per person and traveled number of trips per person. The number of trips in this mode remains stable in Juarez, while the traveled distance experiences small growth. Lille had shown a slight increase for both mobility indicators.

Mexican cities will experience strong downward trend of Vehicle Passenger mode in terms of number of trips and traveled distance (Figure 4.19). In contrast, the city of Lille will maintain the same levels in mobility (trips and km) from 2000 to 2030.

Figure 4.20 shows Public Transport mode forecasts. This mode has different results for each case study. Barely noticeable decrease in Juarez and increase in Puebla and Lille. The growth is more important in the French city.

Description of travel behavior changes by age category (generation effect) can be found in section 6.3. Description of the Full Age-Cohort Model, Ageing AC Model and Behavior AC Model can be found in section 4.3.

⁹⁴ Data from Paris was obtained from Zoran [32].

⁹⁵ Paris Region was included for « All modes » only.

Figure 4.17. "ALL MODES" Age-Cohort travel demand forecast models

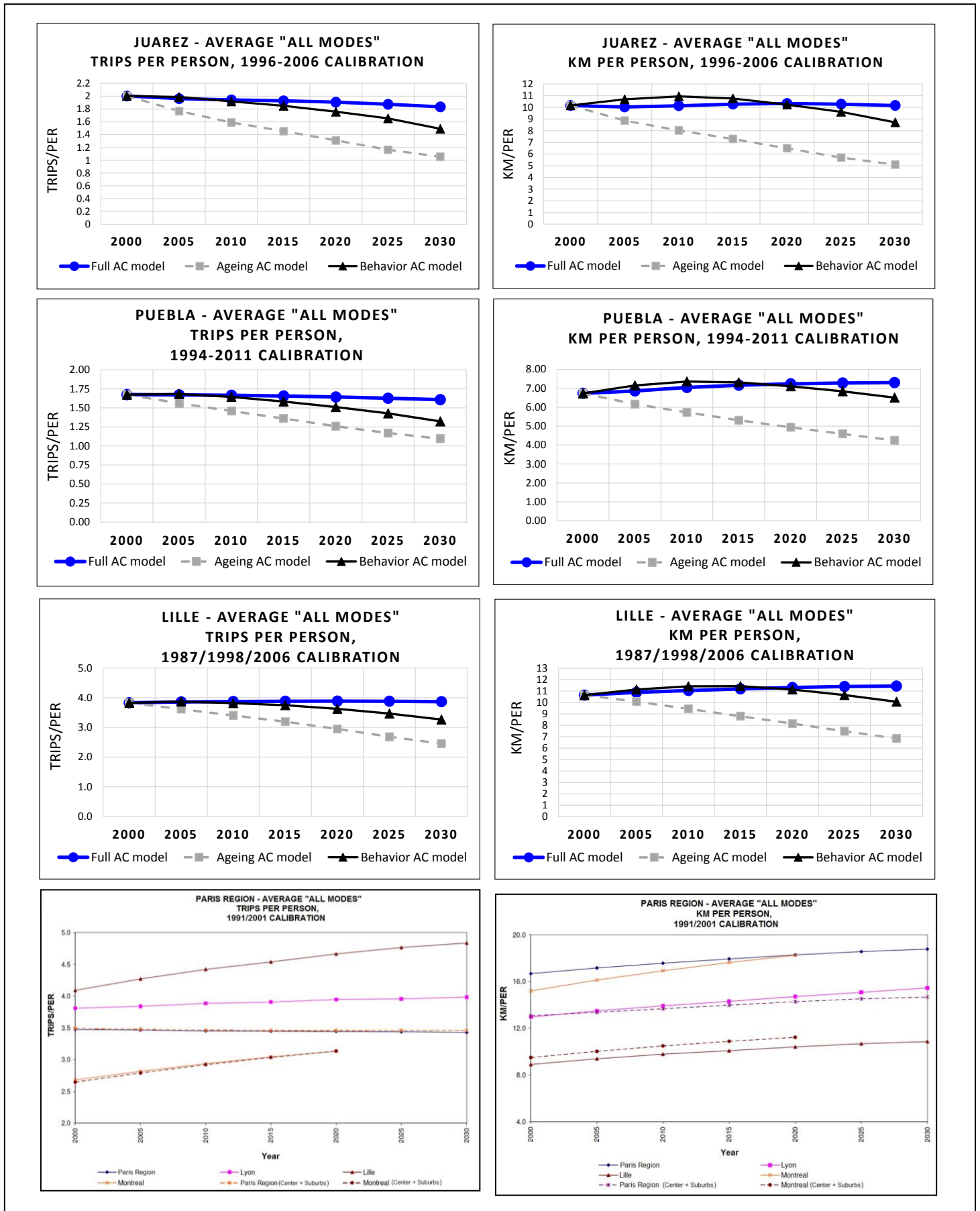


Figure 4.18. "VEHICLE DRIVER" Age-Cohort travel demand forecast models

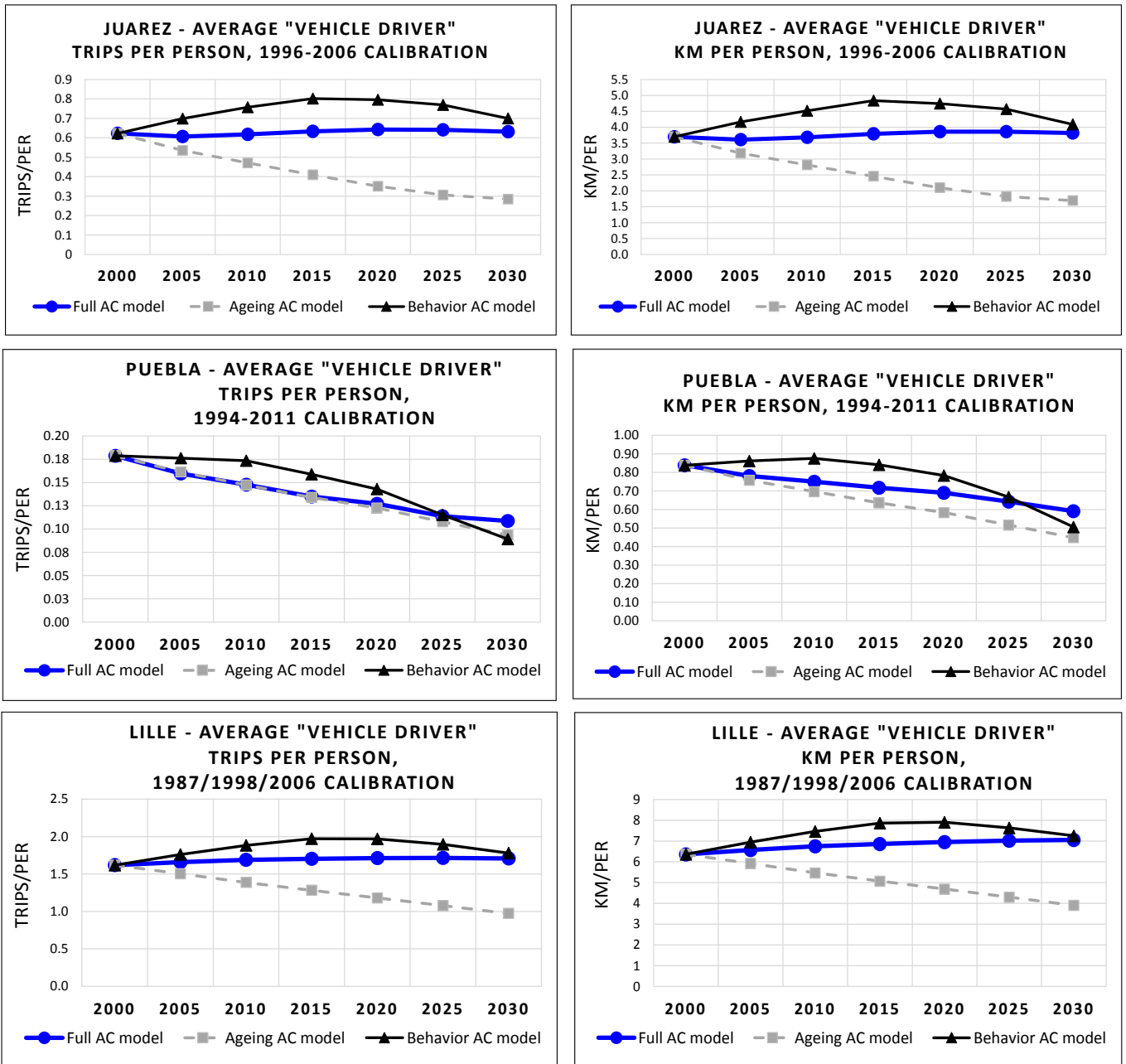


Figure 4.19. "VEHICLE PASSENGER" Age-Cohort travel demand forecast models

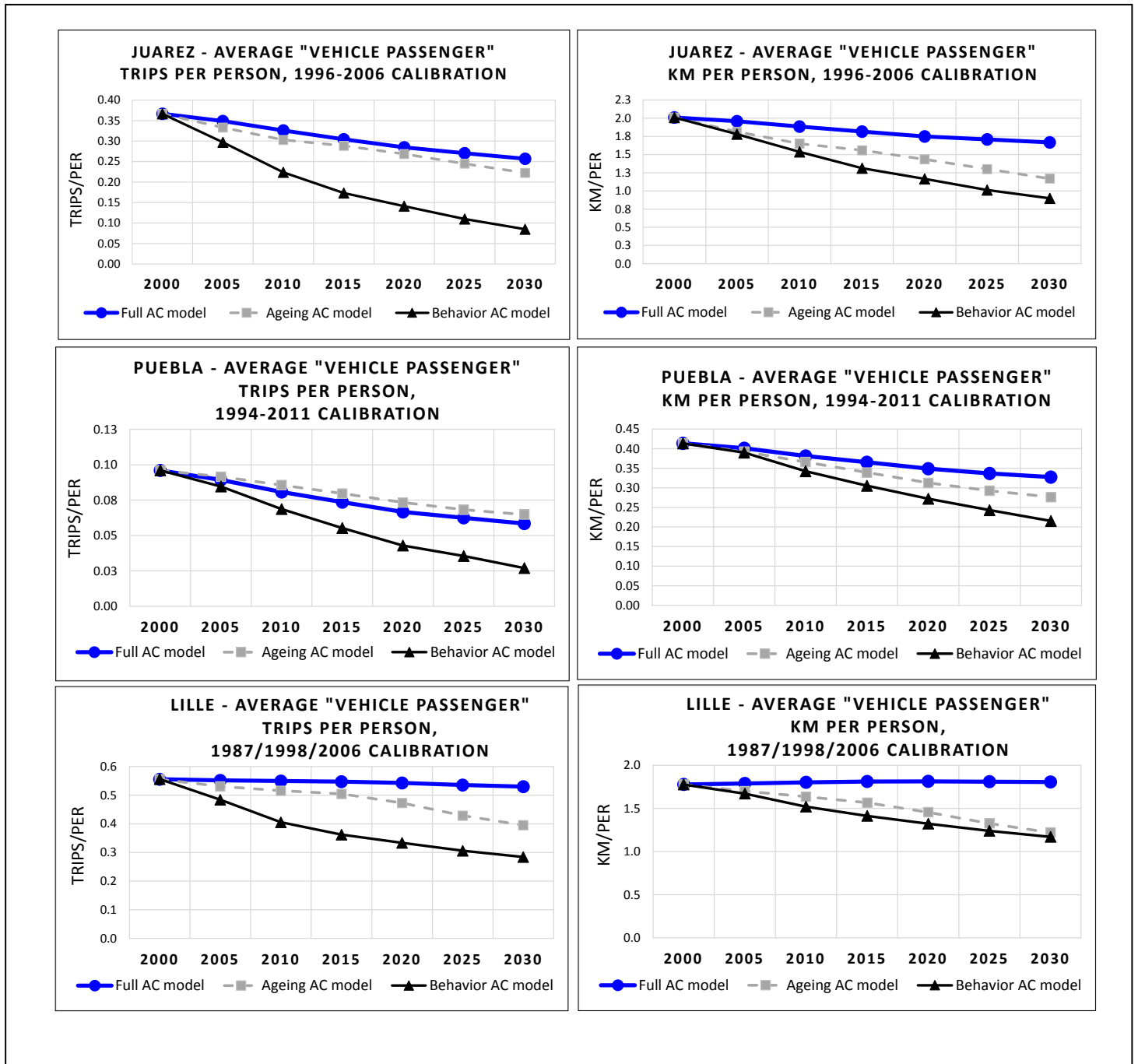
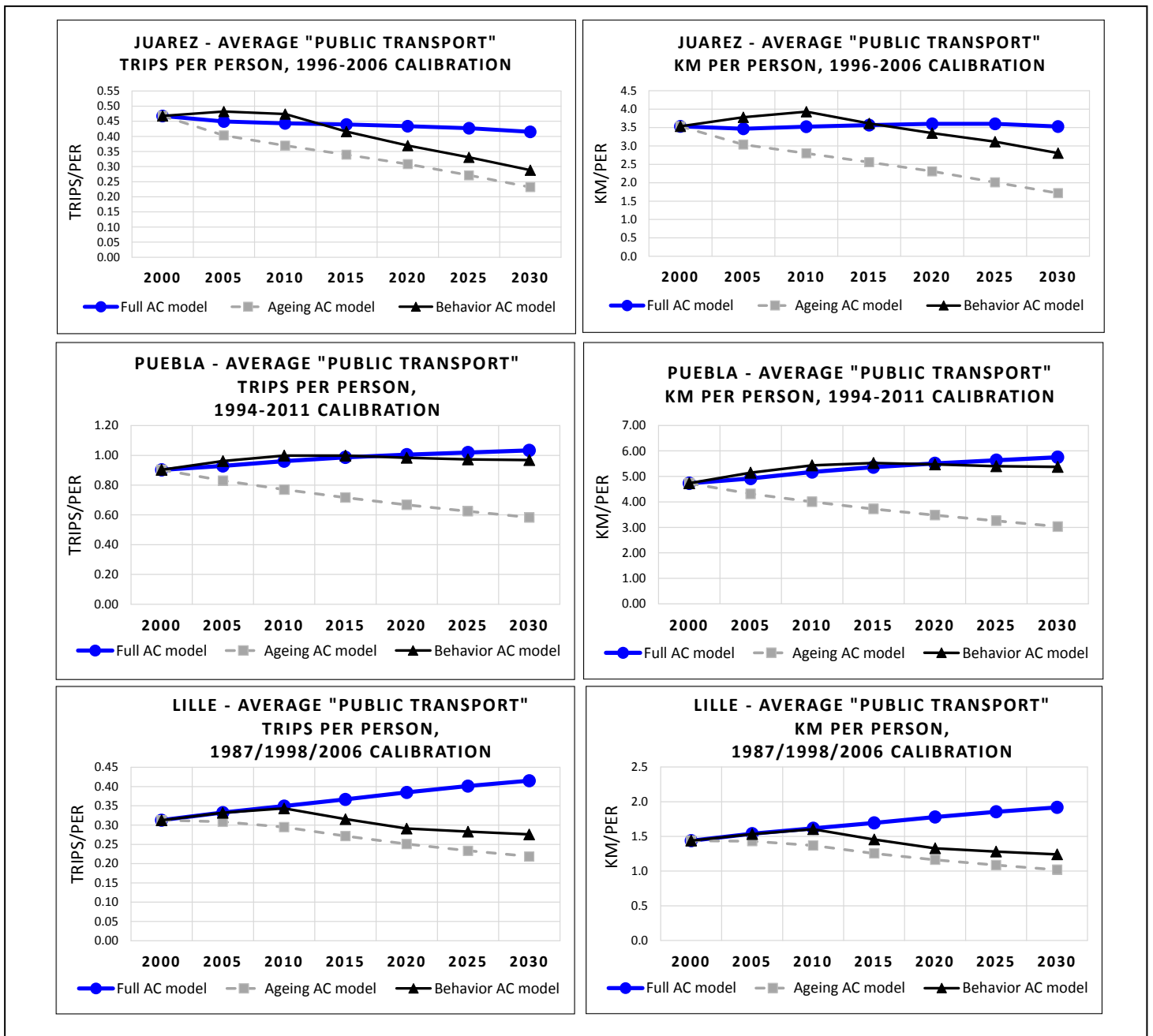


Figure 4.20. "PUBLIC TRANSPORT" Age-Cohort travel demand forecast models



4.4.2.2 Mobility forecasts in relative numbers, 2 calibrations

In order to facilitate the analysis of future per capita travel trends and to see if peak car and/or peak travel could be observed more clearly and in a more distant future the Age-Cohort model was applied to a period covering from the year 2000 to 2050 in Mexican cities. In addition, results are now shown in relative numbers in terms of a base index of 1 in the year 2000. Moreover, models shown in the next figures were

based on an additional calibration in order to see the differences in results between trends with and without more recent travel survey (e.g. 1994 vs 1994-2011) allowing us to identify recent changes in travel behavior which are applied in long-term travel demand.

For All Modes in Juarez we would see a stable demand in veh-km, the positive impacts of behavior being compensated by the negative impacts of ageing, in a context of slow demographic growth. For Vehicle Driver, the ageing factor is very different from the one observed in Puebla. It has a negative effect for all the period of forecast, but the Behavior Model gives a strong positive impact, reaching a peak around 2020. In the "Juarez Auto Driver Model" the impact of changes of population age pyramid and mobility behavior seems to slow down the private vehicle trend observed in the past (increase only of 10% from the base index to 2050) showing some evidence of saturation or peak car in developing countries. Nevertheless, ageing is not sufficient to slow down traveled kilometers by private vehicles, only to maintain same levels in the analyzed period. The Auto-Passenger reaches a peak in 2005 and then diminishes constantly. Public transit with the ageing model sees a downward trend for all the period. The Behavior Model gives a peak in 2015 and then diminishes constantly. The inflection for car-driver use point appears in 2020, which could not be explained by population ageing, since only 5.4% will be aged 65 or over in 2015, but probably by a beginning of saturation of individual car ownership, with 72% of households having cars, as compared with 84% in France in 2007-08, and 36.4% of households having more than one car, as compared to 38% in France in 2008 [150] and in contrast to other major non-border Mexican cities, where this percentage of households with at least one motorized vehicle hardly goes over 45%. In Mexico City for example, only 37% of the households have a vehicle available [159]. Here, also, average vehicle age is increasing as described in previous section.

With respect to Puebla, the behavior model shows a downward trend, which reflects the results of the O-D Surveys of 1994 and 2011 showing a decrease in personal motorization. A trend, which might not be structural since the O-D survey in 1994 was made in a peak economic activity and the 2011 O-D survey in a low economic context. Per capita Auto Passenger distance decrease and Total Auto Passenger distance increase and peaks at 2030 when calibrating with the base year 1994 and also with the calibration of 1994/2011 then decreases. This means that total distance increases mainly for demographic growth, since the ageing and behavior factor have a negative impact. Public Transport sees a negative impact with ageing (students use

them more than elderly) but strong impact with behavior (students and young adults use more and more PT), which reflects the results of the O-D's, which may extrapolate a cyclical phenomenon. For All Modes, veh-km reaches a peak around 2035 and then stabilizes.

The results for Lille presented here are based on a calibration of the model with the two most recent O-D surveys of 1998 and 2006 to capture the Peak travel effect. The simulation over the period 2000-2030 measuring the sole impact of ageing of the population with fixed behavior shows a monotonous tendency of diminishing mobility. If we keep the age structure of 2000 to measure the sole impact of changing behavior, this diminution is postponed for Auto Driver and All Modes and stops the renewal of Public Transport use, which would stagnate starting in 2015. For Auto Passengers the projection at fixed population structure of 2000 (behavior effect only) would be lower than the projection of ageing only, a result opposite than for the other modes. This could mean that there are more drivers (and less passengers) in the new cohorts of elderly who keep their car as long as they can drive it. For Public Transit use, ageing alone induces a decrease, because students use them more than elderly due mainly to decrease of mobility. The behavior model gives a diminution of use until 2010 then a decrease, and the complete Age Cohort model gives an increase in Public Transportation use.

In summary, Age-Cohort Travel Demand models (Figures 1 to 6 from Annex 10) calibrated with most recent Household Travel Survey compared to previous one influences future mobility trends towards:

- 1) important increases of per capita "All modes" traveled distance in Juarez and Puebla and negative impact in Lille;
- 2) the same per capita number of "All modes" trips in Juarez, small increase in trips/pers. in Puebla and important decrease in Lille for the same mode and mobility indicator;
- 3) small increase of per capita traveled distance as "Vehicle Driver" in Juarez , moderate decrease in Lille and important decline in Puebla;
- 4) small decrease in trips/pers. for "Vehicle Driver" mode in Juarez, moderate decline in Lille and important decrease in Puebla;
- 5) moderate decreases in "Vehicle Passenger" traveled distance per person in Puebla and Lille, and significant decline in Juarez;

- 6) significant decrease in “Vehicle Passenger” per capita trips in Mexican cities, and moderate decrease in Lille;
- 7) significant increases in traveled distance per person in “Public Transport” in Mexican cities and moderate positive change in Lille for the same mobility indicator;
- 8) moderate increase of number of “Public Transport” trips per person in Juarez and Lille, and significant positive change in Puebla.

4.4.3 Global travel demand forecasts

Projected travel demands depend heavily on population projections. The results presented in Figures 1 to 6 from Annex 11 relate to global travel demand forecast from Model 4 with demographic scenarios (a) and (b). Global or total distance and number of trips at city level were projected comparing models taking into account the increasing population and age pyramid changes (model a) versus total population fixed at year 2000 but with a changing age pyramid (model b) having different effects for each city. It is not surprising that both models show similar results for Lille and Juarez since both cities have a lower population growth rates compared to Puebla. Lille showed moderate growth rates and, as mentioned before, the population forecast of Juarez was projected taking into account the great deceleration due to population exodus of those escaping the violence and economic crisis and relocating people from Juarez to southern cities and to the U.S. in search for employment [160]. The contribution of population growth on transportation demand is greater in Puebla due to a strong increase of population in this city.

General trends of global travel demand⁹⁶ by mode show already stabilization of “All modes” in Juarez with a rate of 1.05 in the year 2050 with respect to 2000 for total travel distance (calibrated on 1996/2006 and with model (a)), and a decrease by 0.9 for total number of trips for the same calibration and population forecast. Puebla’s projections are more bell-shaped than other case studies. In Puebla, in order to put the results from the 1994-2011 calibration in perspective we made a simulation calibrated on 1994 only, in this case the Auto Driver simulation shows a strong increase until reaching a peak around 2030 and then diminishing matching the forecast made previously by Bussière [81] for this city. Here, “All modes” traveled distance based on model (b) and with 1994/2001 calibration, reach peak in the year 2030 at 1.1 with respect to the year 2000, while in model (a) it reaches its maximum

⁹⁶ Considering a constant geographical area over time.

point in the year 2040 with an explosive rate of 1.63 with respect to the year 2000 (Figure 3 from Annex 11). Peak travel is clearer in the French cities, at least for global number of trips, which are slowing down faster than global traveled distance. In fact, as can be observed in following figures, there is a gap between the level of development of trips versus distance forecasts in all case studies regardless the specificity linked to structural and behavioral changes of each city. In Juarez, Puebla, Lille and the Paris Region the slowdown is more pronounced in the trips forecasts compared to distance forecasts. "All modes" traveled distance trends in Lille decrease starting the year 2010 reaching a rate of 0.96 in 2030 with model (a) and 1998/2006 calibration. With respect to the number of trips the decline begins in the year 2000 reaching a rate of 0.91 in 2030. According to Zoran Krakutovski [32], rates in the Paris Region in 2030 with respect to 2000 are 1.09 for total number of trips and 1.25 for total traveled distance (Figure 4.21).

With respect to total vehicle traveled trips as a driver:

- it increases slowly but gradually in Juarez reaching a rate of 1.15 in 2050;
- it stabilizes between 2000 and 2010 in Puebla, then falls down to 0.9 in the year 2030 and then continues to drop reaching 0.75 in 2050;
- it stabilizes between 2000 and 2010 in Lille, then falls down to 0.92 in the year 2030.

With respect to total vehicle kilometers traveled as a driver:

- it grows slowly but continuously in Juarez reaching a rate of 1.09 in 2030 and 1.15 in 2050 with respect to the base year 2000;
- it reaches its maximum at 2020 in Puebla with 1.15 with respect to base year then decreases to 1 in the year 2040;
- it reaches peak car in Lille in 2010-2015 then gradually returns in 2030 at the levels observed in the year 2000.

With respect to total vehicle traveled trips as a passenger:

- it drops drastically in Juarez reaching a rate of 0.8 in 2020 and 0.6 in 2045 compared to base year 2000;
- it reaches its maximum in Puebla in 2005 with 1.05 then begin to drop reaching 0.9 in 2030 and 0.75 in 2050;
- it has already reached its maximum point at base year in Lille, falling to 0.85 in 2020 and 0.79 in 2030.

With respect to total vehicle kilometers traveled as a passenger:

- it drops significantly in Juarez reaching a rate of 0.9 in 2020 and 0.8 in 2040 compared to base year 2000;
- it reaches its peak in Puebla in 2030 with a rate of 1.15 then falls down gradually to base levels in 2050;
- it has already reached its maximum point at base year in Lille, falling to 0.9 in 2030.

With respect to total traveled trips by Public Transport:

- it has already reached its maximum point at base year in Juarez, falling to 0.9 in 2035 and continues to drop;
- it increase significantly in Puebla, reaching apparent maximum point in 2040-2050 with a rate of 1.75 compared to base year;
- it continues to increase in Lille, with a factor of 1.40 in 2030.

With respect to total traveled kilometers by Public Transport:

- it grows slightly in Juarez, up to 1.09 in 2025 where stays stable;
- it increases significantly in Puebla, reaching apparent maximum point in 2040-2050 with a rate of 1.9 compared to base year;
- it continues to increase in Lille, with a factor of 1.35 in 2030.

Furthermore, results show that travel demand forecasts depend largely on population projections. Figure 4.21 shows that “All modes” travel demand is not proportional to population growth in Juarez and Lille; this is particularly pronounced for total number of trips. With respect to population growth and total travel distance it is less proportional in Lille than in Juarez. Translating this travel demand into “All modes” per capita activity results show that in Juarez and Lille the average number of trips and traveled kilometers per person decrease as follows: demographic projections in Juarez is 1.03 in 2030 while trips/per 0.92, and km/per remains at 1 in 2030 after reaching its higher point at 1.02 in 2020. Demographic projection in Lille is 1.02 in 2030 while trips/pers. is 0.91, and km/per drops down to 0.95.

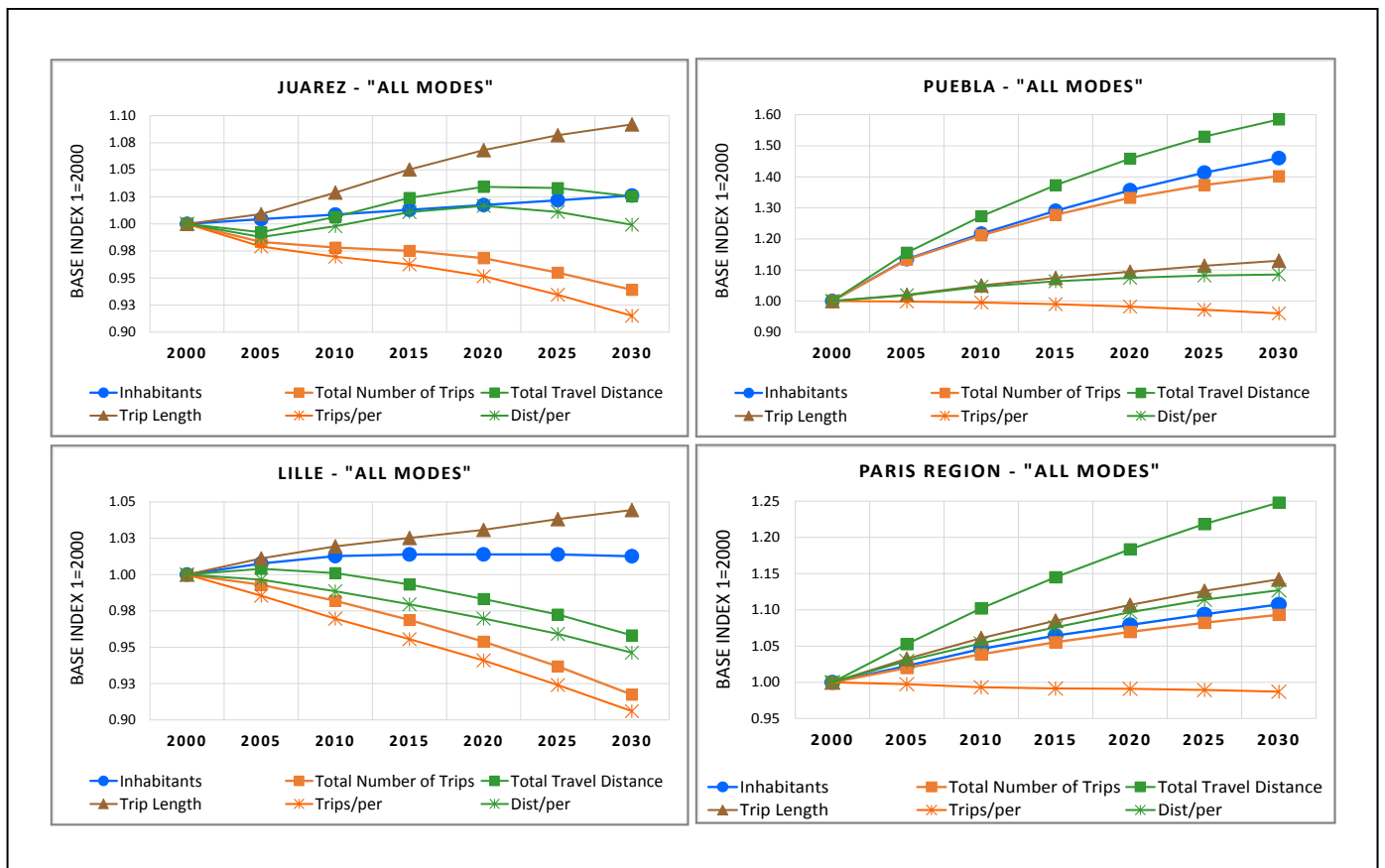
As shown in Figure 4.21 “All modes” trend lines from total inhabitants and total number of trips are proportional in Puebla and the Paris Region. In Puebla both trends are identical from 2000 to 2015. Then growth in “All modes” volume in Puebla is expected to change by 1.40 in 2030 while population by 1.45. In the Paris Region, total inhabitants and total number of trips grow almost identically reaching

approximately a rate of 1.1 by 2030. Total “All modes” travel distance is expected to grow similarly to population forecasts in Puebla and the Paris Region, but with a much rapid growth compared to the increase of total number of trips.

Translating this travel demand into “All modes” per capita activity, results show that in Puebla and the Paris Region the average number of trips and traveled distance per person changes as follows: demographic projections in Puebla is 1.45 in 2030 while trips/pers. are stable at base levels until slight decrease after 2010 reaching 0.96 in 2030, and km/per increase at a rate of 1.1 in 2030. Demographic projections in the Paris Region is 1.10 in 2030 while trips/pers. seems to be unchanged at base levels or at most 0.99 compared to the year 2000. With respect to travel distance per capita, it follows almost exactly the same trend as population forecasts but with a slight higher rate of 1.12 km/per in 2030 in relation to base year.

In all case studies the average travel distances per trip (trip length) will continue to increase. Average trip length growth in 2030 with respect to the year 2000 is 1.05 in Lille, 1.09 in Juarez, 1.12 in Puebla and 1.14 in the Paris Region (Figure 4.21).

Figure 4.21. Population and “All modes” Age-Cohort mobility forecasts



Source for the Paris Region: [32]

4.5 Chapter summary

A) With respect to forecasted total mobility⁹⁷ trends (Figure 4.21).

Decrease or Peak Travel is observed starting from:

- base year 2000 in total traffic volumes (total number of trips) in Lille and Juarez and continues to drop at a slightly higher rate in the French city;
- base year in trips per person in Lille and Juarez and continues to drop at a slightly higher rate in the French city;
- base year in total and per capita traveled distance in Lille, but with slower rates compared to trips;
- 2020 in total and per capita traveled distance in Juarez, per capita activity stabilizes at base levels in 2030, while total distance continues to increase slightly.

Stabilization of travel activity with respect to base year is observed in:

- Per capita traveled distance in Juarez after hitting its maximum at year 2020;
- Trips per person in Puebla and Paris in the period from 2000 to 2030.

Moderate growth of travel activity with respect to base year (2000) is observed in:

- Total travel distance in Juarez (1.03 in 2030);
- Per capita traveled distance in Puebla (1.1);
- Per capita traveled distance in Paris (1.13);
- Total number of trips in Paris (1.1).

Significant growth of travel activity with respect to base year (2000) is observed in:

- Total travel distance in Paris with a rate of 1.25 in 2030 with respect to base year;
- Total travel distance in Puebla (1.6);
- Total number of trips in Puebla (1.4).

In our case studies in Mexico, we can expect also a saturation phenomenon that could take place in roughly 20 years. With respect to emerging economies, despite the great disparities from one country to another, and from one city to another, the example of Puebla and Juarez can give us an idea of the magnitude of the challenge to be taken up in the years ahead: a determinant factor is population growth which will remain relatively strong for at least another one or two generations combined with unplanned urban growth, which significantly increases the use of motorized

⁹⁷ considering all modes of transportation.

modes. Yes, the trend towards ever-greater urban mobility, which seems to be reversing in developed countries, can be expected to spread to a number of emerging economies, but only in a couple of decades. The challenges for sustainable transport are as great as ever.

B) With respect to forecasted Travel Demand shifts due to calibrations.

The comparison across countries shows different patterns, reflecting the diversity of socio-cultural and economic contexts and of historical development. Is there a common pattern of development in terms of transportation trends in urban areas in France and Mexico? A way to identify relative trend patterns per mode after controlling for geography, and running per capita and total demand models is to make abstraction of all results by creating a trend matrix of all Age-cohort travel demand model forecast available (Annex 12). The purpose of this matrix is to facilitate comprehension and give a more clear insight not only of the different full Age-cohort models developed by mode but also their relative trend effects when adding (or calibrating with) the most recent survey into the models compared to the trends that included only the surveys developed in the 90's. The intention is to observe the variations in relative influences among surveyed years for each city/mode/model and to consider whether "peak travel" is resulting from mainly demographic previous trends, or if it is a "break" compared to previous trends.

A similar way of interpreting complex results from a trend decomposition approach but applied to national travel surveys was done by Kuhnimhof et al. [161], where in the light of comparing patterns of travel trend development from Germany, Great Britain, USA and France an aggregation of results into two different study periods was made in order to investigate the contribution of travel behavior changes and ageing of the population. After analysis of the Age-cohort model trend matrix a pattern appears in Puebla and Juarez. This pattern of travel trend development clearly separates both of them from the pattern of Lille⁹⁸. Indeed, the main difference is the strong decline of "All modes" models in the French city showing noticeable saturation or peak travel while in the Mexican cities there is still a relative positive influence for total mobility when taking into account latest surveys.

⁹⁸ Paris Region was calibrated with 1991-2001 only. This model was developed by Zoran Krakutovski [32] and is shown in Figure 4.21 and compared to other case studies below.

Two modes of transportation seem to have the similar relative trends with different calibration periods in the French and Mexican cities.

The first one is “Public Transportation” with an increasing relative influence with most recent surveys. The reasons could be very different from one country to another, as we expect for instance rapid and sooner ageing of the population in coming years in Lille, which might promote the shift to public transportation mode. On the other hand in the Mexican cities we expect ageing of the population years later in comparison to Lille and it is important to mention that there was no major public transport projects implementation in between both surveys, which leads us to link the increasing use of Public Transportation mostly to poverty. Public Transportation relative impacts are all positive but different; stronger in Puebla and lower in Lille and Juarez.

The second mode that have similar trends pattern of development in both countries is “Auto Passenger” which has a decreasing relative influence when taking into account most recent surveys. These relative impacts are directionally similar but different in magnitude; stronger in Lille and Juarez and lower in Puebla. Possible hypotheses that can be tested for viable explanation for having directionally similar trends in these three different cities are listed below having in mind that it is not in the scope of our study to attempt to quantify shift in mode of transportation over the years. Instead our methodology is to some extent comparable to the analysis done by Kuhnimhof et al., (2013) *“It doesn’t include the effects of individuals changing from one group to another”*, in the sense that each mode was projected separately and refers to within-group travel demand evolutions only [32]. As a matter of fact another promising path of research when data becomes available could be running all AC models including more disaggregate socioeconomic and spatial variables in order to better understand the determinants of urban mobility or applying mode choice modeling methods over long periods of time. Having clarified previous point, possible hypotheses for Puebla’s downstream trend of “Auto Passenger” could be that people might have shifted from “Auto Passenger” towards “Public Transport” due to poverty amplified probably by the economic crisis of year 2008 (Puebla is the only case study surveyed after this financial crisis), the appearance of generations more prone to the use of “Public Transport” and also probably due to possible survey bias. Besides to this probable shift from “Auto Passenger” to “Public Transport” due to generational or behavioral changes, in Juarez an additional possible hypothesis that needs to be tested for this city is the probable shift from

“Auto Passenger” towards “Auto Driver” even if Juarez shows a stable occupancy rate of 1.7 passengers per vehicle in 1996 and 2006 (as shown in next Chapter).

Annex 12 shows that total distance and per capita age-cohort models in Juarez seem to have slightly positive relative trend patterns. Additionally, as described in the next Chapter, longer trip distances in Juarez and Paris Region were traveled by less occupied vehicles. A decrease in “Auto Passenger” mode in developing countries is not good news for CO₂ emissions; on the other hand in this particular situation public policies could play an enormous role in shaping the future of sustainable mobility in the city in the form of infrastructure projects (e.g. HOV lanes, park-and-ride facilities, etc.) and strategies and incentives (e.g. carpooling) in order to reverse this significant decreasing trend of Vehicle Passenger trips and distance, at least for commuter trips (work and school purposes).

In France per capita car use had a decreasing trend after 90's (Kuhnimhof et al., 2013). Our methodology confirms this decrease trend for Lille, France. Actually we observed that both motorized modes had a decrease in relative trend probably because of strong ageing of population. “Auto Driver” mode in Puebla experiences also a decreasing relative trend only when taking into account the most recent survey implemented in 2011 so it has to be observed in the context, as mentioned before, of peak economic crisis that could have amplified the downstream trend of “Auto Driver”. We could probably expect a reverse of trend with future surveys. Opposed to the cases of Puebla and Lille, “Auto Driver” mode in Juarez has a strong positive trend. Urgent political action is needed for the purpose of diminishing CO₂ emissions and local pollutants related to private car use. The need to reverse this trend in this city is accentuated by the fact that the car fleet ageing is increasing significantly (see Chapter 5) and also because people drive bigger (more pollutant) vehicles compared to Puebla. As stated by [162] :

“Border cities drive larger and older vehicles, a higher percentage of foreign (north American) origin. The motorization rate (private vehicle / total population) is also higher in the northern border cities compared to the rest of the country (Mexico), mainly due to higher availability of used vehicles”.

Reducing the age limit of imported used cars is therefore one strategy for car fleet renewal in border cities. In Juarez peak car is not clear since the last survey shows a strong use of private vehicle and population ageing is not strong enough to slow down high motorization trends in following years. Even with apparent stabilization

and slowdown of motorized modes in Juarez and Puebla the problem will be accentuated due to the uncontrolled urban growth and lack of urban planning. That is, the new population is gradually living outside the original geographical limits of the city. People living in the outer suburbs (and even beyond) tend to be more car-dependent compared to people living in the rest of urban area. In addition, in the next decades if poverty persists and lack of strict regulation towards the importation of old vehicles in Mexican border cities, the answer to the demographic pressures towards more individual motorization may be further ageing of the vehicles. In spite of the complexity of having different observations and models to compare, the relative trend analysis shows different patterns of development between France and Mexico. However we expect also travel activity to have a peak in these Mexican cities but decades later compared to French cities. It is also clear that even if relative trends tend to be similar in Juarez and Puebla there is sufficient evidence that indicates that there is no general pattern in Mexican cities and mobility behavior can vary considerably from one city to another.

Chapter 5. ENVIRONMENTAL ASSESSMENT FROM DAILY MOBILITY

Chapter 5. Environmental assessment from daily mobility

Introduction

Chapter 1 described the need for reducing greenhouse gas emissions (GHG) in order to reach established targets in France of at least 60–80% reduction below base year (1990) by 2050. Since there is no viable way to meet these climate-protection targets without addressing transportation-related activities, the development of GHG emissions inventories at city level is hence needed. The objective of this Chapter is then to evaluate the consequences of observed urban mobility on air pollutant emissions. Socio-economic and geospatial factors are taken into account in these inventories.

The interest will be focused on the most populated area among case studies, the Paris Region (section 5.1.1). Then, GHG emissions calculations for Mexican cities and Lille are presented in Section 5.1.2⁹⁹. Section 5.2 explores in greater detail the driver-passenger dimension by focusing on occupancy rates in private vehicles and their influence on CO₂ emissions. Indeed, the trends envisaged in Chapter 4 have shown the declining trend of vehicle passenger mode in long-term projections.

In addition of the main objective of this chapter, which is to establish an exhaustive inventory for several Mexican and French cities, we focus on different methodological issues:

- The integration of ingoing and outgoing trips in the inventory and the imputation of the type of fuel when this information is missing, with the example of Paris Region,
- And the elucidation of an important, although often neglected, factor of energy efficiency: the occupancy rate (number of persons in vehicles).

⁹⁹ Calculations for Juarez and Puebla have been developed by the author, results from Lille are taken from [93].

5.1 The inventories of GHG emissions

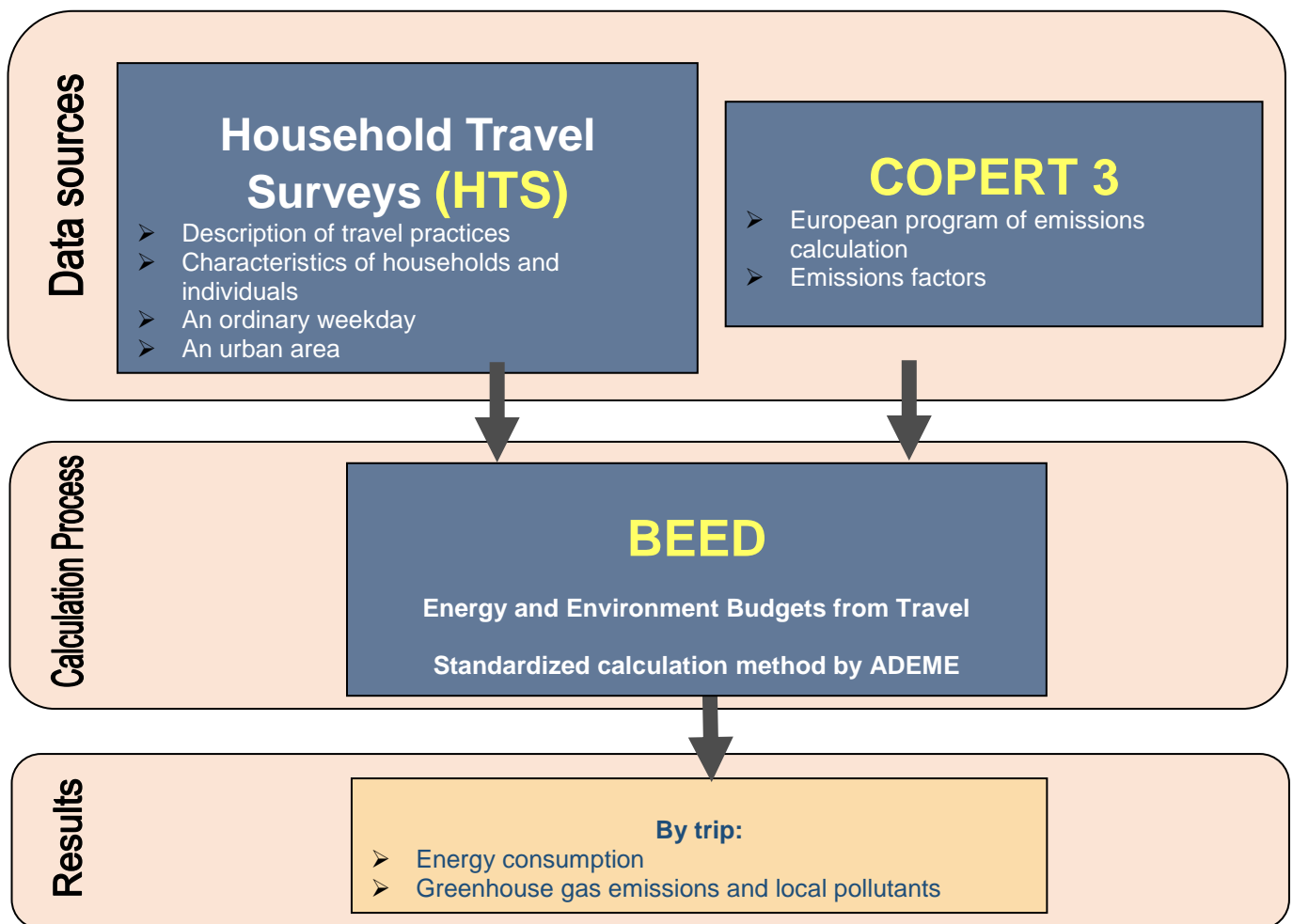
Table 5.1. BEED methodology description¹⁰⁰

BEED methodology: A closer look to a more detailed inventory
<p>The concept used, BEED (Energy Environment Budgets from Travel), is to assess, for an individual or a household, the energy consumed and the volume of pollutants emitted during their travel activity during a typical week day.</p>
<p>This approach differs from engineering methods and conventional inventories thanks to a more detailed analysis of the relationship between urban planning, residents' daily mobility and energy and environmental impacts. Therefore, it allows to account for differentiation between categories of individuals and households, with the intention to answer questions such as:</p>
<p>"Who consumes and who pollutes? And where?",</p>
<p>by linking transport-related energy consumption and emissions to socio-economic characteristics (e.g. income, profession, etc.), demographic characteristics (e.g. size and structure of households) and geographic characteristics (household location within the urban areas considered) and by the life cycle position from individuals (e.g. gender, age and activity status), just as captured in travel surveys.</p>
<p>Practically, the BEED method relies on Household Travel Surveys (HTS) to estimate and assess the consumption and emissions of each trip, as a function of its traveled length, speed and its (or their) mode(s) of transport(s) used, and its consumption and emissions coefficients derived from the methodology advocated in the MEET project, which resulted in the Copert3 model, harmonizing emission transport factors at European level.</p>
<p>Five pollutants (the main air pollutants emitted by vehicles) are estimated in the BEED method: CO₂, CO, VOC, NOx and Ps particulates. Quantities are estimated simultaneously with the energy consumption through the carbon assessment equation (see box in section 1.2.1 from [93]).</p>
<p>Conducting a BEED study requires knowledge of the length of each trip. Only trips made in the study area (internal trips) and only traveled by its inhabitants, are taken into account in the BEED method. As traveled distances are not recorded at the time of the survey, they are calculated afterwards based on origins and destinations of trips, as well as modes of transportation used.</p>
<p>These quantities (grams of oil equivalent and grams of pollutants estimated at the disaggregated finest level, that is for each trip - or the same unimodal path in a trip in more recent HTS) are then summed per individual and per households within city limits established at the HTS (e.g. an urban area, a town, district, etc.); these additions are a "Energy Environment Budgets from Travel" (BEED), consisting of a "Energy-Transport-Budget" or daily energy expenditure (assessed in "grams of oil equivalent") and an "Environment-Budget", indicating the volumes emitted (in grams) for each of the five gases and pollutants considered.</p>
<p>These budgets represent, per individual and per day, the energy consumption and total emissions of trips within the urban area of residence; they can be listed based on their socio-economic, demographic and geographic determinants. These analyzes makes the BEED methodology an original tool by linking the environmental assessment with the characteristics of individuals and their mobility patterns, placed in their spatial context, to better appreciate the link between urban choices, mode of operation of transport systems and mobility practices.</p>
<p>Finally, with a final addition, the method quantifies the total daily onsumption and emissions from the entire study area.</p>

Source: [93].

¹⁰⁰ Translation from original french version of BEED's methodology description is taken from [93]. Further information about this methodology can be found in [82, 83, 84, 85, 91, 92, 93, 94, 95] and section 5.1.1 of this chapter.

Figure 5.1. BEED methodology flowchart



Adapted from [93].

5.1.1 Paris Region¹⁰¹

¹⁰¹ This section is a reprint of: TAPIA-VILLARREAL, Irving. Évolution de la mobilité quotidienne, et de ses impacts en termes d'énergie et d'émissions : un diagnostic des évolutions en Île-de-France entre 1991 et 2001. <http://asrdlf2011.com>



<http://asrdlf2011.com/>

ÉVOLUTION DE LA MOBILITÉ QUOTIDIENNE, ET DE SES IMPACTS EN TERMES D'ÉNERGIE ET D'ÉMISSIONS: UN DIAGNOSTIC DES ÉVOLUTIONS EN ÎLE-DE-FRANCE ENTRE 1991 ET 2001.

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Résumé

Un des efforts majeurs des politiques de réduction des émissions de CO₂ en milieu urbain porte sur la gestion des déplacements. Ainsi, l'analyse et la compréhension des pratiques de mobilité quotidienne sont indispensables pour le développement durable des villes. L'objectif de cet article est d'analyser conjointement l'évolution de la mobilité quotidienne des habitants de la région Île-de-France entre 1991 et 2001 (dates des deux dernières enquêtes de mobilité disponibles lors de la rédaction de cette communication) et celle des conséquences environnementales de ces déplacements, en termes de consommation d'énergie et d'émissions de polluants locaux et de gaz à effet de serre (GES). Ce travail applique la méthodologie standardisée (DEED - Diagnostic Énergie Environnement Déplacement) sur des données issues des Enquêtes Globales de Transport (EGT). Le champ d'application de cette méthodologie, habituellement limité aux déplacements « internes » à la région urbaine francilienne, a ici été étendu afin de rendre également compte du poids des déplacements « d'échange », c'est-à-dire les déplacements des résidents dont l'origine ou la destination sont situés à l'extérieur du périmètre enquêté - ici l'ensemble de la Région Île-de-France. Un soin particulier a donc été apporté à l'estimation et à l'analyse de ces déplacements dits « d'échange ». Par ailleurs, une reconstitution minutieuse des données manquantes a été réalisée, notamment grâce à la modélisation des caractéristiques du parc automobile, dans le but de comparer ces deux EGT et donc de rendre compte de l'évolution décennale.

En visant à renforcer la compréhension des comportements de déplacement, nous précisons la comparaison du bilan global des émissions de polluants locaux et GES entre 1991 et 2001 grâce à une décomposition par modes de transport et nous isolons les principaux déterminants géographiques et socio-économiques sur la base du calcul des budgets-énergie-émissions quotidiens au niveau individuel. Cette recherche permet ainsi d'éclairer le lien entre comportement de mobilité urbaine et impacts environnementaux des déplacements.

Les résultats obtenus soulignent la forte croissance des émissions dans les années 90, liée d'une part au processus d'étalement urbain et d'autre part à l'augmentation du nombre des déplacements réalisés, des distances parcourues par jour en ÎDF, et du recours à l'automobile, en générant une quantité croissante de CO₂. Dans les années 2000, le plafonnement de la circulation, lié notamment à la diminution de la part des déplacements en voiture, a dû infléchir sensiblement cette tendance.

Au total, mettant en balance les impacts de ces différents éléments, les résultats montrent que les technologies sur les véhicules particuliers (ex. pot catalytique, filtre à particules, etc.) ne peuvent être, au moins quant aux progrès qui ont été réalisés dans les années 90, l'unique élément des stratégies de réduction des émissions des gaz à effet de serre et des polluants locaux.

Mots-clés

Mobilité quotidienne, évolution de la mobilité, DEED, émissions gaz à effet de serre, émissions de CO₂, enquêtes ménages déplacements.

Introduction

Dans le cadre de l'adhésion de la France au protocole de Kyoto en 1997 les pouvoirs publics sont amenés à prendre des mesures en vue d'une stabilisation des émissions polluantes en 2010 au niveau de celles de 1990 et d'une division par quatre des émissions de 1990 à l'horizon 2050. Dans ce contexte, ce travail vise à évaluer la manière dont les comportements de mobilité qui en découlent contribuent largement à la croissance des émissions de gaz à effet de serre et polluants locaux.

L'objet de l'article est d'étudier l'évolution du bilan du secteur des transports de la région Île-de-France notamment par l'analyse de la mobilité quotidienne des habitants sous l'angle des consommations d'énergie et d'émissions de polluants. Nous nous sommes intéressés aux bilans pour les années 1991 et 2001. Cela n'a pas seulement permis de situer la valeur de base « 1990 » établie lors du protocole à Kyoto, mais aussi de situer les valeurs obtenues en 2001 qui permettront d'identifier la tendance au cours de la décennie 90. Ce travail a été développé sur la base des Enquêtes Globales de Transport (EGT)¹⁰² de 1991 et 2001 d'Île-de-France.

Dans une première partie nous décrirons la méthode pour rendre compte du poids des déplacements « d'échange ». Nous expliquerons dans une deuxième partie la méthode de reconstitution des caractéristiques du parc automobile manquantes dans l'enquête de 1991. Nous analyserons les calculs des émissions polluantes effectués lors de l'application de la méthodologie standardisée « Diagnostic Énergie Environnement des Déplacements » (DEED)¹⁰³, et seront présentés dans une troisième partie les principaux résultats obtenus. Finalement une quatrième partie sera l'occasion de mettre en évidence dans quelques conclusions les principales évolutions des mobilités franciliennes de 1991 à 2001, qui permettront d'approfondir les connaissances des liens entre mobilité quotidienne et impacts environnementaux.

¹⁰² C'est une enquête auprès d'un échantillon représentatif de l'ensemble des ménages de la RIF (région Ile de France), qui recense l'ensemble des déplacements des personnes (de 6 ans et +) au cours d'une journée.

¹⁰³ Elaborée par l'INRETS-DEST et par l'ADEME [Gallez et al., 1998] puis réactualisé en 2010 [Quételard, 2010] permettant notamment d'obtenir des calculs d'énergie plus proches par rapport à la mobilité observée. Les améliorations du logiciel consistent notamment à l'actualisation des facteurs d'émissions de polluants.
<http://www2.ademe.fr/servlet/KBaseShow?sort=-1&cid=96&m=3&catid=13711>

1. Traitement des déplacements d'échange

1.1 Délimitation de la zone d'étude.

Nous avons analysé dans le bilan interne les déplacements dont l'origine et la destination sont à l'intérieur de l'aire d'étude qui est constituée des 8 départements d'Île-de-France (75, 77, 78, 91, 92, 93, 94, 95). Les déplacements dits « d'échange » donc qui sortent ou entrent dans le périmètre francilien, seront également pris en compte dans le bilan global, mais pas ceux de transit ne faisant que traverser la région. La méthode utilisée consiste à évaluer pour tous les déplacements réalisés et pour tous les modes de transport¹⁰⁴, au niveau ménage ou individu, les conséquences environnementales de la mobilité, c'est-à-dire l'énergie consommée et les substances polluantes émises au cours d'un jour de semaine en hiver hors vacances scolaires. Les principaux polluants atmosphériques routiers estimés dans cette étude sont le dioxyde de carbone (CO₂), le monoxyde de carbone (CO), les composés organiques volatils (COV), les oxydes d'azote (NO_x) et les particules en suspension (Ps). Par ailleurs, il existe des limitations à la cartographie des consommations et des émissions polluantes dues aux déplacements des franciliens, limitations qui sont inhérentes à l'usage des Enquêtes Globales de Transport. « Le périmètre de la région Île-de-France retient des communes rurales éloignées de Seine-et-Marne, mais n'intègre pas celles du sud de l'Oise qui sont pourtant plus proches de Paris » (Hivert, Lecouvey 2006).

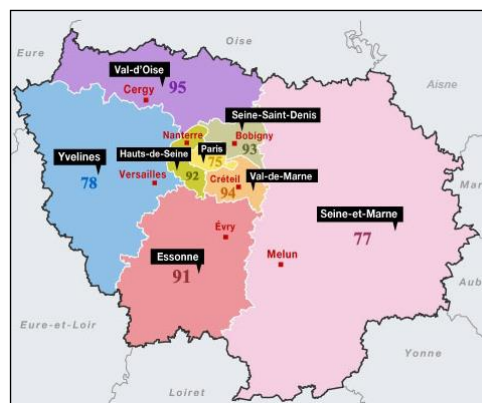


Figure n° 1 : Zone d'étude : Île-de-

Ainsi l'aire enquêtée est fixe d'une enquête à l'autre malgré le développement toujours plus important de l'urbanisation. En raison de la disponibilité des données nous n'avons exploité dans ce travail que l'information incluse dans le découpage administratif imposé dans les EGT, ce qui signifie que nous avons respecté ses limites géographiques dans le présent diagnostic environnemental.

1.2 Contrainte méthodologique du « DEED classique ».

La zone d'enquête¹⁰⁵ a été divisée en carrés de 300m de côté, appelés carreaux. Ce zonage est la base utilisé a posteriori dans la méthode « DEED classique »¹⁰⁶ afin de calculer les

¹⁰⁴ Nous avons exclu à dessein dans ce rapport le transport aérien ainsi que le transport de marchandises.

¹⁰⁵ Enquête Ménage Déplacement 1991 et 2001

¹⁰⁶ Diagnostic Énergie Environnement des Déplacements consacré à l'analyse des consommations énergétiques et des émissions polluantes dues à la mobilité quotidienne des résidents dans une région urbaine.

distances des déplacements qui s'effectuent selon la méthode « à vol d'oiseau » entre le carreau d'origine et celui de destination (CERTU 2005)¹⁰⁷ défini comme:

Distance (Zone A à Zone B) = $((X_b - X_a)^2 + (Y_b - Y_a)^2)^{1/2}$
où les centroïdes des zones A et B ont respectivement pour coordonnées (Xa, Ya) et (Xb, Yb).

Figure n° 2 : Méthode de calcul de distance du déplacement.

Nous expliquerons l'inconvénient majeur lié à l'usage du DEED « classique » lorsqu'on étudie des déplacements d'échange réalisés entre l'intérieur et l'extérieur du périmètre (ou vice-versa). Cette contrainte concerne principalement l'utilisation du logiciel DEED-ADEME¹⁰⁸ qui ne fonctionne que sur les déplacements "internes" à la zone d'étude. A priori cette approche a comme conséquence la méconnaissance de la localisation de l'origine ou de la destination des déplacements d'échange donc, la méconnaissance de la distance parcourue.

Constat de départ

Elimination des individus non mobiles ou externes¹⁰⁹

Test de l'existence d'un déplacement pour chaque individu.

→ si déplacement, test sur le caractère interne du déplacement

→ si déplacement externe (ZORI¹¹⁰ ou ZDEST¹¹¹ non présent dans le fichier zone) élimination du déplacement (et de tous les trajets attachés) et actualisation du fichier individu, ménage.

→ si non déplacement, élimination de l'individu, et élimination du ménage s'il est seul dans le ménage.

Figure n° 3 : Critères d'élimination des individus lors de l'utilisation du logiciel DEED

Rappelons également que dans le cadre du DEED « classique » l'EMD nous permet d'estimer les impacts environnementaux uniquement pour les déplacements dont on connaît la distance ou dont on reconstitue la longueur entre carreaux, c'est-à-dire seulement pour la mobilité quotidienne des résidents qui est interne au périmètre de l'enquête. « En un mot, le DEED, comme l'enquête-ménages, n'est initialement centré que sur les déplacements voyageurs internes » (Dupont, et al., 2009). Par conséquent, les individus ne faisant pas de déplacement ou n'effectuant un déplacement qu'en dehors de l'aire d'étude sont automatiquement éliminés des fichiers créés par le DEED « classique »¹¹². Comme mentionné précédemment, la méthode nous impose de ne pas dépasser le périmètre d'Île-de-France, néanmoins nous devrions, dans la mesure du possible, bien prendre en compte toutes les parties des déplacements réalisées à l'intérieur de ce périmètre.

¹⁰⁷ La sinuosité du réseau a été mise en compte par le CERTU à partir des coefficients de correction qui conduisent à des paramètres a posteriori appliqués à chaque mode de transport pour calculer la distance de chaque déplacement.

¹⁰⁸ Logiciel mis en place par (cf. [Gallez et al., 1998], [Quételard, 2002] et [ADEME et al., 2002])

¹⁰⁹ Source : 'Logiciel DEED : Diagnostic Energie Environnement Déplacements. Présentation et Analyse fonctionnelle du logiciel DEED. Réalisé par l'ADEME avec le concours de l'INRETS et d'IMTrans, 2002.

¹¹⁰ ZORI=Zone d'origine du déplacement ¹¹¹ZDEST=Zone de destination du déplacement

¹¹¹

¹¹² Nous exploiterons et décrirons toutes les déplacements internes dans le bilan interne ÎDF.

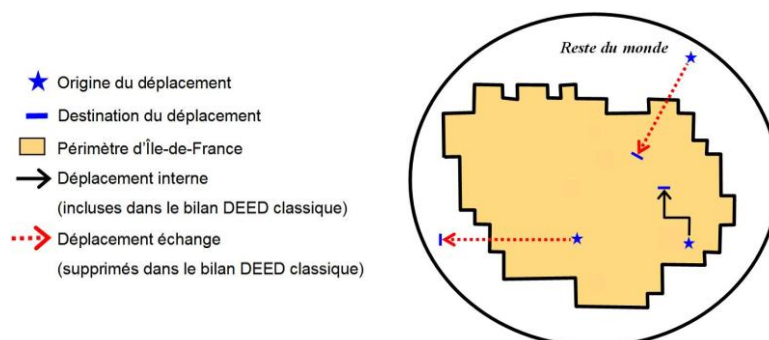


Figure n° 4 : Critères d'élimination de déplacements (méthode actuel).

Les effets négatifs de cette élimination de données conduisent à un bilan incomplet, d'une part par la suppression de certains déplacements d'échanges parcourus à l'intérieur du périmètre : par extension des émissions polluantes liées à ces trajets, et d'autre part par la suppression de ménages et d'individu qui réalise ce type de déplacement. Notre premier objectif sera donc de récupérer et de représenter dans le bilan global les parties « internes » des déplacements « d'échange ». Dans cette étape, nous nous intéressons notamment à l'analyse des résidents enquêtés au niveau ménage et individu qui sortent ou entrent dans le périmètre francilien, ceci afin de les prendre également en compte dans le bilan environnemental global. Nous voulons répondre aux questions suivantes : le poids des déplacements d'échange est-il négligeable à l'échelle de la région francilienne ? Pourquoi doit-on reconstituer les déplacements d'échange ? Quelles sont leurs caractéristiques et leurs impacts dans le bilan global ? Le tableau n°1 montre la répartition par type de trafic (nombre de déplacements effectifs) de l'enquête ménage déplacements Région Île-de-France 1991 et 2001.

Type de trafic	1991	2001
interne	32852709	33898560
échange	271209	324982
Ensemble	33123918	34223542

Tableau n° 1 : Répartition par type de trafic

En 1991 et 2001 la partie des déplacements internes représente 99% tandis que la partie des déplacements d'échange est 1%. Nous avons observé également des cas où les origines et les destinations de déplacements sont situées hors de la zone d'enquête. Ce type de trafic appelé transit, et qui sera négligé dans cette étude représente (0,01%) en 1991 avec 4468 déplacements effectifs ainsi que (0,03%) en 2001 avec 7929 déplacements effectifs. On notera que les déplacements traversant l'Île-de-France, souvent effectués par des non-franciliens, échappent aux EGT. Par ailleurs, selon l'organisation de données dans les enquêtes EGT¹¹³ la longueur du déplacement peut se décomposer en la somme des trajets¹¹⁴ composant ce déplacement. Nous avons donc analysé au niveau désagrégé les trajets composant chaque déplacement classé d'échange¹¹⁵ dans le but de retenir toutes les informations existantes. Au niveau désagrégé correspondant à l'année 1991, le nombre total des trajets non-pondérés liés aux déplacements d'échange est de 1052 trajets dont 396 trajets (38%) ont des distances renseignées. En 2001 nous avons au total 1069 trajets non-pondérés dont 262 trajets (25%) dont on peut calculer la distance entre le carroyage d'origine et le carroyage de destination. Ces informations sont directement utilisables dans le bilan global des émissions de GES (38%

¹¹³ Méthodologie CERTU

¹¹⁴ Ainsi appelés moyens

¹¹⁵ Déplacements sortants et entrants du périmètre francilien.

de trajets en 1991 et 25% de trajets en 2001). Nous rappelons que normalement ces trajets (et ses déplacements) sont supprimés dans la méthode DEED « classique ». Cette analyse nous a permis d'identifier les trajets d'échange sans distance renseigné dans les EMD et pour lesquels nous proposerons ensuite un traitement spécial afin de les retenir dans le bilan environnemental global.

1.3 Reconstitution des trajets d'échange

Dans cette étape, nous proposerons une méthode de reconstitution de distances pour les trajets d'échange sans distance renseigné. Cet article vise à établir une hypothèse permettant d'intégrer les déplacements d'échange dans le bilan environnemental global. Comment peut-on calculer les émissions polluantes des trajets d'échange en respectant le périmètre rigoureusement établi dans les EMD? Quels types d'hypothèses devrait-on formuler pour incorporer les déplacements d'échange dans la méthode DEED? Dans cette partie nous décrirons le traitement pour la prise en compte des déplacements d'échange.

Dans le cas des déplacements sortants, nous ne pouvons pas calculer la distance parcourue au cours du dernier trajet car le carroyage de destination n'est pas renseigné dans les enquêtes EGT. Dans le sens opposé, nous ne pouvons pas calculer la distance parcourue du premier trajet réalisé correspondant au déplacement entrant car le carroyage d'origine n'est pas renseigné dans les EGT.¹¹⁶ Un soin particulier doit donc être apporté à l'estimation réaliste de ces distances méconnues. La figure n°5 montre le périmètre d'Île-de-France, dans lequel nous représentons des trajets d'échange différents afin de comprendre l'approche méthodologique proposée.

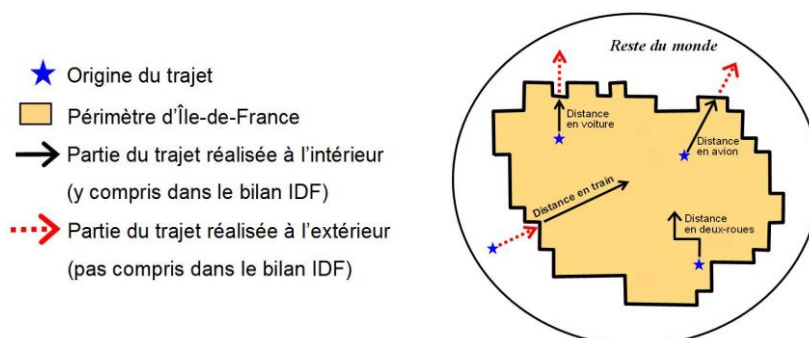


Figure n° 5 : Critères de reconstitution des trajets (méthode proposée).

Par convention, une délimitation du territoire sera effectuée et permettra de définir, si nécessaire, la limite entre l'Île-de-France et les départements voisins. Nous proposerons une approche suivant une logique de découpage des trajets d'échange (sortants et entrants) dont on n'affectera¹¹⁷ à la région d'Île-de-France que les émissions polluantes émises à l'intérieur de cette région. Par exemple, si la partie du trajet sortant se prolonge vers l'extérieur du périmètre d'étude, un découpage du trajet sera fait à dessein afin de respecter cette limite géographique avec en ligne de mire de ne récupérer que la partie interne dans le bilan ÎDF (figure n°5). C'est-à-dire que toute distance parcourue en dehors de l'Île-de-France, et par extension les émissions qui lui sont liées, seront attribuées dans le bilan environnemental de la

¹¹⁶ Pour les déplacements transit, le carroyage de destination n'est pas renseigné seulement pour le dernier trajet réalisé. Également le carroyage d'origine n'est pas renseigné seulement pour le premier trajet réalisé.

¹¹⁷ Réincorporer dans le bilan global les parties du trajet correspondant à l'intérieur du périmètre francilien.

région voisine. Rappelons que le problème ne se pose que pour l'estimation de la distance parcourue à l'intérieur de l'Île-de-France. Pour calculer ces distances manquantes, nous avons toujours fait l'hypothèse que chaque voyageur choisit le plus court chemin. Tout compte fait, la plus proche sortie (ou entrée) sur le périmètre de la région nous semble correcte pour les hypothèses que nous voulons formuler.

Par ailleurs nous avons tracé délibérément dans la figure n°5 des trajets d'échange réalisés en utilisant des modes de transport différents afin de remarquer que dans les EGT toutes les informations concernant le mode de transport utilisé sont toujours renseignée pour la totalité des trajets. Cela nous permettra d'appliquer a posteriori des facteurs d'émissions à chaque trajet une fois que la reconstitution de leurs distances sera effectuée. Par conséquent, nous avons fait l'hypothèse du plus court chemin parcouru à « vol d'oiseau ». Les distances seront calculées à l'aide d'un Système d'Informations Géographiques (SIG) de façon automatique pour l'ensemble des 165081 carreaux pavant l'Île-de-France. Nous avons tout d'abord mis en place des centroïdes représentant chaque carreau et qui ont pour but de permettre le calcul de la distance entre le périmètre et chaque centroïde ou carreau, notamment grâce aux fonctions SIG qui permettent le calcul des distances en respectant l'espacement minimal entre les centroïdes et le périmètre francilien.

Nous constatons dans la figure n°6 que le plus court chemin ou parcours possible est toujours pris en compte entre les centroïdes et la limite du périmètre représentant l'aire d'étude.

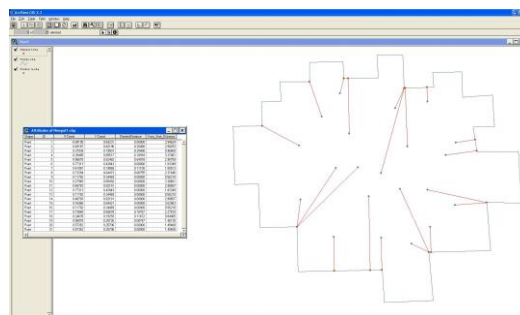


Figure n° 6: Outil de géotraitement

2. Méthodologie de la simulation du type de carburant pour l'EMD 1991.

La consommation d'énergie et les émissions polluantes estimées dans la méthode DEED s'obtiennent en fonction de la distance parcourue et du mode de transport utilisé. Pour ce dernier nous avons besoin de préciser les caractéristiques du parc automobile qui détermineront les facteurs d'émission, et donc la quantité de polluants émise au kilomètre parcouru. D'ailleurs dans certaines EGT, les caractéristiques des véhicules sont absentes dans le tableau ménage. Dans l'EGT 2001, la variable « type de carburant utilisé » est renseignée. Pourtant lors de l'enquête 1991, la question n'avait pas été posée. Grâce à une modélisation nous avons reconstituée la variable manquante « Type de carburant » en utilisant les variables disponibles, à savoir celles portant sur l'année de mise en circulation et sur la puissance fiscale. Rappelons enfin que cette simulation n'a été conduite qu'à partir des caractéristiques des véhicules particuliers, nous n'ajouterons ou ne modifierons donc aucune information concernant les autres modes de transport.

2.1 Caractérisation du « type de carburant »

Avant de simuler le type de carburant utilisé lors d'un déplacement, nous avons en premier lieu identifié la structure du parc automobile par type de carburant. Cela a notamment été possible par les relations existantes entre les variables « année de mise en circulation », « puissance fiscale » et « type de carburant » disponibles dans l'enquête nationale Parc Auto 1990 France entière (tableau n°2).

Année de mise en circulation <1980				
Puissance Fiscale	VP1		VP2, VP3, VP4	
	%Diesel	%Essence	%Diesel	%Essence
2 à 20 cv	0	100	0	100

Année de mise en circulation > 1985				
Puissance Fiscale	VP1		VP2, VP3, VP4	
	%Diesel	%Essence	%Diesel	%Essence
2 et 3 cv	0	100	0	100
4 cv	12	88	13	87
5 cv	33	67	25	75
6 cv	35	65	35	65
7 cv	10	90	10	90
8 cv	5	95	5	95
9 cv	5	95	5	95
10 cv	5	95	5	95
11 à 20 cv	0	100	0	100

Tableau n°2 : Vagues annuelles ParcAuto 1990 France entière.¹¹⁸

2.2 Simulation du type de carburant

Dans l'étape précédente nous avons identifié le profil de la structure du parc en fonction du type de carburant grâce aux données existantes dans ParcAuto 1990 France entière. Cela nous permettra de simuler l'information manquante. Ensuite, nous avons obtenu une classification en fonction du rang du véhicule dans le ménage (1er, 2ème, etc.), du « type de carburant » (essence ou diesel) mais aussi à partir de l'année de mise en circulation et de la puissance fiscale. Dans le tableau ci-dessous sont listés les résultats de la simulation réalisée dont les pourcentages Essence-Diesel des voitures principales et secondaires correspondent aux mêmes pourcentages observés et ressemblent aux proportions données par les profils établis à partir de la base de ParcAuto 1990 France entière.

Carburant véhicule particulier 1	Pourcentage	Carburant véhicule particulier 3	Pourcentage
Essence	85,19%	Essence	65,03%
Diesel	14,81%	Diesel	34,97%
Carburant véhicule particulier 2	Pourcentage	Carburant véhicule particulier 4	Pourcentage
Essence	68,87%	Essence	65,52%
Diesel	31,13%	Diesel	34,48%

Tableau n° 3 : Type de carburant simulé pour l'enquête 1991.

2.3 Simulation de l'existence du Pot Catalytique

Après avoir simulé les pourcentages des véhicules essence et diesel, nous avons également identifié les véhicules équipés de pots catalytiques¹¹⁹. Dans le tableau n°4 nous présentons un rappel de la chronologie d'apparition du pot catalytique en fonction de la puissance fiscale et du type de carburant utilisées dans cette simulation.

¹¹⁸ Calculs développés par Laurent Hivert au sein d'IFSTTAR/DEST.

¹¹⁹ Le principe du catalyseur est destiné à réduire les gaz polluants imbrûlés à l'échappement et a été mis au point sur les véhicules plus récents avec le but de répondre aux normes internationales en matière environnementale.

Condition	Essence	Diesel
Année < 1989	Non catalytique	Non catalytique
1989 => Année < 1992 et Puissance Fiscal entre 2 et 10 Chevaux	Non catalytique	Non catalytique
1989 => Année < 1992 et Puissance Fiscal = 11 Chevaux	33% Avec pot catalytique	Non catalytique
1989 => Année < 1992 et Puissance Fiscal entre 12 et 23 Chevaux	Avec pot catalytique	Non catalytique
Année = 1992 et Puissance Fiscal = > 12 Chevaux	Avec pot catalytique	Non catalytique

Tableau n°4 : Utilisation du pot catalytique en France.

	Type de carburant véhicule 1		Freq.cumulée	Pourcentage
	Fréquence	Pourcentage		
cumulé				
2: Diesel sans pot catalytique	1751	15.70	1751	15.70
3:Essence avec pot catalytique	46	0.41	1797	16.12
4:Essence sans pot catalytique	9354	83.88	11151	100.00

Tableau n°5 : Résultats finales des simulations¹²⁰

Le tableau n°5 affiche les variables « type de carburant », résultats de la macro appliquée à l'année 1991. En confrontant le parc automobile issu de cette simulation à celui fourni par l'enquête « ParcAuto » France entière 1990 déjà décrit, nous pouvons valider la représentativité du parc, ce qui nous permet donc de l'utiliser avec la méthode DEED dont nous allons montrer le bilan à l'étape suivante.

3. Calcul des émissions et de la consommation énergétique.

D'abord, on obtient la consommation d'énergie et les émissions polluantes liées à chaque déplacement (Dupont et al, 2009) en multipliant les facteurs unitaires issus de la méthodologie COPPERT III¹²¹ par la distance parcourue. Ensuite, pour estimer les budgets quotidiens nous avons additionné les consommations et émissions liées aux déplacements pour chaque unité au niveau individu ou ménage. Cette méthode nous permet de générer un bilan global, ainsi que diverses analyses désagrégées.

$$\begin{aligned} Cons_{\text{dépl}} &= UCons^{\text{mode}} \cdot Dist_{\text{dépl}} \\ Emis_{\text{dépl}} &= UEmis^{\text{mode}} \cdot Dist_{\text{dépl}} \end{aligned}$$

$$DEED_{ind} = \begin{cases} TEB_{ind} = \sum_{\text{dépls}} Cons_{\text{dépl}, ind} \\ PEB_{ind} = \sum_{\text{dépls}} Emis_{\text{dépl}, ind} \end{cases}$$

3.1 Résultats globaux

Cette partie reprend les résultats les plus importants, en valeur absolue et en évolution 2001/1991. Dans un premier temps, nous souhaitons quantifier la répartition par type de trafic en IDF. Le poids des déplacements d'échange est-il donc négligeable dans le bilan environnemental global? Pour répondre à cette question, nous présenterons les déplacements et émissions polluantes en mettant en évidence les impacts des déplacements internes vis-à-vis des déplacements d'échanges afin d'évaluer leur contribution à l'échelle globale. On peut observer la tendance croissante dans les années 90 du nombre de déplacements pour tous les

¹²⁰ La simulation des véhicules 2, 3 et 4 été également réalisé.

¹²¹ « Computer Programme to Calculate Emissions from Road Transport est une méthodologie européenne permettant le calcul des émissions du transport routier. L'ADEME préconise cette méthodologie pour le calcul des émissions réelles, méthodologie qu'elle a adaptée à la situation française et mise en oeuvre dans la version 2.0 du logiciel IMPACT-ADEME ». Source: ADEME(2003) Logiciel IMPACT-ADEME Version 2.0 : émissions de polluants et consommation liées à la circulation routière. Livret de présentation.

types de trafic (tableaux 6 et 7). Ce bilan montre également une faible proportion des déplacements d'échange par rapport aux internes, (0,8%) en 1991 et (1,0%) en 2001 (figure n°7). On a constaté l'importance toujours largement prédominante du poids du trafic interne, en revanche les déplacements d'échange ont crû rapidement entre 1991 et 2001. Si les composantes du trafic interne se caractérisent par une légère augmentation globale (+3% Dépl, +9% Cons, et +5% CO2), des disparités très marquées existent par rapport aux déplacements d'échange qui ont fortement augmenté entre 1991 et 2001 (+20% Dépl, +26% Cons, et +20% CO2) (figure n°8). D'ailleurs, on constate toujours une augmentation des émissions liées aux déplacements internes et d'échanges malgré les technologies apparues pendant la période (tableau n°4). La proportion des déplacements d'échange par rapport au total du CO2 émis (tonnes) est de l'ordre de 2,6% en 1991 et 3,0% en 2001, alors que les proportions des déplacements effectués sont 0,8% et 1,0% respectivement. Ces différences peuvent être expliquées par des choix modaux contrastés entre les voyageurs « d'échanges » et les voyageurs « internes », notamment par une plus forte utilisation de la voiture (figure n°14).

1991	Dépl	%	CONS	%	CO2	%
Interne	32852709	99,18%	8315	97,66%	25034	97,40%
Entrant	137863	0,42%	97	1,14%	322	1,25%
Sortant	133346	0,40%	103	1,21%	346	1,35%
Ensemble	33123919	1	8514	1	25701	1

2001	Dépl	%	CONS	%	CO2	%
Interne	33898560	99,00%	9104	97,30%	26192	97,03%
Entrant	165819	0,50%	122	1,30%	388	1,44%
Sortant	159163	0,50%	130	1,40%	415	1,54%
Ensemble	34223542	1	9356	1	26995	1

Tableau n° 6 : Répartition par trafic et tonnes de CO2 en 1991

Tableau n° 7 : Répartition par trafic et tonnes de CO2 en 2001

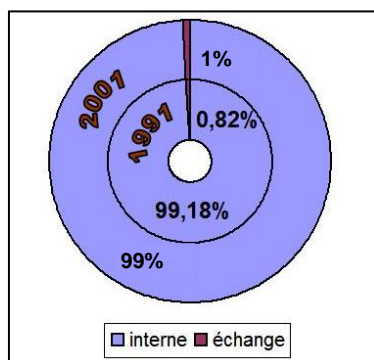


Figure n° 7 : Répartition par type de trafic

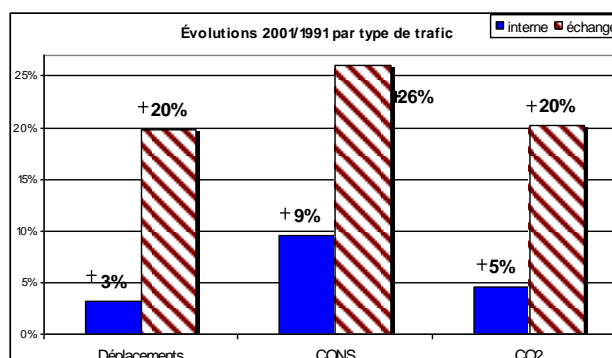


Figure n° 8 : Principaux évolutions par type de trafic

3.2 Bilan pour les déplacements internes à la région

En ce qui concerne les déplacements internes on peut constater (tableau n°8) une augmentation (+3,2%) du nombre de déplacements internes, (+4,7%) de la distance parcourue, (+20,1%) de la durée, (+9,5%) de la consommation de carburant et (+4,6%) de CO2, tandis que les polluants NOx et PS diminuent pendant cette période. Pour un déplacement interne moyen, le tableau n°9 confirme les tendances toujours en augmentation de la durée du déplacement (+16%) pendant la période étudiée. Par contre on observe une stabilisation de la distance parcourue du déplacement moyen (+1%) pendant la même période.

Bilan Interne	1991	2001	%Variation
Déplacements	32852708	33898560	3,2%
Distance (1000 km)	227798	238502	4,7%
Durée (1000000 hr)	12,22	14,68	20,1%
Vitesse (km/hr)	16,4	15,2	-7,3%
CONS (tonnes)	8314	9104	9,5%
CO2 (tonnes)	25033	26192	4,6%
CO (tonnes)	473	664	40,4%
HC (tonnes)	77	82	6,5%
NOx (tonnes)	110	102	-7,3%
PS (tonnes)	29,7204	9,34576	-68,6%

Tableau n°8 : Bilan Interne

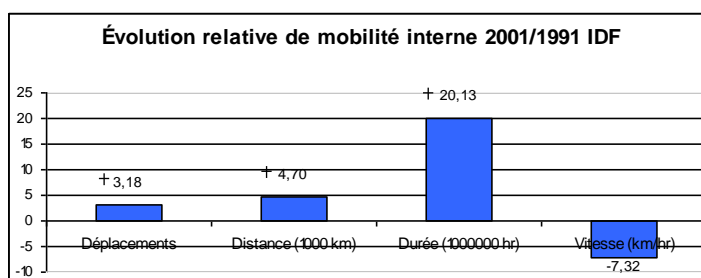


Figure n° 9 : évolution relative de la mobilité interne

Par ailleurs, le bilan interne au niveau individuel montre une stabilisation globale (-1,7%). En revanche, on observe que les franciliens passent plus de temps pour se déplacer pendant une journée (+14,4%) et se sont déplacés plus lentement en passant de 16,4km/h en 1991 à 15,2km/h (tableau n°10).

Déplacement Moyen	1991	2001	%Variation
Distance km	6,9	7,0	1%
Durée hr	0,4	0,4	16%
CONS gr	253,1	268,6	6%
CO2 gr	762,0	772,7	1%
CO gr	14,4	19,6	36%
HC gr	2,3	2,4	3%
Nox gr	3,3	3,0	-10%
PS gr	0,9	0,3	-70%

Tableau n° 9 : Déplacement moyen

Bilan Individuel	1991	2001	%Variation
Dépl. Internes	3,53	3,47	-1,7%
Distance (km)	24,5	24,4	-0,3%
Durée (hr)	1,3	1,5	14,4%
Vitesse (km/hr)	16,4	15,2	-7,3%
CONS (g)	893	931	4,3%
CO2 (g)	2688	2678	-0,4%
CO (g)	51	68	33,7%
HC (g)	8	8	1,4%
NOx (g)	12	10	-11,7%
PS (g)	3	1	-70,1%

Tableau n° 10 : Bilan Individuel

3.3 Bilan Échange

Le bilan des déplacements d'échange montre que ce type de trafic prend une place de plus en plus importante au niveau global. Cela notamment grâce à des forts taux de croissance 2001/1991 par rapport au trafic interne (figures 10 et 11).

Bilan Échange	1991	2001	%Variation
Déplacements	271209	324982	19,8%
CONS (tonnes)	200	252	26,0%
CO2 (tonnes)	668	803	20,2%
CO (tonnes)	6	11	83,3%
HC (tonnes)	0	2	-
NOx (tonnes)	2	4	100,0%
PS (tonnes)	0	0	0,0%

Tableau n° 11 : Bilan échange

Les figures ci-dessous mettent en évidence le décalage significatif entre les évolutions des trafics internes et d'échange. Nous notons que les déplacements d'échanges progressent beaucoup plus rapidement que les déplacements internes. Par exemple, l'évolution relative 2001/1991 de CO2 liée aux déplacements internes est de l'ordre de +4,6%, tandis que cette évolution représente +20% pour les déplacements d'échange.

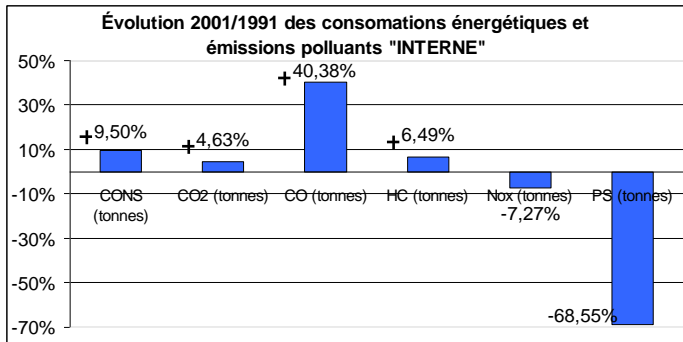


Figure n° 10 : Principaux évolutions du trafic interne

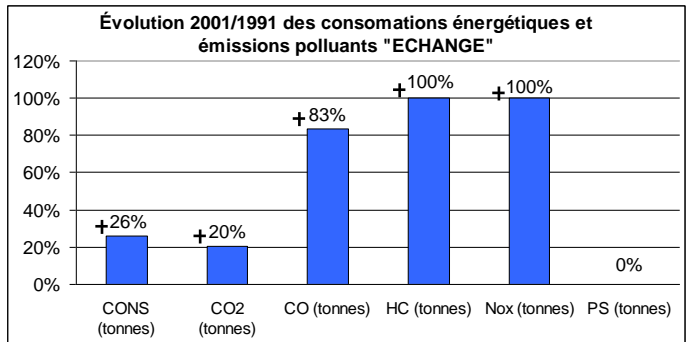


Figure n° 11 : Principaux évolutions du trafic échange

Par ailleurs, dans l'aire métropolitaine lilloise (LMCU) en 2006 la répartition par type de trafic des émissions de gaz à effet de serre du transport voyageurs montre une importance plus forte des déplacements d'échange par rapport à l'IDF avec 23%, tandis que les déplacements internes émettent 74% et finalement le transit avec une part de 3% (cf. rapport DEM, Hivert et al., 2009).

3.4 Évolution des déplacements par mode de transport

Le choix modal est un des déterminants clés dans l'analyse de l'évolution de la mobilité. Plusieurs points ressortent dans la figure n°12: par exemple nous constatons une augmentation de la part des déplacements internes, de la distance parcourue et de la durée réalisée en véhicule particulier et deux roues.

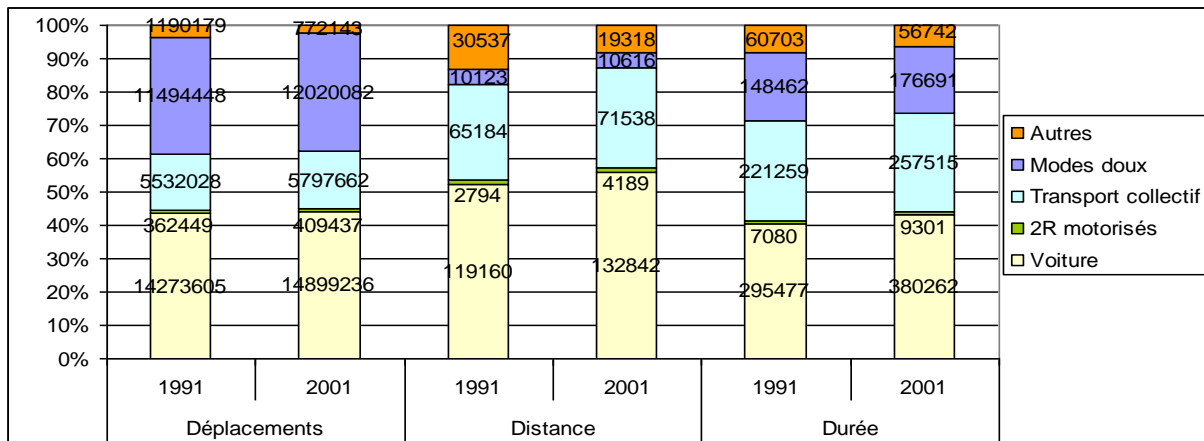


Figure n° 12 : Évolution des déplacements internes par mode de transport

3.5. Les modes de transport utilisés sont-ils les mêmes pour les voyageurs internes et d'échanges?

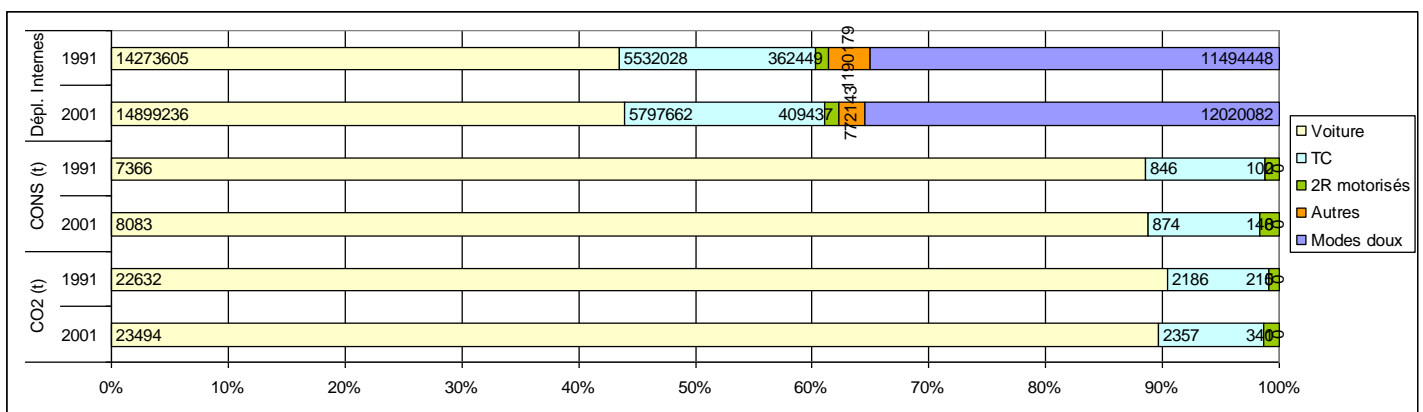


Figure n° 13 : Évolution des déplacements internes et émissions par mode de transport

A cette étape nous analyserons la décomposition des consommations et émissions par modes de transport et par type de trafic. D'un côté, on observe pour le trafic interne (figure n°13) une préférence pour la voiture et une stabilisation dans sa participation globale : (43%) en 1991 et (44%) en 2001 des flux de trafic de voyageurs (nombre de déplacements). Cela représente (90%) du total de CO2 en 1991 et 2001.

Nous observons au niveau des déplacements internes une participation importante des modes doux (35% des déplacements) en 1991 et 2001. D'un autre côté, pour les déplacements d'échange (figure n°14) la prépondérance de la voiture est plus importante (56%) en 2001, part en hausse par rapport à 1991 (51 %). Sa contribution aux émissions polluantes est encore plus importante : elle génère 98 % des émissions de CO2 en 1991 et 97% en 2001. Cette analyse met clairement en évidence l'impact de l'utilisation de la voiture sur la consommation d'énergie et les émissions polluantes de CO2.

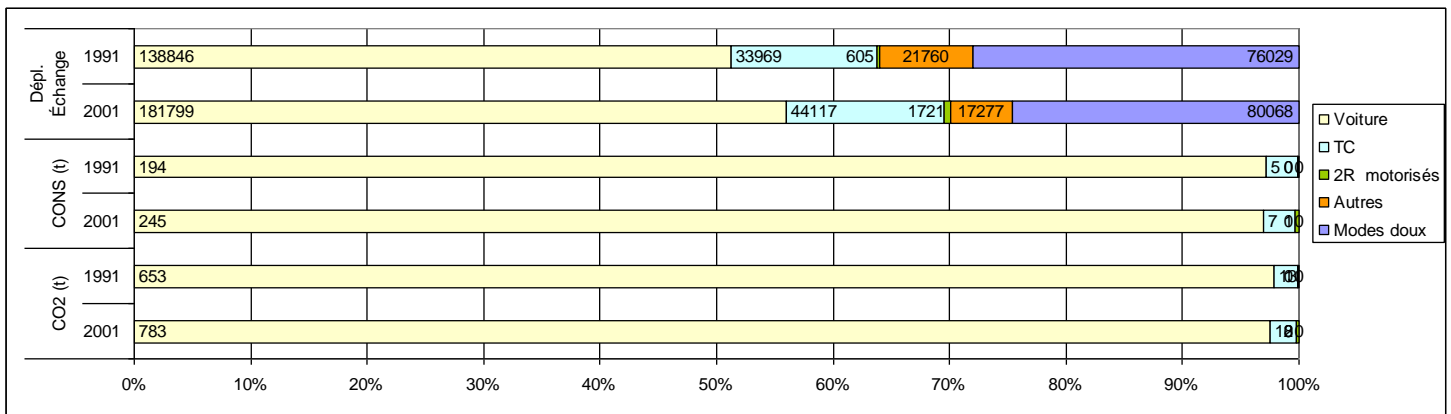


Figure n° 14 : Évolution des déplacements d'échange et émissions par mode de transport

3.6 Les émissions polluantes des déplacements des franciliens : Quels sont les principaux déterminants géographiques et socio-économiques ?

D'abord on analysera le poids du nombre de déplacements effectifs individuels selon le sexe et les émissions de CO2 liées (tonnes). Les hommes sont les plus importants émetteurs de CO2, d'une enquête à l'autre, tant pour le type de trafic interne que d'échange. Les consommations et émissions individuelles des hommes sont plus élevées que celles des femmes. Pourtant les consommations et émissions individuelles des femmes se rapprochent de celles des hommes. On observe une tendance à la convergence même si l'écart entre les hommes et les femmes est encore marquée (figures 16 et 17).

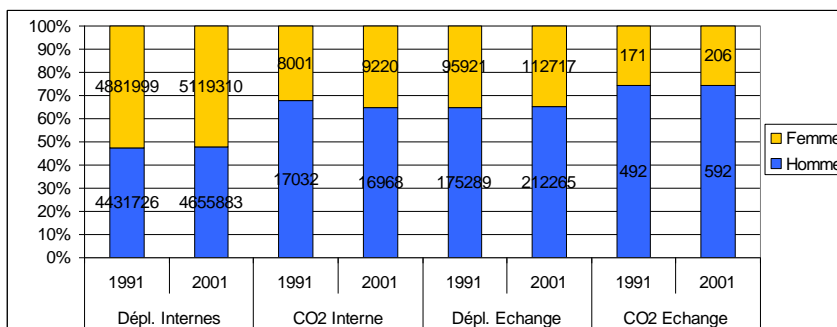


Figure n° 15 : Consommations et émissions individuelles selon le sexe

Pourtant il est important de noter les différences entre ces deux catégories. D'une part, on constate une stabilisation chez les hommes des émissions de CO₂ (-0,4%) liées aux déplacements internes, tandis que chez les femmes elles augmentent de (+15%). Un autre angle d'analyse est le type de trafic réalisé. Ici on peut observer une différence entre la participation des hommes et des femmes en termes de nombre de déplacements. C'est-à-dire que les femmes réalisent (52,4%) des déplacements internes en 1991 comme en 2001. Alors que leur participation au total des déplacements d'échange est seulement de 35% à ces deux dates.

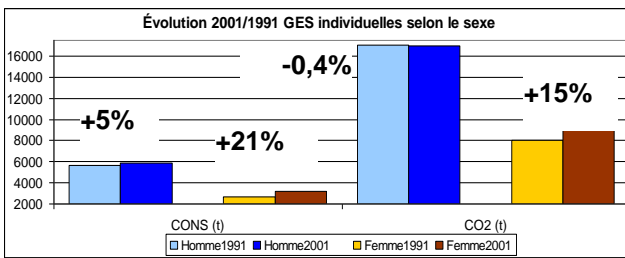


Figure n° 16 : valeurs absolues selon le sexe

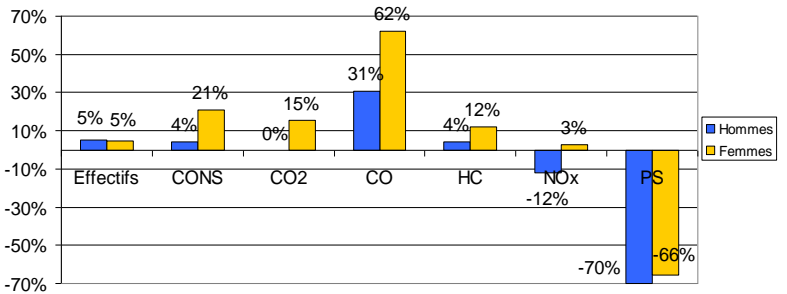


Figure n° 17 : évolutions relatives 2001/1991 individuelles selon le sexe

D'ailleurs, si l'on observe l'âge de l'individu ainsi que son niveau d'études vis-à-vis des émissions polluantes émises, on constate des différences aussi significatives. Les comportements de mobilité varient beaucoup en fonction de l'âge de l'individu, ainsi que de son niveau d'études, et expliquent une part importante des consommations et émissions de CO₂.

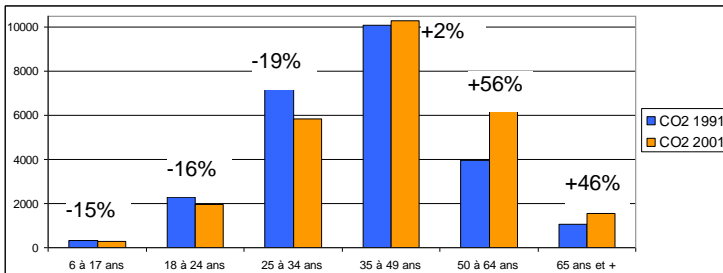


Figure n° 18 : Tranche d'âge des déplacements internes

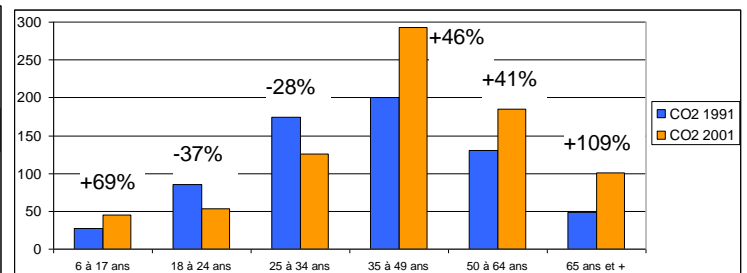


Figure n° 19 : Tranche d'âge des déplacements d'échange

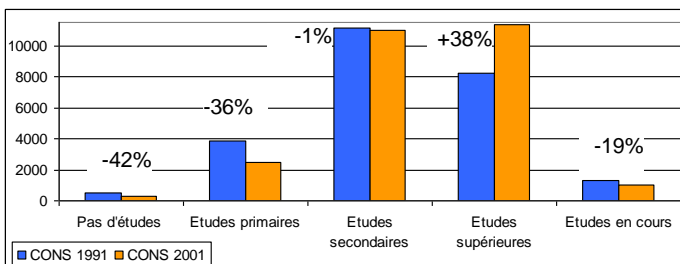


Figure n° 20 : Niveau d'études des déplacements internes

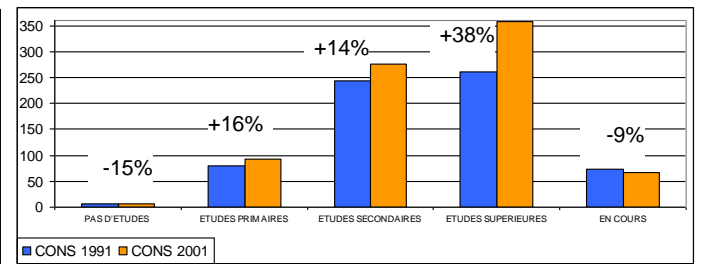


Figure n° 21 : Niveau d'études des déplacements d'échange

Plusieurs traits importants apparaissent à la lecture des figures 18 à 21. Nous observons d'abord que la tranche d'âge de 35 à 49 ans reste la plus émettrice en termes de pollution CO₂ dans les deux enquêtes. On observe les évolutions les plus importantes au cours des années 90 à partir de la cinquantaine. Cela pour les voyageurs internes et d'échange. Dans les deux cas (bilan interne et échange) on observe l'augmentation relative la plus importante chez ceux qui ont suivi des études supérieures. Notons aussi des comportements contrastés entre le bilan interne et d'échange. Dans le premier cas (déplacements internes), il existe une stabilisation des émissions de CO₂ pour ceux qui ont suivi des études secondaires et pour la tranche 35 à 49 ans. Tandis que pour les déplacements d'échange on peut constater toujours des

progressions beaucoup plus importantes que pour les déplacements internes, (+14%) et (+46%) respectivement.

3.7 Niveau de revenus et catégorie sociale

Nous allons maintenant analyser l'effet du revenu et de la catégorie sociale sur les émissions polluantes. Le revenu est l'une des variables les plus discriminantes en matière de dépenses énergétiques. On notera que certaines tranches de revenu sont plus émettrices par rapport aux autres mais on constate que ce n'est pas la même tranche les deux années étudiées. Même si l'inflation a été modérée pendant cette période (moins de 2% par an), cela fait environ 20% de dépréciation monétaire sur la période. Ce sont donc à peu près les mêmes ménages (en termes de revenu relatif) qui polluent le plus. En 1991 les ménages avec revenu entre 30490 et 36588 euros polluaient le plus entre toutes les catégories de revenu (bilan interne). Tandis qu'en 2001 c'est la tranche entre 36588 et 54882 euros la plus émettrice en termes de CO₂.

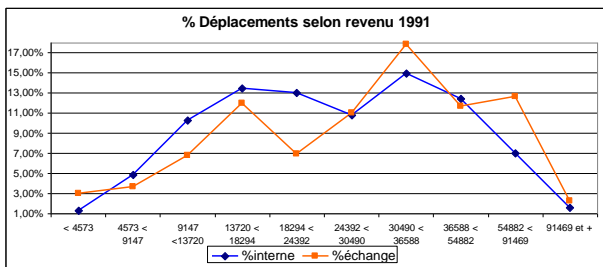


Figure n° 22 : Déplacements internes selon revenu 1991

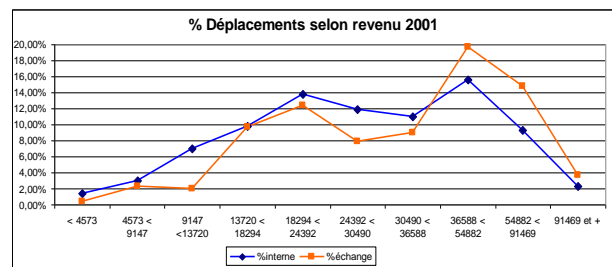


Figure n° 23 : Déplacements internes selon revenu 2001

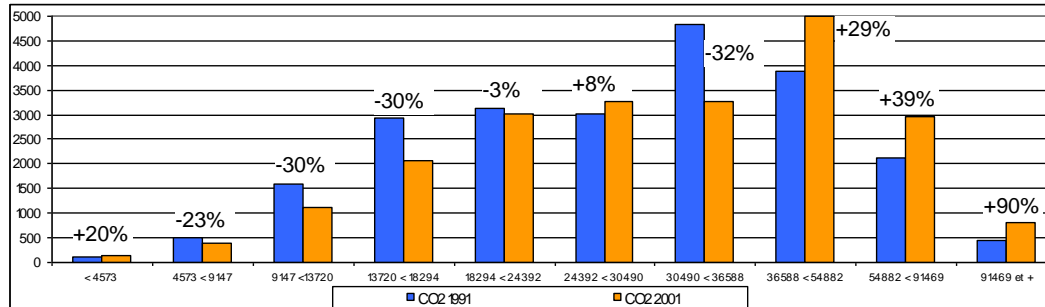


Figure n° 24 : émissions individuelles des déplacements internes selon les revenus du ménage

Il en ressort deux faits importants si l'on analyse les figures 25 et 26. Premièrement il existe une grande différence entre les évolutions liées à la catégorie sociales « ouvriers » (-12%) et « artisans » (-16%) observées dans le bilan interne par rapport au bilan d'échange (+45%) et (+37%) respectivement, cela est probablement lié à un habitat de plus en plus périphérique pour ces catégories. Deuxièmement, chez les retraités les déplacements d'échange (+101%) se sont accrus deux fois plus vite que les déplacements à l'intérieur de l'Île-de-France (+52%).

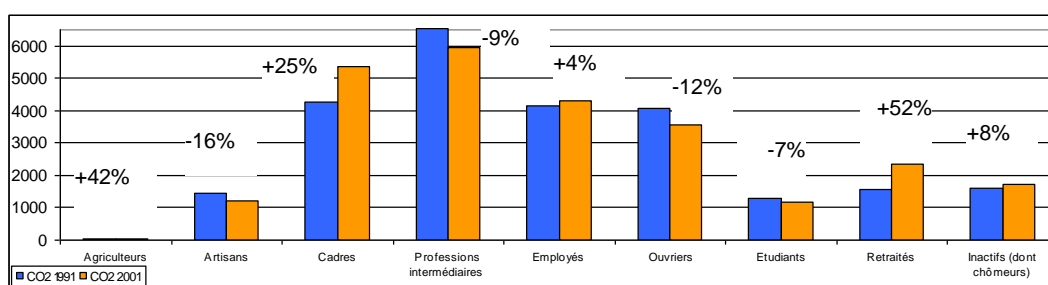


Figure n° 25 : Catégorie sociale des déplacements internes

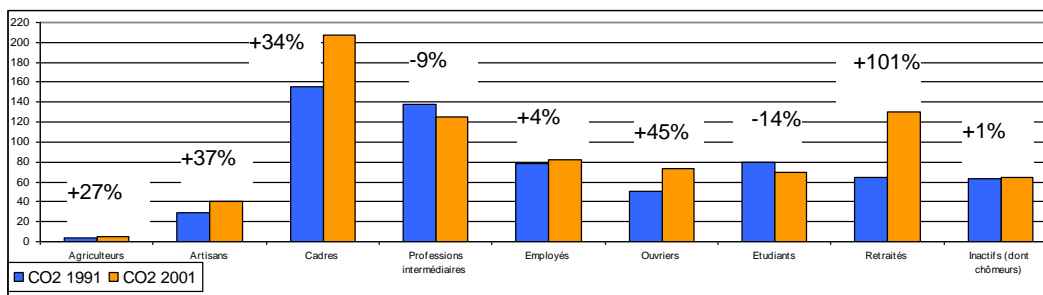


Figure n° 26 : Catégorie sociale des déplacements d'échange

3.8 Le rôle des structures urbaines : une géographie des déplacements en profonde mutation

Finalement, nous examinerons les émissions de CO2 à travers les caractéristiques du lieu de résidence. Dans ces tableaux on peut constater l'incidence de l'étalement urbain sur les émissions de CO2.

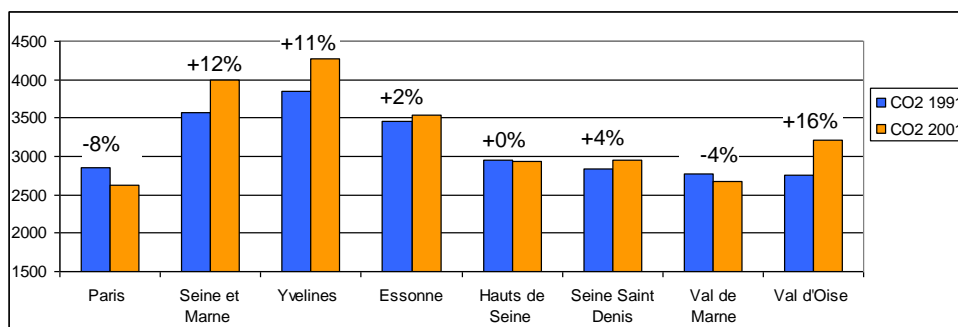


Figure n° 27 : Lieu de résidence des déplacements internes

Comme le montre notre analyse ci-dessous, dans le cas des voyages « d'échange » une forte croissance de la consommation et des émissions est observée soit une croissance relative pendant la période 2001/1991 de (+45%) de CO2 en Yvelines, (+43%) en Val-de-Marne, (+27%) en Hauts de Seine et (+45%) en Val-d'Oise.

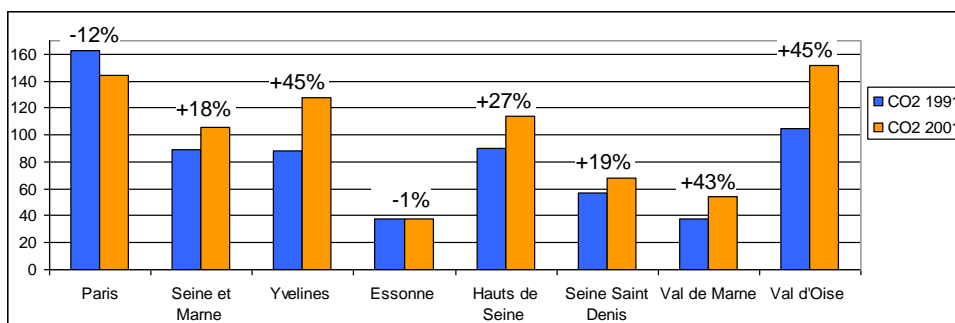


Figure n° 28 : Lieu de résidence des déplacements d'échange

En revanche, si on compare le bilan interne et d'échange nous observons toujours une diminution des émissions de CO2 des Parisiens et une stabilisation chez les habitants de l'Essonne. Ceux des Hauts-de-Seine ont pu stabiliser leurs émissions uniquement pour le bilan interne. L'accent sera mis sur les évolutions relatives 2001/1991 en fonction du zonage en trois cercles: Paris, Petite Couronne et Grande Couronne. La distance parcourue et le mode ont été les éléments prépondérants pour expliquer ces évolutions d'émissions contrastés entre ces trois zones, ainsi que l'implantation des villes nouvelles dans la périphérie.

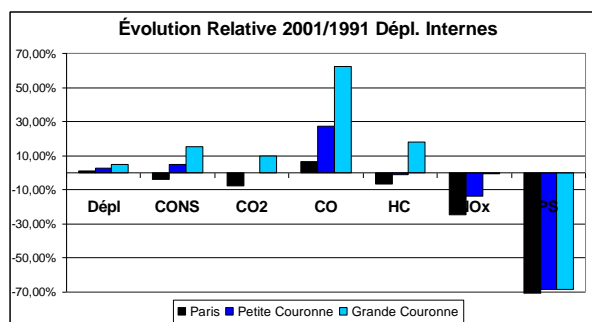


Figure n° 29 : Lieu de résidence bilan interne

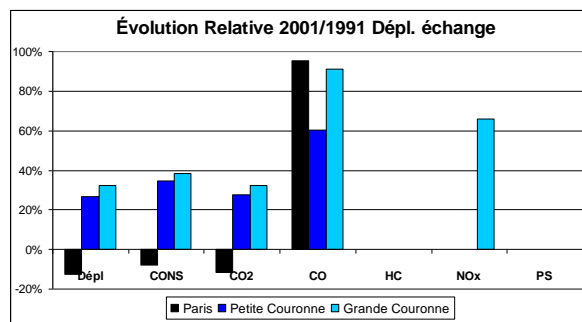


Figure n° 30 : Lieu de résidence bilan d'échange

Conclusion

L'implémentation de nouvelles technologies dans les modes motorisés a-t-elle suffi à une stratégie de réduction des émissions de polluants locaux et de GES en Ile-de-France au cours des années 90 ? Tout d'abord, nous avons constaté des tendances toujours défavorables en matière environnemental sur l'ensemble des déplacements internes et d'échange pendant la période et dans l'aire étudiée. Parmi les modes polluants, le CO₂ lié aux déplacement en voiture a augmenté seulement de (+4%) entre 1991 et 2001, contre (+8%) en TC et (+58%) en deux-roues motorisés. Cela peut indiquer l'influence positive de l'implantation des technologies dans les voitures. En revanche, comme nous l'avons vu précédemment dans le bilan interne et d'échange et par mode (figures n°13 et n°14), il existe une forte croissance des émissions liée d'une part à l'augmentation du nombre des déplacements réalisés, des distances parcourues par jour en ÎDF, et du recours à l'automobile, d'autre part au processus d'étalement urbain qui ont généré une quantité croissante de CO₂ émis sur cette période (figures n°29 et n°30). Par conséquent, au niveau global cette étude a montré que les progrès technologiques sur les véhicules particuliers (ex. pot catalytique, filtre à particules, etc.) mis en place pendant cette période (et leur diffusion dans le parc automobile), ne peuvent être l'unique élément des stratégies de réduction des émissions des GES et des polluants locaux.

Le profil socio-économique du voyageur « plus émetteur » est-il fixe dans le temps ?

Selon ce qui vient d'être présenté, on peut confirmer qu'existent des contrastes entre les caractéristiques socio-économiques des individus plus ou moins émetteurs de CO₂ en ÎDF. Non seulement d'une enquête à l'autre, mais aussi entre le bilan interne et d'échange.

Doit-on prendre en compte les déplacements d'échange dans les bilans environnementaux ? Comme nous l'avons vu précédemment, la distinction entre déplacements internes et d'échange réalisé dans cette étude nous a permis d'identifier le décalage entre les attitudes et comportements entre ces types de trafics en termes de mobilité. Les préférences et les choix peuvent dans certains cas être contrastés. Même s'il est plus faible que dans des métropoles de province comme Lille, le poids des déplacements d'échange est loin d'être négligeable puisque on peut observer qu'il va croissant et pourrait peut-être encore se renforcer dans le futur. Est il donc important de suivre ces comportements dans les années à venir. C'est-à-dire, d'évaluer et de mesurer la mobilité d'échange et ses impacts environnementaux. Il serait également intéressant d'évaluer les impacts environnementaux de la mobilité de transit ; mais, comme les enquêtes EGT ne s'adressent qu'aux habitants de la région, elles ne peuvent rien dire sur le transit.

Dans quelle mesure l'étalement urbain observé au cours de la décennie joue-t-il un rôle dans les impacts environnementaux ? Finalement, le présent article permet de dépasser le lien entre la forme urbaine et les émissions polluantes liées à la mobilité quotidienne. L'ensemble de ces analyses permet de confirmer que plus les lieux de résidence s'éloignent des centres, plus les émissions polluantes s'accroissent en raison surtout d'une dépendance au véhicule particulier. L'analyse montre que les villes nouvelles n'ont pas le même profil de mobilité par rapport au centre ville. Un des facteurs de cette croissance est lié à l'augmentation de la population observée dans ces départements périphériques à l'espace francilien. En raison de la forte croissance des émissions liée au processus d'étalement urbain observée dans la présente étude on peut par conséquent donner des arguments environnementaux à la critique de l'étalement urbain comme facteur de pollution le plus important.

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5.1.2 Juarez and Puebla

GHG and local pollutants rely on travel intensity and technological advances on private vehicles observed on recent decades. As for the case of the Paris Region, the application of the GHG assessment methodology in Mexican cities required prior simulations due mainly to missing information regarding the composition of the fleet. The simulations developed for each Household Travel Survey from Juarez and Puebla were focused in particular on completing data such as the year of construction of the vehicle, its size (measured in number of cylinders), the type of fuel and lastly technological advances on private vehicles and their dissemination throughout the fleet, in particular catalytic converter and particulate filter¹²². It is commonly known that transport-related GHG emissions are mostly caused by private modes. For instance in 2001 in the Paris Region only 44% from all trips was traveled by private vehicles, but generated 90% of the total CO₂ emissions (section 5.1.1). In 2006 in Lille, the share of car trips was 54% and accounted for 92% of CO₂ emissions [93]. Results from table 5.30 show that in Juarez the share of CO₂ emissions due to Private Vehicle remained stable in both years with 77% of total CO₂ emissions. Public Transport emissions shifted from 23% in 1996 to 20% in 2006¹²³. The 3% left was due to motorcycle and other motorized modes. Puebla experienced more important changes. On the one hand, CO₂ emissions from vehicle trips accounted for 41% in 1994 and 34% in 2011. On the other hand Public Transport emissions went from 57% to 63%¹²⁴. Motorcycle and other motorized modes gained 1 point from 2% to 3% between these surveys.

Results from section 5.1.1 show that total per capita CO₂ emissions in the Paris Region were 2688 g in 1991 and 2678 g in 2001. According to [93], per capita CO₂ emissions due to total mobility in Lille were 1794 g, 2201 g, and 2084 g in 1987, 1998 and 2006 respectively. Results for Mexican case studies (Table 5.04) show lower per capita GHG emissions but mainly due to lower mobility which is almost half of what is observed on the French side. Per capita CO₂ emissions from total mobility in Juarez was 1007 g in 1996 and 1103 g in 2006. Each inhabitant in Puebla emitted on average 539 g of CO₂ in 1994 and 472 g in 2011.

¹²² Similar simulations were also developed and fully described for the Paris Region (section 5.1.1).

¹²³ In 1996 the shares of traveled kilometers of Vehicle Driver and Public Transport were 36% and 34%. In 2006 the share of Vehicle Driver remained stable while Public Transport increase 1 point.

¹²⁴ In 1994 the shares of traveled kilometers of Vehicle Driver and Public Transport were 15% and 64%. In 2011 the share of Vehicle Driver decreased 4 points while Public Transport increased 8 points.

As could be expected, GHG emissions per kilometer are much higher in the developing world. As stated in [93], GHG emissions per traveled kilometer had significant evolutions in Lille in the 1998/2006 period; global mobility per kilometer had a decrease in total energy expenditure (goe¹²⁵/km) of -10% in that period which represented reductions of -9% in CO₂, -65% in CO, -64% in VOC, -46% in NO_x and lastly -26% in PM. Translating this reductions into yearly evolution the changes were -1.2% in energy expenditure, -1.2% in CO₂, -8.1% in CO and VOC, -5.7% in NO_x and -3.5% in PM. Both Mexican cities had lower reductions per traveled kilometer. For instance Juarez, which could be compared to Lille in terms of modal share and survey years, shows a reduction in the period from 1996 to 2006, considering all modes mobility, yearly decreases of -0.1%, -3.9%, -3.5%, -2.5% and -3.1% in CO₂, CO, VOC, NO_x, PM respectively.

Results also show that technological advances that have been a benefit to reduce CO, VOC, NO_x and PM emissions in the Paris Region (described in section 5.1.1) and Lille [93] have been observed with significantly much slower rate in Mexican vehicle fleet. The main reason is the rapid ageing of the vehicle fleet probably due to low purchasing power which does not allow the purchase of new vehicles and therefore slow down the vehicle fleet renewal and also policies facilitating the importation of vehicles of 10 years old and over from the U.S. The average age of vehicles in Puebla increased from 9.4 years in 1994 to 13 years in 2011. In other words, in the 2011 survey the average year of construction of the vehicles was 1998 and 1984 in older survey. In 1996 Juarez had a vehicle fleet with an average age of 12.7 years, which increased to 13.8 years in 2006. Meaning that in 2006, the average construction year of vehicle was 1992. Hence, reductions of GHG emissions per km and by mode are lower in Mexican cities. Results from [93] show that each kilometer traveled as Vehicle Driver mode in Lille (2006) emitted on average 205 g of CO₂, 4.8 g of CO, 0.5 g of VOC, 0.6 g of NO_x and 0.06 g of PM. As shown in Table 5.20 GHG emissions per each kilometer traveled in private car as a driver are considerably higher in Mexican cities, in particular carbon monoxide and volatile organic compounds emissions.

Table 5.2. GHG emissions from Vehicle Driver kilometers, Juarez and Puebla

GHG emissions	JUAREZ 1996	JUAREZ 2006	Yearly evolution	PUEBLA 1994	PUEBLA 2011	Yearly evolution
CO ₂ (g/km*)	228.0	225.5	-0.1%	226.0	222.4	-0.1%
CO (g/km)	59.0	36.2	-3.9%	41.3	11.2	-4.3%
VOC (g/km)	5.3	3.3	-3.7%	3.8	1.1	-4.1%
NO _x (g/km)	2.3	1.7	-2.7%	1.8	0.9	-2.9%
PM (g/km)	0.1	0.08	-3.9%	0.09	0.0	-4.7%

*grams per kilometer

Table 5.3. Evolution of global GHG emissions by mode, Juarez and Puebla

	JUAREZ 1996	JUAREZ 2006	Yearly evolution	PUEBLA 1994	PUEBLA 2011	Yearly evolution
Total Population	966246	967441	+0.012%	1175488	1738573	+2.82%
Total_trips (M*)	1.9	2.0	+0.2%	2.1	2.9	+2.5%
Total_km (M)	9.1	10.1	+1.1%	7.8	11.9	+3.2%
Total Energy (toe**)	445.4	435.8	-0.2%	277.2	289.3	+0.3%
Total CO ₂ (t)	973.4	1067.0	+1.0%	633.5	820.3	+1.7%
Total CO (t)	218.8	148.7	-3.2%	92.1	32.9	-3.8%
Total VOC (t)	19.6	14.1	-2.8%	8.4	4.0	-3.0%
Total NO _x (t)	10.5	8.8	-1.7%	7.2	6.2	-0.8%
Total PM (t)	0.6	0.4	-2.4%	0.4	0.3	-0.9%
PVD_trips (M)	0.6	0.6	+0.8%	0.3	0.2	-0.3%
PVD_km (M)	3.3	3.6	+1.1%	1.1	1.3	+0.6%
Energy_PVD (toe)	345.7	338.2	-0.2%	109.2	98.0	-0.6%
CO ₂ _PVD (t)	746.9	822.4	+1.0%	258.3	279.6	+0.5%
CO_PVD (t)	193.2	132.1	-3.2%	47.2	14.0	-4.1%
VOC_PVD (t)	17.2	12.1	-3.0%	4.3	1.4	-3.9%
NO _x _PVD (t)	7.5	6.1	-1.8%	2.1	1.2	-2.6%
PM_PVD (t)	0.4	0.3	-3.2%	0.1	0.02	-4.6%
PT_trips (M)	0.5	0.4	-0.6%	1.0	1.7	+3.9%
PT_km (M)	3.1	3.5	+1.3%	5.0	8.7	+4.3%
Energy_PT (toe)	97.1	85.1	-1.2%	163.5	181.3	+0.6%
CO ₂ _PT (t)	219.9	213.7	-0.3%	364.2	514.3	+2.4%
CO_PT (t)	24.8	14.1	-4.3%	43.9	17.8	-3.5%
VOC_PT (t)	2.2	1.5	-3.4%	3.9	2.3	-2.3%
NO _x _PT (t)	3.0	2.4	-1.9%	5.0	4.8	-0.3%
PM_PT (t)	0.2	0.1	-1.6%	0.3	0.3	+0.2%
Motorbike_trips (M)	0.001	0.002	+12.6%	0.003	0.01	+12.2%
Motorbike_km (M)	0.01	0.02	+29.9%	0.01	0.04	+20.1%
Energy_BIKE (toe)	0.3	1.2	+26.1%	0.5	1.4	+10.4%
CO ₂ _BIKE (t)	1.3	2.6	+9.9%	1.4	2.2	+3.7%
CO_BIKE (t)	0.1	0.5	+22.2%	0.2	0.5	+9.4%
VOC_BIKE (t)	0.1	0.3	+16.8%	0.1	0.2	+4.1%
NO _x _BIKE (t)	0.0	0.0	+0%	0.0	0.0	+0%
PM_BIKE (t)	0.0	0.0	+0%	0.0	0.0	+0%
Other motorized_trips (M)	0.002	0.01	+30.8%	0.01	0.02	+5.5%
Other motorized_km (M)	0.02	0.1	+44.2%	0.03	0.1	+9.2%
Energy_OTHER (toe)	2.3	11.3	+39.0%	4.0	8.6	+7.0%
CO ₂ _OTHER (t)	5.3	28.2	+43.3%	9.7	24.2	+8.8%
CO_OTHER (t)	0.6	2.1	+23.7%	0.8	0.5	-2.1%
VOC_OTHER (t)	0.1	0.2	+24.7%	0.1	0.1	-1.6%
NO _x _OTHER (t)	0.04	0.2	+43.2%	0.1	0.2	+8.8%
PM_OTHER (t)	0.004	0.02	+45.0%	0.01	0.02	+9.5%

*One million (1 000 000). **Tonne of oil equivalent.

Changes on travel behavior described on Chapters 3 and 4 have clear impacts on CO₂ emissions. Results of CO₂ emissions due to daily travel activity by gender in the Paris Region show that females increased their share of total CO₂ emissions due to daily travel activity from 32% in 1991 to 35% in 2001. Results from Chapter 3 show that the share of the most pollutant mode of transportation 'Vehicle Driver' has been increasing in Lille since 1987 for females going from 40% to 48% in 2006. According to [93] females accounted for 42% of CO₂ emissions in Lille (2006).

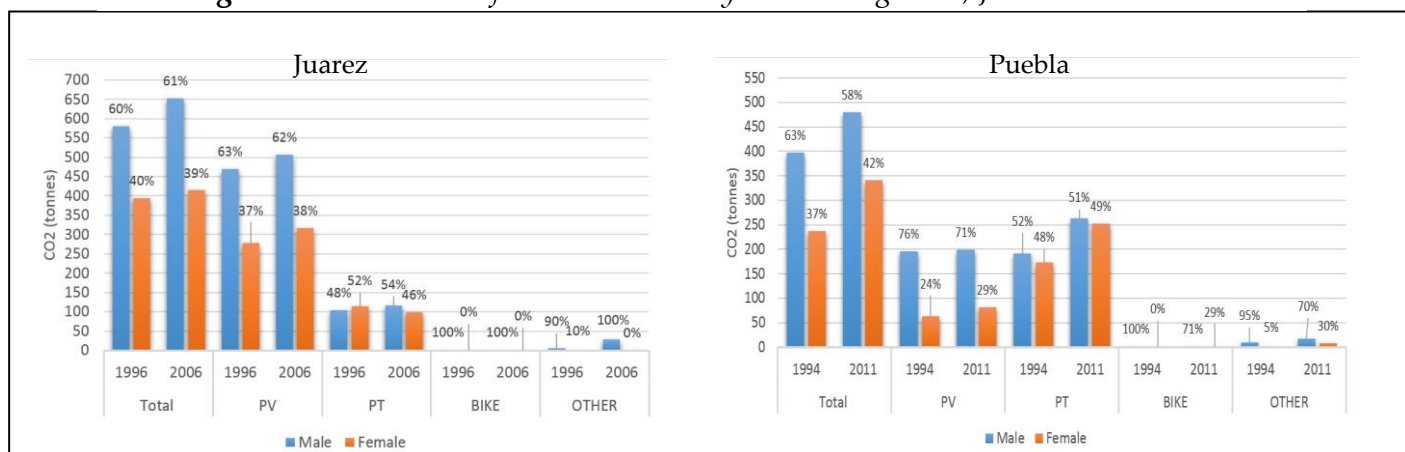
The assessment of CO₂ emissions by gender in Mexican cities (Figure 5.2) confirm this trend showing an increase of CO₂ shares of global mobility from females in Puebla (37% to 42%) and stabilization in Juarez (40% to 39%). In Puebla the increase was due to increases in both Vehicle Driver (24% to 29%) and Public Transport mode (48% to 49%). Stabilization of global mobility from females in Juarez was due mostly to the decrease of Public Transport share (52% to 46%).

Table 5.4. Evolution of GHG emissions per person and by mode, Juarez and Puebla

	JUAREZ 1996	JUAREZ 2006	Yearly evolution	PUEBLA 1994	PUEBLA 2011	Yearly evolution
Total_trips/person	1.99	2.02	+0.2%	1.74	1.69	-0.2%
Total_km/person	9.5	10.5	+1.1%	6.6	6.9	+0.2%
Total Energy (goe*/per)	461.0	450.4	-0.2%	235.8	166.4	-1.7%
Total CO ₂ (g**/per)	1007.4	1102.9	+0.9%	538.9	471.8	-0.7%
Total CO (g/per)	226.4	153.7	-3.2%	78.3	18.9	-4.5%
Total VOC (g/per)	20.3	14.5	-2.8%	7.1	2.3	-4.0%
Total NOx (g/per)	10.9	9.1	-1.7%	6.1	3.5	-2.5%
Total PM (g/per)	0.6	0.5	-2.4%	0.3	0.2	-2.5%
PVD_trips/person	0.6	0.6	+0.8%	0.2	0.1	-2.1%
PVD_km/person	3.4	3.8	+1.1%	1.0	0.7	-1.5%
Energy_PVD (goe/per)	357.7	349.6	-0.2%	92.9	56.3	-2.3%
CO ₂ _PVD (g/per)	773.0	850.1	+1.0%	219.7	160.8	-1.6%
CO_PVD (g/per)	200.0	136.5	-3.2%	40.1	8.1	-4.7%
VOC_PVD (g/per)	17.8	12.5	-3.0%	3.6	0.8	-4.5%
NOx_PVD (g/per)	7.8	6.4	-1.8%	1.8	0.7	-3.6%
PM_PVD (g/per)	0.4	0.3	-3.2%	0.1	0.01	-5.0%
PT_trips/person	0.5	0.5	-0.6%	0.8	1.0	+0.7%
PT_km/person	3.2	3.6	+1.2%	4.3	5.0	+1.0%
Energy_PT (goe/per)	100.5	87.9	-1.3%	139.1	104.3	-1.5%
CO ₂ _PT (g/per)	227.6	220.9	-0.3%	309.8	295.8	-0.3%
CO_PT (g/per)	25.6	14.5	-4.3%	37.3	10.2	-4.3%
VOC_PT (g/per)	2.3	1.5	-3.4%	3.3	1.3	-3.5%
NOx_PT (g/per)	3.1	2.5	-1.9%	4.3	2.8	-2.1%
PM_PT (g/per)	0.2	0.1	-1.6%	0.2	0.2	-1.8%
Motorbike_trips/person	0.001	0.002	+12.5%	0.002	0.004	+6.4%
Motorbike_km/person	0.01	0.02	+29.9%	0.01	0.02	+11.7%
Energy_BIKE (goe/per)	0.3	1.3	+26.1%	0.4	0.8	+5.1%
CO ₂ _BIKE (g/per)	1.4	2.7	+9.8%	1.2	1.3	+0.6%
CO_BIKE (g/per)	0.2	0.5	+22.1%	0.2	0.3	+4.4%
VOC_BIKE (g/per)	0.1	0.3	+16.7%	0.1	0.1	+0.9%
NOx_BIKE (g/per)	0.0	0.0	+0%	0.0	0.0	+0%
PM_BIKE (g/per)	0.0	0.0	+0%	0.0	0.0	+0%
Other motorized_trips/person	0.002	0.01	+30.7%	0.01	0.01	+1.8%
Other motorized_km/person	0.02	0.1	+44.1%	0.03	0.1	+4.3%
Energy_OTHER (goe/per)	2.4	11.7	+39.0%	3.4	5.0	+2.8%
CO ₂ _OTHER (g/per)	5.5	29.1	+43.3%	8.2	13.9	+4.1%
CO_OTHER (g/per)	0.6	2.2	+23.6%	0.7	0.3	-3.3%
VOC_OTHER (g/per)	0.1	0.2	+24.6%	0.1	0.03	-3.0%
NOx_OTHER (g/per)	0.04	0.2	+43.1%	0.1	0.1	+4.0%
PM_OTHER (g/per)	0.004	0.02	+44.9%	0.01	0.01	+4.5%

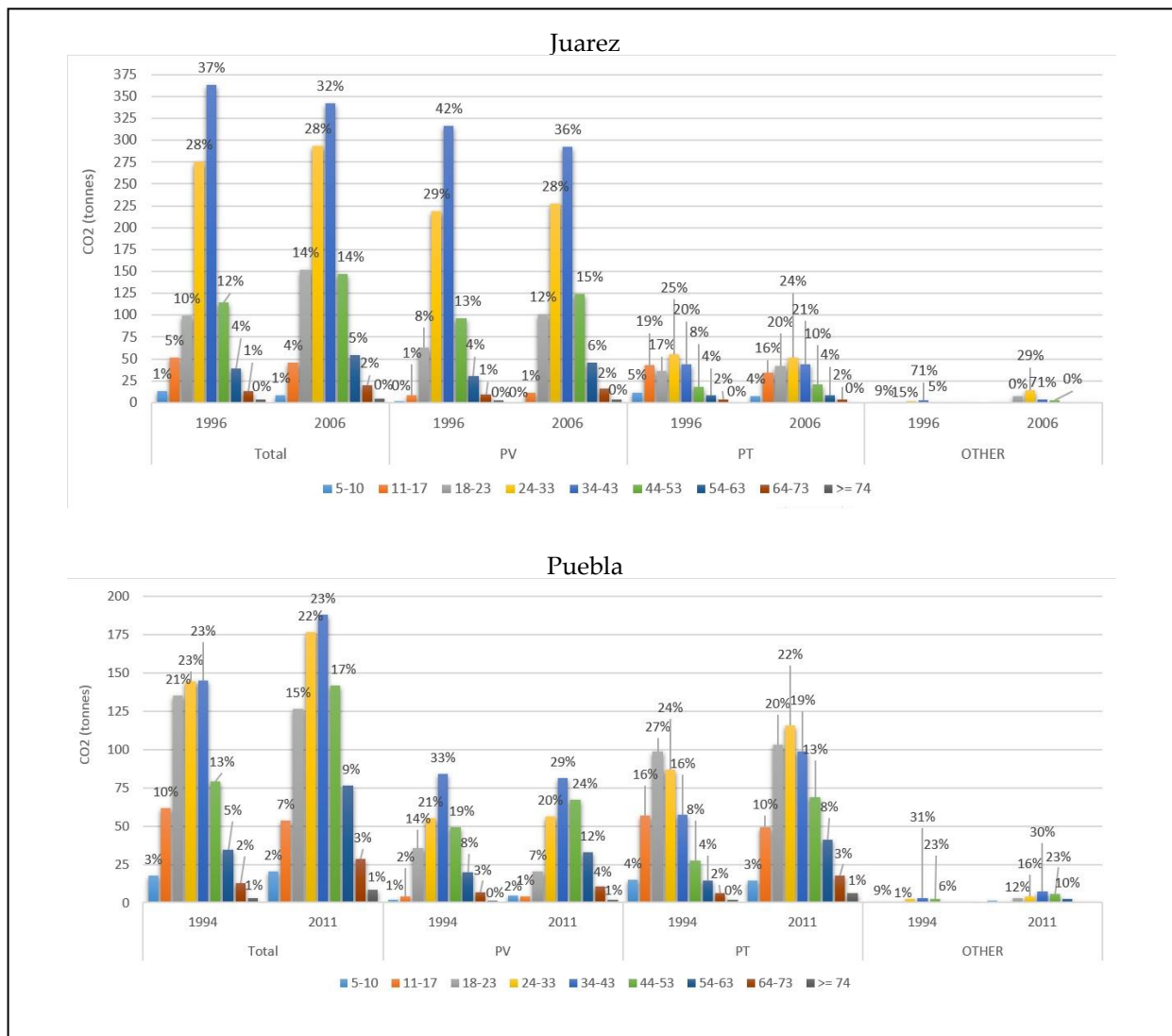
*Grams of oil equivalent. ** Grams.

Figure 5.2. Evolution of CO₂ emissions by mode and gender, Juarez and Puebla



Chapter 3 has already described a shift towards more travel activity of elderly people, stagnation or decrease for adults from mid 30's to mid 50's, which are the most active of all age groups, and a decreasing activity from younger generations, including young adults. As could be expected the results confirm the major impact of the position in the life cycle of the person on transport-related CO₂ emissions. In all case studies the curve is bell-shaped, peaking around forty years old in all case studies. In Paris the increase of CO₂ emissions per age bracket between surveys was +56% for '50-64' years old and +46% for people older than 64 years old (Figure 18, section 5.1.1). In other words, people belonging to the '50-64' age bracket in 2001 polluted in total +56% more compared to the same age group in 1991. '18-24' years old had a decrease -16% and those corresponding to the age bracket of '25-34' emitted -19% less than the same category one decade earlier. Similar behavior changes can be observed in Mexican cities, more pronounced in Puebla than in Juarez (Figure 5.3). In Puebla, those belonging to the '44-53' age bracket were responsible for 13% of total CO₂ emissions in 1994 increasing up to 17% in 2011. In the same way, those from the '54-63' age bracket accounted for 5% of total CO₂ emissions in 1994 increasing up to 9% in 2011. Younger adults (18 to 23 years old) emitted less CO₂ in 2011 compared to 1994 (15% vs 21%). This phenomenon can be observed in both Private Driver and Public Transport modes. For instance, young drivers emitted half of CO₂ emissions in most recent survey (7% vs 14%) and those from the same age group but traveling in Public Transport accounted for 27% of CO₂ emissions in 1994 and decreased to 20% in 2011. The peak of CO₂ emissions from global mobility remain stable in Puebla at the '34-43' age group with 23% in both years. CO₂ emissions curves of mobility disaggregated by age and transport mode tend to flatten in Juarez. The peak, which is situated as mentioned before at the '34-43' age bracket had a share of 37% in 1996 decreasing down to 32% in 2006 for total mobility and from 42% to 36% for vehicle driver. In the case of Juarez CO₂ emissions tend to spread or redistribute not only towards older generations but also to young adults. This is why the shift towards more CO₂ emissions due to travel activity from older generations is less clear in Juarez than in Puebla. Younger adults accounted for 10% in 1996 of CO₂ emissions due to global mobility, increasing up to 14% ten years later. In the same manner individuals belonging to the '44-53' age category increased their share from 12% to 14%. With respect to private driver mode, younger drivers increased their share from 8% to 12%, and '44-53' individuals from 13% to 15%. The shifts for older generations is also positive but less pronounced increasing only by 1 or 2 points.

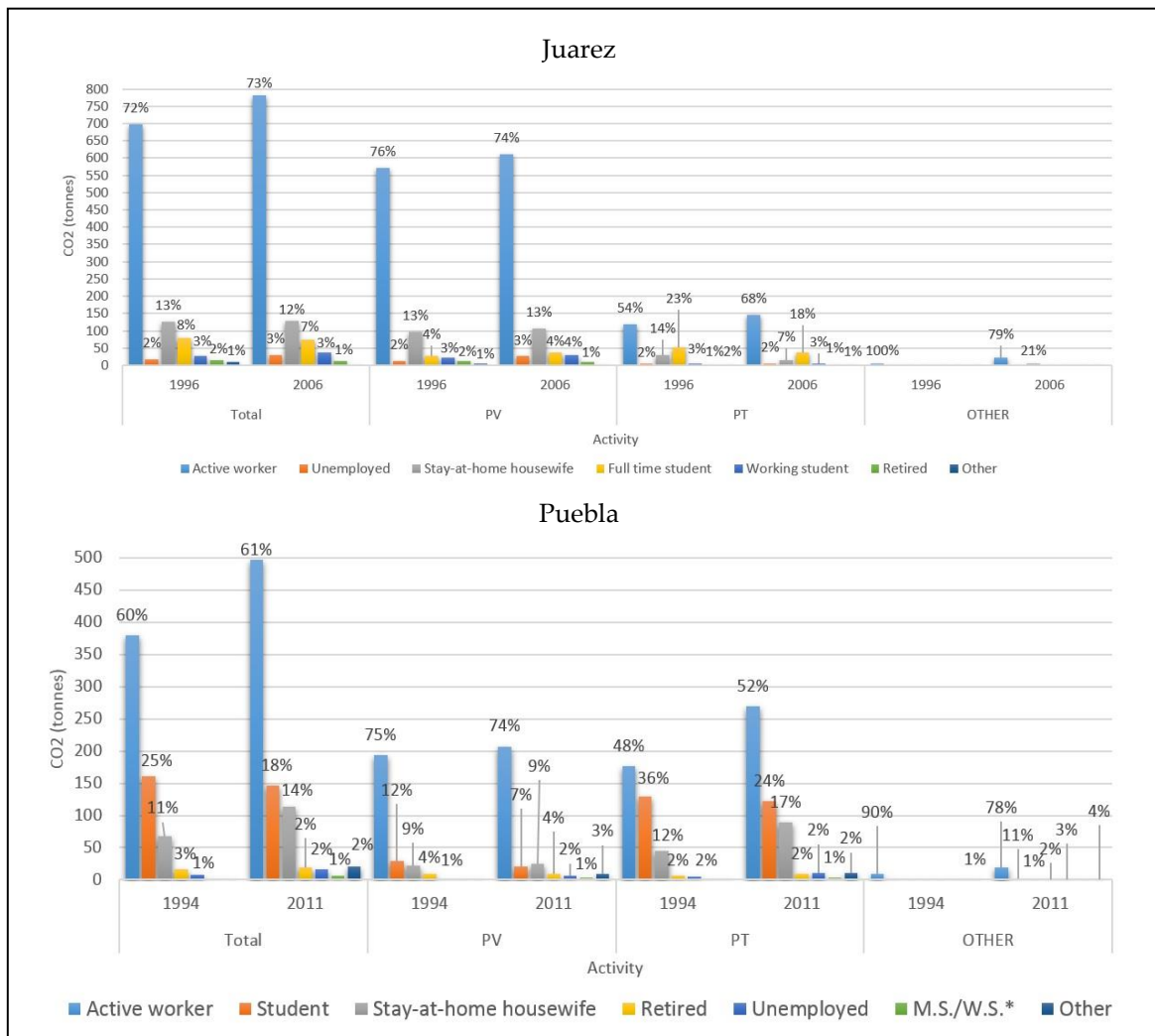
Figure 5.3. Evolution of CO₂ emissions by mode and age, Juarez and Puebla



As for French cities, active working people in Mexican cities are responsible for most of GHG emissions among all activities (e.g. student, retired, etc.) (Figure 5.4). In the Paris Region (Figure 25 from the section 5.1.1) and Lille [93] retired people increase their share of CO₂ emissions (+52% in Paris and +7% in Lille). This is not the case in Mexican cities, in which retired individuals had almost the same shares of CO₂ in both travel surveys: approximately 3/4 of CO₂ emissions from all mobility and private vehicle mode were caused by people belonging to this category in Juarez. The environmental impact of active workers using Public Transport in Juarez was 4.8 times less compared to CO₂ emissions from Private Vehicle mode. The rate was 4.2 in 2006. From the 697 tonnes of CO₂ emitted by active workers in 1996, 82% was due to Private Vehicles and 17% to Public Transport. In 2006 the total emissions due to active workers was 781 tonnes of CO₂ of which 78% was due to car trips, 19% by

Public Transport and 3% by other modes. One difference between Juarez and Puebla is that active workers in the second city represent also the majority of GHG emissions, but in a more balanced way between activity groups (approximately 61% of CO₂ emissions in both years vs 73% in Juarez) and their CO₂ emissions are almost equally distributed between the main transportation modes used by people belonging to this activity. The total of 380 tonnes of CO₂ emitted by active workers in 1994 was caused almost equally by Private Vehicles and Public Transport modes, with 51% and 46% respectively, the rest by other modes. In 2011 the total emissions due to active worker trips was 497 tonnes of CO₂ in which 42% was due to Private Vehicle, 54% by Public Transport and 4% by other modes. Another difference observed in Mexican cities is the order of GHG emissions generation between students and stay-at-home housewives. Stay-at-home housewives emitted 1.18 and 1.16 times more CO₂ than students from the city of Juarez when taking into account all modes of transportation.

Figure 5.4. Evolution of CO₂ emissions by mode and activity, Juarez and Puebla



*Military Service (1994), Worker/student (2011).

In contrast, students from the city of Puebla emitted 2.39 times more CO₂ than stay-at-home housewives in 1994 and 1.28 in 2011. Analysis by transportation mode show that housewife drivers, commonly known as soccer moms, emitted 1.93 more CO₂ than student drivers from Juarez in 1996, and 1.6 in 2006. Student drivers from the city of Puebla emitted 1.35 times CO₂ more compared to housewife drivers in 1994. This is reversed in 2011 when housewife drivers emitted 1.23 times more CO₂ than student drivers. As mentioned before the majority of CO₂ emissions due to Public Transport were caused by active workers. In both Mexican cities they are followed by students then by housewives.

Moreover, it is commonly known that dense urban areas are more prone to develop mixed land use and better connectivity which result in shorter travel distances; adding it to the availability and accessibility of public transport tends to slow down the increase of private vehicle use¹²⁶ and GHG emissions (35, 42, 52, and 80). Urban sprawl intensifies road construction and discourages public transport service. As a consequence, people living in the outer suburbs are more prone to private mode use. The analysis of the relation between urban form and transport-related GHG emissions confirm in all case studies that GHG emissions are higher in the suburbs compared to the city-center and higher in the outer suburbs compared to inner suburbs. The proportion of CO₂ emissions in the city center in Paris represented 24% in 1991 and 18% in 2001; the inner suburbs¹²⁷ was 28% in 1991 and 30% in 2001; and lastly the outer suburbs¹²⁸ accounted for 48% in 1991 and 53% in 2001 (Figure 29 section 5.1.1). Estimates from 2006 in Lille confirm that urban density is also inversely proportional to the GHG emissions going from 13% in the city-center, 21% in the inner suburbs and up to 66% in the outer suburbs (Figure 5.5). In Lille the gap between urban and suburban CO₂ emissions strongly increased from 1987 to 2006. In Mexican cities the share of CO₂ emissions due to global mobility in city-centers decrease from 16% to 11% in Juarez and from 35% to 21% in Puebla (Figure 5.6). Shares of CO₂ emissions from total mobility in Mexican inner suburbs went from 59% to 55% in Juarez and stabilized in Puebla from 41% to 42%. CO₂ emissions from people living in the outer suburbs increased in Juarez accounting for 24% to 34% of total emissions. Outer suburbs in Puebla increased their share accounting from 24% in 1994 and 37% in 2011.

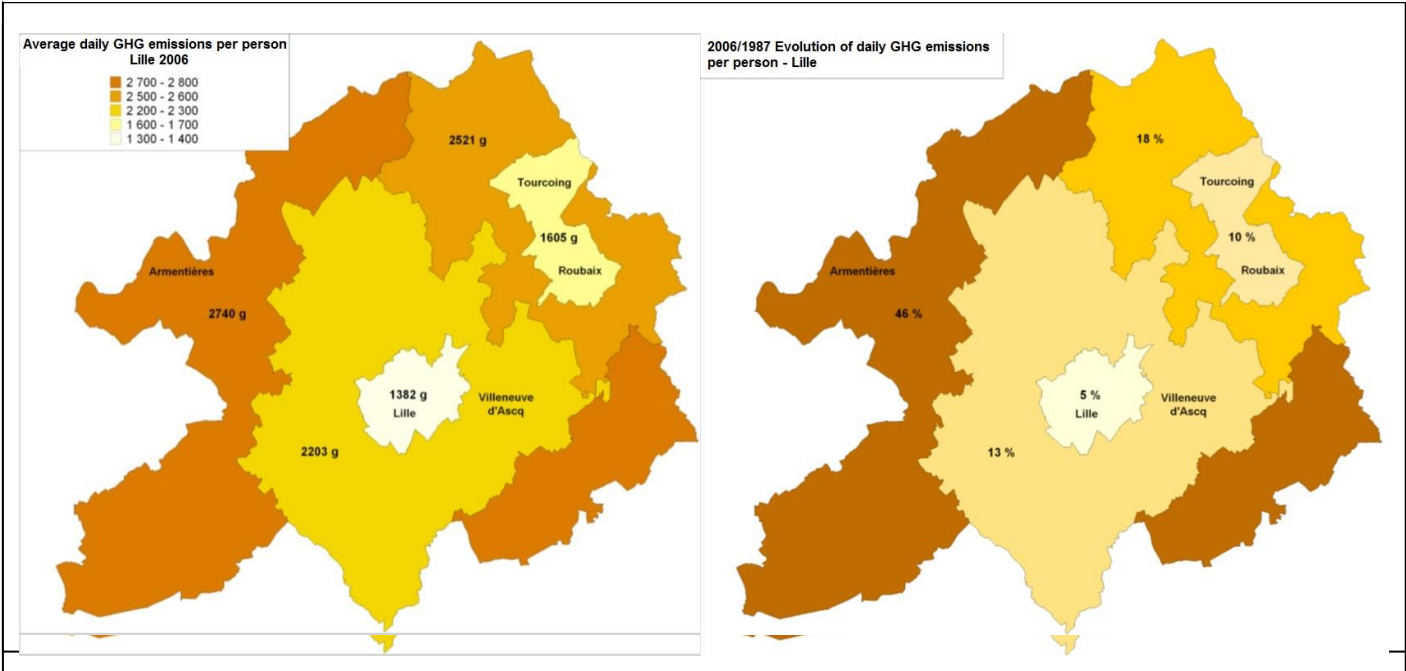
¹²⁶ See figures 3.5 to 3.8 from Chapter 3 for more description about the evolution of vehicle ownership, number of trips and traveled kilometers by mode and zone of residence for each case study.

¹²⁷ Formed by the departments Hauts de Seine, Seine Saint Denis and Val de Marne.

¹²⁸ It consists of the area formed by the departments Val d'oise, Seine et Marne, Yvelines and Essone.

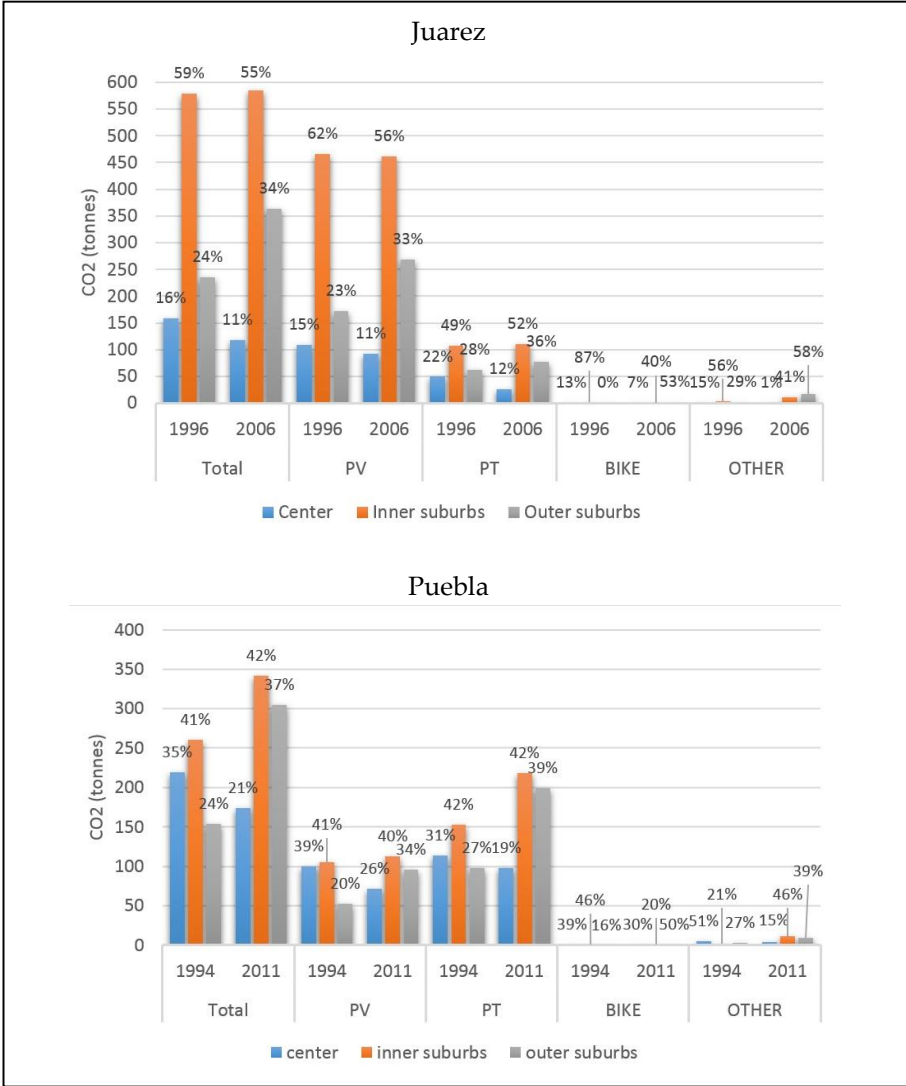
GHG emissions grew more with distance to urban centers and as densities decrease. In the city-center of the Paris Region the evolution rate of CO₂ emissions between 1991 and 2001 was -9%, CO₂ emissions stabilized in the inner suburbs and outer suburbs had a growth of +10% (Figure 29 section 5.1.1). In Lille the increase of daily GHG emissions per person was more pronounced in the outer suburbs (+46%) compared to the city-center (+5%). On the one hand, GHG emissions in Lille tend to decrease or stabilize in the center as well as in the inner suburbs. On the other hand, the outer suburbs show more pronounced increases of GHG emissions from daily passenger mobility. In Mexican cities the CO₂ emissions due to global mobility in city-centers had a relative evolution of -26% in Juarez and -21% in Puebla. Inner suburbs had relative evolutions of +1% in Juarez and +31% in Puebla. CO₂ emissions from people living in the outer suburbs increased significantly in terms of proportion and evolution rates. Juarez had an evolution of +54% of CO₂ from people living in the outer suburbs. The evolution in Puebla in this zone was +99%.

Figure 5.5. Average (2006) and evolution (2006/1987) of daily GHG emissions per person by zone, Lille



Source : [93]

Figure 5.6. Evolution of CO2 emissions by transportation mode and zone of residence, Juarez and Puebla



Results have shown the detrimental environmental impact of private vehicle use. As mentioned before, 90% of CO₂ emissions in the Paris Region were due to this transport mode; the shares were approximately 92% in Lille, 77% in Juarez and 40% in Puebla depending on the year. Next section explores an important component of private vehicle use, which is the driver-passenger dimension through the analysis of vehicle occupancy rates in urban areas.

5.2 Influence of vehicle occupancy on CO₂ emissions: a comparative study of French and Mexican cities. ¹²⁹

¹²⁹ This section is a reprint of: Tapia-Villarreal, Irving; Heddebaut, Odile; Madre, Jean-Loup; Quételard, Bernard. Influence du taux d’occupation des véhicules sur les émissions de CO₂ : étude comparée de villes françaises et mexicaine. Contribution à l’ouvrage ERAMOB/CEREMA : Mobilité en transitions. De la connaissance à l’aide à la décision. February 2015.

Irving Tapia-Villarreal, Odile Heddebaut, Jean-Loup Madre, Bernard Quételard

Influence du taux d'occupation des véhicules sur les émissions de CO₂ : étude comparée de villes françaises et mexicaine.

Résumé

La consommation d'énergie d'un véhicule dépend de son poids ; le nombre de passagers peut beaucoup varier, mais leur poids est faible par rapport à celui du véhicule. C'est pourquoi le taux d'occupation du véhicule est un facteur majeur des émissions moyennes de CO₂ par déplacement ou par personne. Principalement en raison de la diffusion rapide de la seconde voiture, le taux d'occupation des automobiles est resté stable ou a même diminué au cours de ces dernières décennies. Comme pour le transport public ou le transport de marchandises, le taux d'occupation est plus élevé pour les longues distances que pour les trajets courts, si ce n'est pour les motifs non obligés en ville. Nous montrerons l'influence du taux d'occupation sur les émissions de CO₂ pour les habitants de différentes agglomérations en France et au Mexique, mettant en évidence des contrastes entre les pays du Nord et du Sud de même qu'entre différents types d'aires urbaine (aire métropolitaine versus territoire d'un ancien bassin minier). Puis nous présenterons les principaux déterminants du taux d'occupation (longueur et motif du trajet) et comment ils ont évolué au cours des dernières décennies.

Introduction

Le réchauffement climatique provoqué par les émissions de CO₂ constitue le problème le plus visible d'un système de transport non soutenable. Cet article montre l'influence du taux d'occupation des véhicules sur les émissions de CO₂ pour la mobilité individuelle. Une approche classique pour relier les émissions de CO₂ à l'activité économique est le modèle « ASIF » ainsi nommé selon la structure de l'équation décrite dans la première section (Unander et Schipper, 2000). Toutefois ce modèle a été élaboré pour tous les secteurs de l'économie et ne tient pas compte du taux d'occupation, qui est un facteur spécifique au domaine des transports. L'objectif de cet article est d'introduire le taux d'occupation dans l'approche ASIF. D'abord en prenant l'exemple de la mobilité quotidienne telle que décrite dans les Enquêtes Ménages Déplacements (EMD) nous incluons ce taux d'occupation dans les équations du modèle (section 1). Dans la section 2 nous prenons l'exemple contrasté de cinq zones urbaines en France et au Mexique, parmi lesquelles les changements survenus en dix ans seront examinés pour la région Parisienne et Ciudad Juárez. Sur ces deux exemples, la section 3 présente les déterminants principaux du taux d'occupation ainsi que leurs évolutions à long terme.

1. Une application du modèle ASIF à la mobilité quotidienne mettant en lumière l'influence du nombre de passagers dans les véhicules

L'approche classique ASIF (Fulton et Eads, 2004; Cuenot 2009) relie les émissions de CO₂¹³⁰ à :

A l'activité de transport, mesurée en voyageurs*km sur la base des EMD,
S la part modale ("modal share" en anglais), mesurée sur les voyageurs*km,

I l'intensité en énergie (en litres/km),

F le facteur d'émission (en CO₂/litre)¹³¹,

CO₂ les émissions de CO₂ en tonnes¹³²;

$$CO_2 = A * S * I * F \quad (1),$$

qui est une somme sur les modes et les types d'énergie.

L'inventaire des émissions de polluants atmosphériques en France réalisé par le Centre Interprofessionnel Technique d'Etudes de la Pollution Atmosphérique (CITEPA) montre que la hausse de la part des émissions de CO₂ se poursuit en passant de 28% en 1990 à 31% en 2008. Cette hausse du pourcentage des émissions de CO₂ dues au secteur du transport routier est imputable à l'augmentation du trafic routier (CITEPA, 2010). Quant au Mexique, l'inventaire National d'Émissions de Gaz à effet de serre (Ges) montre que le secteur transport routier en 2006 est le secteur qui contribue le plus aux émissions de CO₂ avec 27% du total (ERG et TransEngineering, 2006). D'ailleurs, vu que plus de 90% des quantités de CO₂ émises par les habitants des zones urbaines pour leur mobilité locale sont dues à l'usage de l'automobile, c'est sur ce mode que va porter essentiellement notre analyse.

Nous introduisons le taux d'occupation L ("Loading factor" en anglais). L, considéré auparavant comme variable fixe ou exogène dans le calcul des émissions polluantes, est le nombre de voyageurs*km pour le mode considéré A*S, divisé par le trafic ("Vehicle Kilometres Travelled (VKT)" en anglais):

$L = A*S/VKT$, et l'équation (1) donne donc:

$$CO_2 = VKT*L*I*F \quad (2),$$

Ces facteurs sont inter-reliés ; par exemple l'intensité énergétique I dépend du poids du véhicule, qui est fonction du taux d'occupation. Pour les voitures, l'écart de poids entre un véhicule occupé seul ou "à plein" est relativement faible ce qui n'est pas le cas pour un camion. Zallinger et Hausberger, (2004) ont estimé le supplément de consommation d'une automobile correspondant à 100 kilos supplémentaires en utilisant le logiciel ARTEMIS/COPERT4.

¹³⁰ Nous ne considérons pas le niveau instantané, plus désagrégé, avec l'influence de la vitesse, de l'accélération et des pentes, qui montre tout l'intérêt de « l'éco-conduite ».

¹³¹ 1 litre diesel = 2,62 kg CO₂ et 1 litre d'essence = 2,32 kg CO₂. Le facteur d'émission d'un « carburant mixte » peut être moindre dans le cas de biocarburants et pour les moteurs à énergie électrique ou hydrogène, si la production d'électricité est réalisée en utilisant des énergies renouvelables ou nucléaire plutôt que des énergies fossiles ; les coefficients d'émissions à la combustion figurent dans le Guide méthodologique - Information CO₂ des prestations de transport Application de l'article L1431-3 du code des transports 'MEDDE2012.

¹³² quand les émissions de CO mais pas celles de CO₂ ont été calculées au Mexique, la conversion a été réalisée via la base COPERT3.

Tableau 1 : consommation de carburant selon le taux d'occupation pour les voitures particulières

		Sur-consommation	Consommation (litres aux 100 voy.km) selon le nombre d'occupants de la voiture				
		(% par 100kg supplémentaire)	1	2	3	4	5
Gazole	Urbain	1,4	8,3	4,2	2,8	2,1	1,7
	Rural	0,6	4,4	2,2	1,5	1,1	0,9
	Autoroute	0,7	4,7	2,3	1,6	1,2	0,9
Essences	Urbain	2,6	13,8	7	4,8	3,6	3
	Rural	1	5,8	2,9	2	1,5	1,2
	Autoroute	3,9	5,7	2,9	2	1,5	1,3

Source: Hugrel et Joumard (2006) pour la consommation moyenne et Zallinger et Hausberger (2004) pour la surconsommation

Bien que la consommation de carburant par véhicule*km varie peu en fonction du nombre d'occupants, ramenée aux voyageurs*km elle est divisée par un facteur d'au moins 4,5 quand on passe d'un conducteur solo à une voiture avec 4 passagers (tableau 1).

La masse de déplacements automobiles $A*S$ de l'équation (1) (ou $VKT*L$ de l'équation (2)) peut également être ré-écrite sous la forme :

$$VKT*L = DIST_{cond} * MOB * VP / OC$$

avec :

MOB = nombre de déplacements ;

VP = part des déplacements en voiture (conducteur + passagers) ;

OC = taux d'occupation = déplacements réalisés en voiture (conducteur + passagers) / déplacements des conducteurs ;

$DIST_{cond}$ = distance moyenne d'un trajet réalisé par un conducteur (en km) ou longueur moyenne d'un déplacement en voiture.

L'objectif étant d'endogénéiser le taux d'occupation dans l'équation de calcul du CO_2 , on obtient :

$CO_2 = DIST_{cond} * MOB * VP * I*F / OC$ (3), en négligeant les autres modes, puisque l'automobile est largement prédominante en matière d'émission de CO_2 liées à la mobilité locale.

Ainsi un changement de X% d'un quelconque paramètre (MOB, VP, $DIST_{cond}$ ou L/OC) a le même impact pour les émissions de CO_2 . Autrement dit agir sur le taux d'occupation (OC) est tout aussi important que de travailler sur le report modal (VP), le nombre de déplacements effectués (MOB) ou la longueur des déplacements ($DIST_{cond}$).

2. Analyse globale dans différentes aires urbaines

L'analyse de l'influence du taux d'occupation a été effectuée sur cinq territoires contrastés en France et au Mexique :

- Trois aires urbaines dans le nord de la France qui ont fait l'objet d'Enquêtes Ménages Déplacements en 2005 et en 2006, soit l'aire de Lille Métropole Communauté Urbaine (LMCU) la capitale régionale, et deux parties différentes de l'ancien bassin minier soit l'aire de Lens Liévin Hénin Carvin, et celle de Béthune Bruay-la-Buissière ;

- l'aire métropolitaine de Paris (la région Île-de-France, IdF), sur la base des enquêtes de 1991 et 2001 ;
- et l'aire urbaine de Ciudad Juárez (CdJ) située au nord du Mexique sur la frontière américaine, qui a été enquêtée en 1996 et 2006.

Elles sont de taille très différente : 11 millions pour la région parisienne, 1,2 million à Ciudad Juárez, un million à Lille, 370 000 à Lens et 220 000 à Béthune. La structure urbaine est principalement concentrique à Paris malgré les six villes nouvelles construites dans les années 1970, polycentrique pour LMCU avec les villes de Lille, Roubaix, Tourcoing et la ville nouvelle de Villeneuve d'Ascq, plus étalée à Ciudad Juárez et dans l'ancien bassin minier.

Tableau 2 : Influence des principaux déterminants pour l'émission de CO2

	Lille 2006	Lens 2006	Béthune 2005	IdF 1991	IdF 2001	CdJ 1996	CdJ 2006
Trajets/pers./jour	3,99	3,87	4,11	3,53	3,47	1,86	2,11
% en voiture	53%	58%	65%	43%	44%	51%	50%
Taux d'occupation	1,35	1,54	1,51	1,30	1,29	1,70	1,70
Distance moyenne / Trajet conducteur (km)	5,7	4,1	4,5	9,6	10,4	3,1	3,7
CO2(gr)/pers/jour	1 975	1 405	1 791	2688	2678	985*	1901*
CO2(gr)/trajet	495	363	436	761	772	529*	899*
CO2(gr)/km	125	122	130	110	110	334*	486*

Sources: Pour Lille, Lens, Béthune et IdF les calculs ont été réalisés à partir des Enquêtes Ménages Déplacements et l'application de la méthode DEED qui a été décrite par Gallez, (1995), Gallez et al., (1998), Hivert, (1994) et Dupont et al. (2006).

* Correspond aux émissions de CO2 estimées à partir de relations entre CO2 et CO observées dans la base COPERT3. Les estimations de CO de Ciudad Juárez (CdJ) ont été réalisées par González-Ayala (2000) à partir de la modélisation de la demande de transport et de facteurs d'émissions issus du logiciel MOBILE6-Mexico.

Le tableau 2 montre qu'en raison de trajets en voiture plus de deux fois plus longs et d'un taux d'occupation plus bas de 20%, les émissions de CO2 par personne et par jour et pour un jour ouvrable sont 90% plus élevées à Paris qu'à Lens, malgré une part modale de la voiture plus faible (43% contre 58%). Parce que les Franciliens se déplacent moins souvent que les habitants des aires urbaines plus petites, le ratio du CO2 émis en moyenne par trajet est même plus élevé (2,1 entre Paris et Lens). Toutefois, l'émission de CO2 par kilomètre est plus homogène : elle est même plus élevée de 15% à Béthune qu'à Paris parce que les habitants effectuent des trajets 80% plus longs quand ils vivent en Île-de-France.

Il existe diverses approches pour estimer les émissions polluantes dues à la mobilité urbaine quotidienne (Verry, 2007). Parmi celles qui reposent sur les enquêtes ménages déplacements on peut citer notamment l'application directe des facteurs d'émissions unitaires à chaque déplacement observé dans l'enquête. Les émissions de CO2 des villes françaises ont été estimées de cette façon avec l'outil Diagnostic énergie environnement déplacements (DEED) mis au point par l'INRETS à la demande de l'ADEME. Cet outil a pour objectif l'estimation des consommations d'énergie, des émissions de polluants locaux et des émissions de GES à partir de la mobilité quotidienne observée directement dans les enquêtes ménages déplacements (EMD) ainsi que des facteurs d'émissions issus du « Computer Programme to Calculate Emissions from Road Transport » (COPERT4). On obtient donc la consommation d'énergie et les émissions polluantes liées à chaque déplacement en multipliant les facteurs unitaires issus de la méthodologie européenne COPERT4 par la distance parcourue de chaque déplacement pour chaque mode de transport utilisé (Gallez, 1995), (Gallez et al., 1998) et (Hivert, 1994). Une autre approche utilisée pour estimer les émissions polluantes liées à

l'activité de transport observée dans les enquêtes ménages déplacements est la méthode qui prend en compte parallèlement la structure urbaine dans le but de modéliser le trafic sur le réseau routier à l'aide du modèle à 4 étapes :1) génération des déplacements, 2) distribution gravitaire des déplacements, 3) répartition modale de la demande et 4) affectation sur les réseaux des transports, visant à appliquer par la suite les facteurs d'émission. Le modèle utilisé dans le cas de Ciudad Juárez (MOBILE6-Mexique) a été développé pour estimer les émissions provenant du secteur des transports routiers (voitures particulières, motocyclettes, taxis, autobus et camions) au Mexique (ERG, 2003). Ce modèle a été adapté à partir du modèle 6.2 de l'agence américaine de protection de l'environnement (EPA) MOBILE en utilisant les émissions observées des véhicules au Mexique et intègre des données provenant de diverses régions pour représenter avec précision l'ensemble du parc de véhicules du Mexique (Burnette et al., 2001). Cette méthode de calcul d'émissions s'appuie notamment sur l'indicateur véhicule-kilomètre parcouru (VKT) moyenne par jour et par type de voie ou d'autoroute, la vitesse moyenne par type de voie ou d'autoroute, la distribution horaire sur le réseau routier des véhicules-kilomètres parcourus (VKT), la déclivité des sorties d'autoroute, données du parc automobile (âge et caractéristiques des véhicules), la distribution de l'indicateur véhicules-kilomètres parcourus (VKT) par type de véhicule et de données météorologiques, entre autres. Cette dernière méthode a été utilisée dans le cas de la ville de Ciudad Juárez. Ces deux méthodes de calcul des émissions reposent sur le modèle ASIF, ainsi les équations présentées dans la section 1 restent toujours valables quelle que soit la méthode utilisée.

3. Les principaux déterminants du taux d'occupation

3.1 Au niveau national en France

Afin d'identifier des facteurs explicatifs adéquats pour une analyse comparative dans le temps et dans l'espace, un modèle logit a été estimé sur les données fournies par le carnet-voiture (journal retraçant l'utilisation d'une automobile pendant 7 jours) de l'enquête nationale transport ENT de 1994, avec 79,4% d'observations concordantes (Rizet et al., 2010). La variable binaire à expliquer est le trajet solo (VSO), qui vaut 1 si le conducteur est seul dans la voiture pour ce trajet, et 0 dans les autres cas. Le motif et la longueur du trajet (en km) sont les meilleures variables explicatives, ainsi que le type de ménage (principalement le nombre de ses membres). Les variables géographiques (la localisation du domicile ou l'origine/destination du trajet) semblent n'avoir presque aucun effet, et l'influence du revenu semble résulter des déterminants principaux décrits ci-dessus. C'est surtout la seconde voiture du ménage, et encore plus la troisième, qui sont utilisées « en solo ». Les voitures sont mieux remplies le samedi et le dimanche, mais aussi le mercredi (accompagnements d'enfants pour des activités extra-scolaires). Par contre, le conducteur est souvent seul pour aller au travail.

A partir d'une comparaison entre les enquêtes nationales transport réalisées en 1994 et 2008, Grimal (2011) a croisé les distances avec les motifs en utilisant une approche par classification automatique. Il a montré en particulier que la baisse du nombre moyen de passagers par voiture est due en partie à une proportion croissante de courts trajets, ce qui n'était pas le cas entre 1982 et 1994 où le taux d'occupation était resté presque constant.

3.2. Évolutions comparées en région parisienne et à Ciudad Juárez

Le nombre de passagers est plus important pour les longs trajets que pour les trajets locaux. Cependant à l'échelle urbaine, le taux d'occupation est légèrement plus élevé pour les très courts trajets que pour les plus longs dans un contexte d'augmentation des distances pour les trajets liés au travail, qui correspondent à des taux d'occupation faibles. En effet, il est plus probable que des personnes qui commencent un déplacement dans la même zone d'origine

aient des destinations dans des zones géographiquement proches (faire des achats dans le magasin de quartier, déposer des enfants dans l'école la plus proche, etc.). Par conséquent, dans une zone urbaine il semble y avoir plus d'opportunités pour plusieurs passagers de réaliser leurs trajets en commun et de partager le même véhicule dans une zone restreinte plutôt que dans un périmètre plus large (tableaux 3 à 6).

Tableau 3 : Influence de la longueur des trajets sur les taux d'occupation chez les Franciliens (IdF)

Quartile	1991					2001					Taux de variation 2001/1991			
	Distance	Moy.	Dépl/Véh.	Pass.	VKT	Distance	Moy.	Dépl/Véh.	Pass.	VKT	L	Dépl.	Pass.	VKT
	(km)	L	(mill)	(mill)	(mill Km)	(km)	L	(mill)	(mill)	(mill Km)	%	%	%	%
Q ₁	0 à 0,6	1,67	2,2	3,7	2,5	0 à 0,7	1,62	2,7	4,4	3,2	-3	+24	+19	+31
Q ₂	0,6 à 1,5	1,53	2,7	4,2	7,3	0,7 à 1,9	1,43	2,9	4,2	9,1	-6	+6	-1	+25
Q ₃	1,5 à 4	1,38	2,8	3,9	19,1	1,9 à 4,9	1,33	2,9	3,9	23	-3	+4	0	+20
Q ₄	4 à 158	1,3	3,1	4	67,1	4,9 à 72	1,23	2,9	3,6	73,4	-5	-5	-10	+9
Ensemble	0 à 158	1,47	10,8	15,8	95,9	0 à 72	1,41	11,5	16,1	108,7	-4	+6	+2	+13

Moy. L : Taux d'occupation moyen

Dépl/véh : Déplacement par véhicule (millions)

Pass : Passagers (millions)

VKT : Véhicules*kilomètres parcourus (millions)

Sources : Enquête Globale Transport (EGT) portant sur la **mobilité de tous les Franciliens pour l'ensemble des modes de transport** 1991 et 2001.

Signalons que dans les villes étudiées, il n'y avait pas, à l'époque des enquêtes utilisées ici, de mesures d'incitation au covoiturage ou de voies réservées aux véhicules à occupation multiple (VOM) ("HOV: High Occupancy Vehicle lanes" en anglais) pour augmenter le taux d'occupation des véhicules privés. Les principales différences entre ces aires urbaines contrastées pourraient être le résultat d'un écart important en termes de revenu entre pays développé et émergent (Pison, 2011). Même si les données ne correspondent pas à la même année, nous observons en général des taux d'occupation plus élevés à Ciudad Juárez qu'à Paris, montrant l'impact de revenus plus faibles. On observe également qu'en Île-de-France, le nombre d'occupants d'un véhicule a décliné entre 1991 et 2001 quelle que soit la longueur du trajet (-4% pour toute la population pendant cette décennie), alors que dans la ville mexicaine le taux d'occupation paraît stable entre 2006 et 1996 (+0,6%), avec une augmentation en dessous de 5 km et une diminution pour les trajets plus longs.

Tableau 4 : Influence de la distance des trajets sur les taux d'occupation à Ciudad Juárez (CdJ)

Quartile	1996					2006					Taux de variation 2006/1996			
	Distance	Moy.	Dépl/Véh.	Pass.	VKT	Distance	Moy.	Dépl/Véh.	Pass.	VKT	L	Dépl.	Pass.	VKT
	(km)	L	(mill)	(mill)	(mill Km)	(km)	L	(mill)	(mill)	(mill Km)	%	%	%	%
Q ₁	0 à 2,2	1,6	0,15	0,24	0,14	0 à 2,7	1,72	0,18	0,31	0,25	+7	+21	+30	+74
Q ₂	2,2 à 4,4	1,55	0,15	0,23	0,48	2,7 à 5,1	1,63	0,18	0,29	0,69	+5	+21	+28	+44
Q ₃	4,4 à 7,9	1,56	0,15	0,23	0,89	5,1 à 8,9	1,45	0,18	0,26	1,23	-7	+20	+12	+38
Q ₄	7,9 à 35	1,49	0,15	0,22	1,76	8,9 à 28,1	1,45	0,18	0,26	2,37	-3	+21	+18	+35
Ensemble	0 à 35	1,55	0,59	0,92	3,27	0 à 28,1	1,56	0,72	1,12	4,54	+1	+21	+22	+39

Sources : Enquêtes Ménages Déplacements 1996 et 2006.

Le motif, second facteur explicatif des taux d'occupation, semble avoir un impact similaire à Paris et à Ciudad Juárez malgré des contextes très contrastés en termes de revenu et de taille d'agglomération, montrant ainsi un potentiel important pour augmenter le remplissage des voitures pour les trajets liés au travail ou aux études (tableaux 5 à 7).

Tableau 5 : Influence du motif de déplacement sur les taux d'occupation et les émissions de CO2 dans la région parisienne (IdF)

	1991							2001						
	Moy.	95%	Dépl/Véh.	Pass.	VKT	Cons	CO2	Moy.	95%	Dépl/Véh.	Pass.	VKT	Cons	CO2
	L	i.c.	(mill)	(mill)	(mill Km)	(gep)	(t)	L	i.c.	(mill)	(mill)	(mill Km)	(gep)	(t)
Travail	1,15	+/- 0,01	4,8	5,5	58	4237	12981	1,07	+/- 0,01	3,8	4,1	50,9	3529	10277
Études	1,32	+/- 0,07	0,13	0,2	1,3	96	295	1,19	+/- 0,07	0,1	0,1	1,1	77	223
Santé	1,39	+/- 0,06	0,19	0,3	1,1	88	271	1,3	+/- 0,06	0,2	0,3	1,5	123	354
Achats	1,49	+/- 0,02	1,43	2,1	7,3	580	1788	1,45	+/- 0,03	1,7	2,5	10,1	790	2273
Visites	1,54	+/- 0,03	0,77	1,2	7,4	531	1636	1,41	+/- 0,03	0,8	1,1	8,2	583	1691
Loisirs	1,58	+/- 0,04	0,53	0,8	3,7	289	890	1,51	+/- 0,04	0,6	1	4,9	379	1096
Personnel	1,62	+/- 0,02	1,71	2,8	11,1	848	2606	1,26	+/- 0,02	1,7	2,1	19,5	1439	4195
Promenade/voiture	1,78	+/- 0,15	0,06	0,1	0,5	39	119	1,73	+/- 0,11	0,1	0,2	0,7	54	156
Accompagnement	2,31	+/- 0,02	1,26	2,9	5,7	460	1411	2,12	+/- 0,03	1,3	2,7	6,2	505	1451
Chercher qqn	-	-	-	-	-	-	-	1,78	+/- 0,03	1,1	2	5,7	457	1314
Ensemble	1,47	+/- 0,01	11	16	96	7168	21996	1,41	+/- 0,01	11,5	16,1	108,7	7937	23032

Cons : consommation énergétique

i.c. intervalle de confiance à 95 %

Sources : EGT 1991 et 2001.

Tableau 6 : Évolution de la mobilité, de la consommation d'énergie et des émissions de CO2 chez les Franciliens (IdF)

	Taux de variation 2001/1991					
	Dépl.	Pass.	VKT	L	Cons	CO2
	%	%	%	%	%	%
Travail	-19	-24	-12	-7	-17	-21
Études	-26	-34	-17	-10	-20	-24
Santé	+18	+14	+37	-7	+40	+31
Achats	+20	+18	+39	-3	+36	+27
Visites	0	-7	+11	-8	+10	+3
Loisirs	+20	+15	+36	-4	+31	+23
Personnel	-3	-24	+76	-22	+70	+61
Promenade	+52	+53	+35	-3	+38	+31
Accompagnement	+2	-7	+9	-9	+10	+3
Ensemble	+6	+2	+13	-4	+11	+5

Sources : EGT 1991 et 2001.

Dans le cas de l'Île-de-France, les trajets liés au travail sont les trajets les moins énergétiquement efficaces en termes de taux d'occupation (seulement 1,15 passager (pass) par véhicule (véh) en 1991 et 1,07 pass/véh en 2001), ils sont donc les plus polluants non seulement par personne mais aussi responsables de la majorité des émissions de gaz à effet de serre générés (59% du total des émissions de CO₂ par les véhicules particuliers en 1991 et 45% en 2001). Ceci peut aisément être expliqué si l'on observe non seulement le nombre élevé de trajets en voiture pour ce motif, mais aussi leur longueur supérieure à celle des autres déplacements. La baisse de 59% à 45% est due à une augmentation des émissions dues aux autres motifs (à l'exception du motif études) durant cette période (Tableau 6).

Tableau 7 : Influence du motif de déplacement sur les taux d'occupation à Ciudad Juárez (CdJ)

	1996					2006					Taux de variation 2006/1996			
	Moy.	95%	Dépl/Véh.	Pass.	VKT	Moy.	95%	Dépl/Véh.	Pass.	VKT	L	Dépl.	Pass.	VKT
	L	i.c.	(mill)	(mill)	(mill Km)	L	i.c.	(mill)	(mill)	(mill Km)	%	%	%	%
Travail	1,22	+/- 0	0,29	0,36	1,8	1,14	+/- 0	0,3	0,34	2,4	-7	+3	-4	+30
Études	1,39	+/- 0,1	0,03	0,04	0,2	1,12	+/- 0,1	0,03	0,03	0,2	-19	-11	-28	+46
Achats	1,74	+/- 0,1	0,07	0,13	0,3	1,64	+/- 0,1	0,08	0,14	0,4	-6	+11	+5	+28
Visites	2,05	+/- 0,1	0,04	0,07	0,2	1,85	+/- 0,2	0,03	0,06	0,2	-10	-6	-15	+17
Loisirs	1,9	+/- 0,2	0,01	0,02	0,1	1,67	+/- 0,3	0,01	0,02	0,1	-12	-2	-14	+17
Repas/extérieur	2,3	+/- 0,3	0,01	0,02	0	1,91	+/- 0,4	0,01	0,02	0	-17	+14	-5	+52
Chercher/déposer qq	2,04	+/- 0,1	0,12	0,24	0,5	2,09	+/- 0,1	0,22	0,46	1	+3	+89	+94	+80
Autre	1,66	+/- 0,1	0,03	0,04	0,1	1,64	+/- 0,2	0,03	0,06	0,2	-2	+37	+34	+51
Ensemble	1,55	+/- 0	0,59	0,92	3,3	1,56	+/- 0	0,72	1,12	4,5	+1	+21	+22	+39

Sources : EMD 1996 et 2006.

Dans le cas de Ciudad Juárez, les estimations en CO₂ au niveau désagrégé ne sont pas encore disponibles mais on peut faire le même type d'observation pour les deux enquêtes (tableau 7). Sur ces deux exemples les trajets dont la destination est le travail ou les études ont non seulement de plus faibles taux d'occupation en moyenne mais également une réelle tendance à l'augmentation des trajets avec un seul occupant à bord du véhicule.

Conclusions

En Île-de-France il y a eu une tendance générale à la baisse des émissions polluantes des transports routiers pendant la période de 2002 à 2012 grâce aux nouvelles normes Euro appliquées aux véhicules particuliers, à la réduction de la vitesse, aux aménagements mis en œuvre par les urbanistes et au développement des modes alternatifs au véhicule particulier [163]. Pendant cette période des initiatives de développement du covoiturage commencent à apparaître provenant de collectivités territoriales et du milieu associatif. En effet, l'article 13 de la loi n° 2009-967 du 3 août 2009 sur la programmation du Grenelle de l'environnement stipule que « l'État encouragera, dans le cadre des plans de déplacements urbains, la mise en place de plans de déplacement d'entreprises, d'administrations, d'écoles ou de zones d'activité, ainsi que le développement du covoiturage ». Malgré cet effort, des niveaux plus optimaux de remplissage des véhicules particuliers sont toujours en attente d'être observés. D'ailleurs, les États Unis ont déjà acquis de l'expérience dans ce domaine non seulement avec les incitations au covoiturage, mais aussi avec la réalisation de voies pour les véhicules à occupation

multiple (VOM) alors qu'en Europe et en Amérique latine, il existe fort peu de cas répertoriés. Ces mesures sont testées dans les zones connaissant des problèmes de congestion (par exemple réduction sur les tarifs d'abonnement sur l'autoroute A14 à l'Ouest de Paris) dans le but de remplir les véhicules lors de déplacements longs et « contraints » et contribuent ainsi à la réduction des émissions de gaz à effet de serre.

Sous réserve de questions méthodologiques, trois résultats ressortent. D'abord en moyenne, les voitures ne sont même pas utilisées à la moitié de leur capacité, en supposant cinq sièges disponibles, comme nous avons pu le constater dans les exemples présentés dans cet article. En outre, le remplissage des voitures, qui avait stagné en France dans les années 80, a repris un mouvement tendanciel à la baisse en raison du poids croissant des trajets courts. Et l'efficacité de l'automobile est particulièrement faible pour les navettes liées au travail ou aux études. Il est d'ailleurs facile d'imaginer des situations où la conduite solo est inévitable comme un trajet pour affaire (visite à un client) par exemple, ou un parent qui rentre seul chez lui après avoir conduit une voiture pleine d'enfants pour une activité de loisir. Par ailleurs, différentes tendances économiques et sociales peuvent favoriser de faibles taux d'occupation comme les horaires de travail plus flexibles ou de plus petites tailles de ménages.

Toutefois, l'analyse identifie également des domaines où il existe un potentiel d'augmentation du taux de remplissage des voitures. Il reste des capacités inemployées pour presque tous les types de trajets et pas seulement pour le domicile-travail et les déplacements courts où l'occupation des véhicules est particulièrement faible.

Cependant, l'approche la plus simple pour augmenter le facteur de remplissage des véhicules serait probablement d'internaliser les coûts externes du transport. Depuis les années 2000, les prix des carburants sont de plus en plus volatiles et orientés à la hausse. Même s'il est difficile de se projeter dans l'avenir, le prix du pétrole, dont les ressources sont limitées, devrait continuer à être orienté à la hausse dans le long terme avec de plus en plus d'instabilité ("bumping plateau"). Hautzinger et al. (2004) ont modélisé les élasticités du prix de l'essence en Allemagne et croisé ces élasticités pour différents modes de déplacement au niveau macro et micro. L'augmentation du prix de l'essence se traduit par une diminution de la demande. L'élasticité pour la voiture comme passager est autour de -0,16, alors qu'elle est autour de -0,38 pour la voiture comme conducteur. Ceci signifie qu'avec une augmentation du prix de l'essence le facteur de remplissage devrait également augmenter.

Concernant les effets de revenu, le nombre moyen de passagers est plus élevé dans les zones à faibles revenus (e.g. dans l'ancien bassin minier du nord de la France en comparaison avec les capitales régionale ou nationale, ou en Amérique latine en comparaison avec l'Europe). Ce contraste a des conséquences évidentes sur l'efficacité énergétique et sur les émissions de CO₂ par personne et par trajet.

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5.3 Chapter summary

Pollutant emissions from mobile sources depend on traffic volumes and technological progress. The implementation of new technologies in motorized modes have not been sufficient to reduce CO₂ emissions in Paris Region (between 1991 and 2001), Lille (1987 and 1998), Juarez (1996 and 2006) and Puebla (1994 and 2011). The diminution is only observed on carbon monoxide (CO), volatile organic compounds (VOCs), nitrogen oxide (NO_x) and particulate matter (PM). It is only since 2006, when the stabilization of traffic volumes in Lille during the 1998-2006 period, allowed to take full advantage of technological advances in private vehicles causing a slight diminution of energy consumption and GHG emissions including carbon dioxide (CO₂) [83, 93]. An example of a synergistic approach to GHG emission mitigation is the case of the Paris Region where a downward trend of pollutant emissions from road transport was observed more recently during the period from 2002 to 2012 thanks to new European emission standards applied to passenger vehicles, the reduction of speed limits, applied urban planning and the development of alternative transportation modes [163]. The decrease of GHG emissions from transport is due also to a peak car phenomenon reported in most recent surveys. The use of car stabilized between 2001 and 2010 (+0.6%) while the average trip length in private vehicles was 300 meters shorter in 2010 compared to 2001 (6.1 km vs 6.4 km) [104].

GHG emissions per unit (km) are considerably higher in Mexican cities. In addition, traffic volumes continue to grow in Juarez and Puebla but for different reasons. On the one hand, the decline of vehicle trips per person observed in Puebla is not sufficient to slow down traffic mostly due to population increase. On the other hand, traffic growth in Juarez was mostly due to the increase of vehicle kilometers traveled per person. According to the latest surveys of Juarez and Puebla, the combination of traffic increase and high rate of old vehicles has not allowed energy saving and pollution mitigation technologies in vehicles to reduce CO₂ emissions in Mexican cities. Based on these results it is unlikely to observe in the near future changes in travel behavior and/or a rapid renewal of the vehicle fleet. This is not good news since in the pledges for Nationally Appropriate Mitigation Actions (NAMA's) and targets submitted at the Copenhagen Accord of the 15th session of the Conference of Parties (COP 15, 2009) to the United Nations Framework Convention on Climate Change, Mexico has set aspirational goals of -30% GHG emissions from Business-as-Usual projection by 2020 and -50% below 2000 levels by 2050. Up to now we have not seen policies which could permit to reach such objectives.

Another finding is that passenger capacity in cars is nowhere used efficiently; occupancy rates are not even close to half load and have not increased over the past few decades; they have stagnated at best, even slightly decreased. This has clearly negative consequences on CO₂ emissions in the long term. The occupation rate in private vehicles tends to be particularly low for commuting trips (work and education) as well for short trips. The United States Environment Protection Agency/EPA [116] estimated the emissions reductions gain from a reduction in vehicle miles traveled (VMT) from 30,000 miles (traveled by 1000 vehicles) to 15,000 miles (traveled by 500 vehicles) that will occur as a result of carpool program implementation which consisted on doubling the occupancy rate from 1 persons/vehicle to 2 persons/vehicle for a daily commute. The daily average CO₂ emission reductions were 12.2 pounds for gasoline passenger cars and 17 pounds for gasoline light trucks. The Swedish National Road Administration [149], estimates that the generation of 6600 tons CO₂ can be avoided per each vehicle used exclusively for car-pooling during one year. Following the same logic from EPA and SNRA we could estimate an hypothetical CO₂ emission reductions for work commuters from the Paris Region of about 5000 tons per day considering the hypothetical case of doubling the occupancy rates observed in 2001.

With respect to urban form, results have shown the detrimental effect of urban sprawl on traffic generation, energy consumption and GHG emissions. The GHG assessments confirm that the outer suburbs of French and Mexican cities are gradually being responsible for more and more of total GHG emissions from daily passenger mobility.

This Chapter has shown that CO₂ emission reduction goals are very difficult to achieve solely with technical solutions and the key to actually reducing carbon footprint from urban daily travel should be aimed also to the reduction of vehicle kilometers traveled (VKT) based on a synergistic approach of pollution mitigation strategies, by combining not only technological progresses but also actions to promote changes in travel behavior. This is clearer in Mexico where the democratization of latest technology have a significant delay compared to the developed world.

GHG emissions assessment show that the pollution mitigation strategies that could generate a potential snowball effect if applied simultaneously are:

- the development of alternatives to private car such as public transport, walking and cycling modes;
- mobility management services to reduce transport volumes (telecommuting replacing physical trips and increasing occupancy rates in private vehicles) and
- increasing density and diversity of land use leading to less motorized trips and a slowdown of urban sprawl.

Chapter 6. CONCLUSIONS

Chapter 6. Conclusions

6.1 Overall contributions

This Ph.D. thesis represents the main result of the international scientific research cooperation program between France and Mexico composed by the French Scientific Cooperation Evaluation-Orientation fund program (ECOS NORD), the Mexican National Association of Universities and Higher Education Institutions (ANUIES) and the Mexican National Council of Science and Technology (CONACYT); it results from the collaboration between the Laboratory of Economics and Social Dynamics of Transport (DEST) from the Department for Planning, Mobility and Environment (AME) at the French Institute of Science and Technology for Transport, Development and Networks (IFSTTAR), the Doctoral School of Economics of the University of Paris 1 Panthéon-Sorbonne and the Department of Urban and Regional Economics at the Faculty of Economics of the Meritorious Autonomous University of Puebla (BUAP - Benemérita Universidad Autónoma de Puebla).

This study made contributions in transport research in a numbers of ways. The research succeeded in filling important gaps in the existing transport literature between different development contexts. As summarized in literature review, the development and application of Age-Cohort Travel Demand modelling and GHG emissions assessment methodology have been mostly studied in the context of developed countries. Nevertheless, understanding urban travel demand and travel behavior changes in developing countries are equally important for clear comprehension of peak car, peak travel and urbanization phenomena, as well as their environmental impacts. Therefore, the study has contributed to the literature by incorporating developing country data, which included at the same time two contrasted urban contexts.

It is important to mention that in Mexico, as for many developing countries, research funds are very limited, therefore the dissemination of research exploiting Mexican travel surveys is minimal and usually limited to global results. Results are generally used by authorities only to enrich urban development plans through the development of transportation projects. Therefore, datasets are usually kept confidential so there is no follow up and no comparative analyzes are systematically made between surveys. Even if available, comparisons are made from global results so it's difficult to statistically follow travel behavior changes between surveys.

Consequently, this research represents an unprecedented effort in Mexican cities to study, in a harmonized way, the most significant socioeconomic, geographic and demographic travel demand factors and their evolution over time through the application of econometric models presented in Chapter 3. Another unprecedented contribution to Mexican cities was the development of Travel Demand Forecasts with the Age-Cohort model approach developed by the French National Institute for Transport and Safety Research (INRETS) taking into account age and cohort effects (Chapter 4). Official detailed demographic projections at the urban level were inexistent in Mexican cities, so had to be developed for this research. Additionally, this project contributed by developing harmonized transport-related energy expenditure and greenhouse gas (GHG) emissions assessments (Chapter 5).

With respect to French case studies, an important contribution to transport research was the addition of the most recent survey from Lille to Travel Demand Forecasts which were developed previously by Krakutovsky [32]. Peak travel phenomena observed on developed countries is only reflected in Lille in the 2006 survey, so calibrating mobility projections with this new data was a crucial task to update overall Travel Demand Forecasts for this city. Moreover, comprehensive GHG emissions estimations from travel activity in the Paris Region were improved by taking into account vehicle technological advances and trips with origins or destinations outside the surveyed area, leading to new results.

The application of these methodologies would not have been possible without an important missing data imputation phase for both Mexican and French case studies. Finally, the fact of applying the same methodologies to Mexican and French cities allowed the analysis and comparison of driving forces behind past and future travel demand in different development contexts.

6.2 Limitations

This research study consisted first on making Household Travel Surveys exploitable and comparable between each other. Access and interpretation of older surveys, especially in the Mexican side, was in particular a very difficult, but a successfully achieved task. In total nine Household Travel Surveys from different cities and countries were corrected and adapted in order to apply in a harmonized way the Econometric Modelling Analysis (Chapter 3), the Age-Cohort Travel Demand model (Chapter 4) and the BEED GHG Emissions Assessment methodology (Chapter 5).

This demanded a great effort but at the end the task was successfully accomplished. However, the following limitations were found throughout the development of this research study project.

- Since data had to be comparable between countries and cities, data availability played a crucial role in present research. Household Travel Surveys were the only comparable source of urban travel activity; as these surveys consider only the inhabitants of the city, this research do not take into account travel activity from tourists, businessman visitors, nor commercial vehicles.
- Households Travel Surveys contained incomplete or missing data that had to be filled or replaced through imputation methods. A common example of missing values in travel diaries is travel distance. Nevertheless, there are variables that couldn't be estimated without incurring significant bias. That is the case of traveled speeds that could be estimated, in a very simplistic way, as a function of transportation mode and traveled distances. However transportation infrastructure play a significant role on traffic congestion, hence on travel speeds. Coded transportation networks by mode are not easily obtainable in particular in developing countries. In addition, it is not in the scope of this study to run traffic assignment, which is the final step in the conventional four step travel demand model and consists on the selection of routes between origins and destinations. Travel speeds can be also estimated with other variables such as time of departure and time of arrival, which are generally inaccurate in travel surveys (i.e. rounded and often biased) and unfortunately had also incomplete or erroneous data in Mexican surveys. Therefore travel speeds are not measured or studied in this research. The objective of this research is to study the dynamics of travel behavior measuring only travel intensity in terms of number of trips and distance travelled; which is the most important variable needed to assess GHG emissions.
- It is generally accepted that travel demand is partly a product of economic growth. Yet, the relationship is far from deterministic, and decoupling of travel intensity from GDP has begun to occur in many OECD countries. Travel Demand Forecasts from the present study could not include income and price effects due to data availability. As mentioned in section 6.4 adequate continuous mobility data is so far inexistent, in particular in developing

countries. In addition, in order to properly take into account income and price effects from cross-sectional data, more than three Household Travel Surveys are needed. As stated by Armoogum et al. [61]: *“In order to be able to distinguish between life-cycle and generation effects, the calibration of an Age-Cohort model (based on the analysis of variance) requires data on the mobility behavior of individuals for at least two observation periods. However, it is preferable to have three or more observations to obtain a residual term taking into account factors not included in the model (i.e. income or price effects)”*. Lastly, respondents are often reluctant to declare their income level; not all income variables available on French and Mexican Household Travel Surveys are coded at individual level, being the individual travel behavior analysis the main scope of this research. Even when available, Mexican survey developers recommend to use per capita and household income with caution as it may be biased due to erroneous answers given intentionally by respondents as they try to hide undeclared income to federal tax authorities.

6.3 Research findings

One of the most influential factors for explaining people’s private vehicle use in terms of traveled trips and kilometers, in all case studies, is vehicle ownership at the household level. At the same time, vehicle ownership has been correlated with household income, household’s location and the total number of adults living in the household, albeit with different effects and trends depending on case study.

- The decoupling of vehicle ownership and household income have been observed only in French case studies (Lille and the Paris Region), where household’s location and total number of adults living in the household are playing more important roles in recent surveys for explaining vehicle ownership. The same trend has been observed at a national level in France [25].
- Contrary to what is observed in Lille and the Paris Region, in Juarez the impact of the most explanatory variable for household vehicle ownership, which is household income, remains stable over the years, as well as the number of adults living in the household and residential location.

- In Puebla the direct comparison of models is not possible due to data availability, in particular household's income is lacking in 1994. However, as for Juarez (both years) and the French case studies (in the 90's), household income is the strongest explanatory factor in 2011. In addition, the geographic factor seems to strengthen its effects regarding household motorization. While in 1994 the zone of residence is not statistically significant, in 2011 the variable is ranked as fourth in the list of explanatory factors.

In addition to driving license and public transport card (when variables are available), household vehicle ownership has been highly correlated with people's travel activity showing generally similar effects in all case studies. In general, results show that the higher the number of vehicles in the household, the higher the traveled kilometers in private vehicle driver and passenger, and the lower traveled distances by Public Transport. In addition, results show the importance of household vehicle ownership in the list of explanatory factors of distance travelled. Findings for each transportation mode and case study are as follows:

- In Juarez (both years), household vehicle ownership is the strongest variable for explaining travel distance by vehicle driver, vehicle passenger and low use of public transport.
- In Puebla, driving license variable is available. In this city vehicle ownership at the household level remains the second factor (only after driving license) for explaining kilometers as a vehicle driver in both years. Household motorization is the strongest explanatory factor of vehicle passenger kilometers as well in both years. Contrary to the Paris Region, household vehicle ownership strengthen its effects for explaining low travel kilometers by Public Transport.
- In Lille, household vehicle ownership is the strongest explanatory factor of vehicle driver kilometers in 1987 and 1998. In 2006, it goes to second place in the ranking of explanatory factors only after driving license. Household motorization gained importance in the most recent survey for explaining kilometers traveled as vehicle passenger and by public transport.
- In the Paris Region, driving license and public transport card variables are available, however vehicle ownership remains the second factor (only after the lack of transport card) for explaining kilometers as a vehicle driver in both years.

Vehicle ownership is not the most important variable for explaining vehicle passenger kilometers in this case study, however it has strengthened its effect in 2001. Moreover, the number of vehicles in the household is not longer a significant variable for explaining traveled kilometers by Public Transport in 2001.

With respect to the urban form factor (zone of residence) as an explanatory variable for people's travel activity, results show that the number of traveled kilometers per person increases with the distance from the city-center for Vehicle Driver, Vehicle Passenger and Public Transport. Indeed, the farther the person lives from the center, the greater the number of traveled kilometers per person, regardless the mode of transportation. Comparing to other explanatory factors of travel activity at an individual level over the years, zone of residence loses importance in Juarez (all modes). In Puebla, zone of residence as an explanatory factor stabilized for Vehicle Driver and Public Transport, while gained strength for Vehicle Passenger. In Lille, it slightly increased its strength as an explanatory factor for Vehicle Driver, it stabilized for Vehicle Passenger and decreased for Public Transport. Zone of residence stabilizes its strength in the Paris Region, being the third explanatory variable in both years for Vehicle Driver, the first for Vehicle Passenger and the second for Public Transport (only after the possession of transport card).

How has gender inequality evolved over time? Men travel longer distances as vehicle driver in all cities, albeit women increased their share of travel kilometers as a driver between surveys in all case studies. Regarding the vehicle passenger mode, women travel longer distances in all case studies and all years; gender convergence of travel kilometers as vehicle passenger was observed only in Puebla and the Paris Region. As for the Public Transport mode, women travel shorter distances in Lille (2006) and the Paris Region (both years), observing in the last case a gender convergence. Moreover, neither gender nor family role (i.e. spouse) are explanatory variables for Public Transport kilometers in Juarez (both years), Puebla (both years) and in Lille (1987 and 1998).

Similarly to developed countries, the age pyramid from Juarez and Puebla is ageing. In other words, the proportions of people aged 45 and older in Juarez and Puebla will continue to increase while the shares of younger generations will continue to decrease. Since elderly people, compared to most active age categories, travel significantly shorter distances per person in all modes of transportation, including

vehicle passenger mode (in which children and teenagers travel the longest average distances per person), the only and exclusive effect of population ageing would lead to a constant decrease of total average traveled kilometers per person. In other words, if the observed changes in forecasts of traveled kilometers by mode and per person were purely a result of population ageing, then all projections of average distances per person would gradually decline for all cities and for all modes of transportation.

However, changes in travel behavior from individuals (by age category) play an important role in long-term mobility projections, not only amplify the population ageing phenomenon in some cases, but could counterbalance the downward trend caused by population ageing in other cases. For instance, total demand by age categories from Household Travel Surveys shows that older generations in France and Mexico are being increasingly responsible for more motorized travel, while more active age categories and younger generations are slowing down the use of private vehicle; except for Juarez in which younger generations also increased their share of car trips. In general and for all case studies, the curve of the total number of trips by age bracket tends to flatten out for vehicle driver. In this mode, individuals around 40 years old make the highest number of trips as drivers in all cities and years. Yet, older generations are increasingly taking over more important shares of vehicle driver activity.

In summary, besides the population ageing phenomenon, the future trends of average travel kilometers per person are also due to changes in travel behavior, in particular:

- In Juarez the slight but steady increase of forecasted average Vehicle Driver kilometers per person is due mostly to the joint effect of population ageing and travel behavior changes due to generation effect to be observed in the future from people 40 to 70 years old, who will travel more kilometers per person by car as a driver compared to people from the same age but from previous years. Combined with the fact that, even if population shares from age brackets 40 years old and younger will decrease, traveled kilometers per person for these age categories will not decrease but will remain stable in the future.

- In Puebla the decrease of forecasted average travel distance as Vehicle Driver per person is due also to per capita travel behavior changes from every age category (young adults, midlife individuals, and elderly people), who will travel fewer kilometers in this mode compared to people with the same age from previous years. In global terms, travel distances as vehicle driver will be increasingly due to older generations but only because of the jointly effect of population ageing and steady population growth, and not because of increases in per capita traveled distances by car as a driver for older age brackets.
- In Lille, shares of people of 60 and older increases. In this city, the average per capita travel distance by Car Driver increases if the Age-Cohort model is calibrated with 3 surveys (i.e. 1987, 1998 and 2006) and decreases if calibrated using the 2 latests surveys. In fact, forecasts show that when calibrating with 3 surveys, travel behavior stabilizes for 40-45 years old and per capita travel distances decreases for people 35 years old and younger. The peak car becomes evident, when the model is calibrated only with data from two most recent surveys; in this case, and in addition to population ageing, the decrease of total average traveled kilometers by car as a driver is due to important travel behavior changes towards fewer traveled kilometers in this mode from people aged 60 years and younger.
- In Juarez, the total average traveled kilometers by Vehicle Passenger per person is expected to decrease in the future. This is due to a combined effect of population ageing and travel behavior changes. On the one hand, people from 50 years and younger will travel on average the same or slightly more vehicle passenger kilometers per person, which correspond to the age categories that will decrease in the future due to population ageing. On the other hand, travel behavior of people 55 years and older will change towards a decrease of vehicle passenger travel kilometers per person, being the age categories that will continue to increase. In addition, population ageing is not strong enough to reverse the decreasing trend of the total average traveled kilometers by Vehicle Passenger per person.
- Total average per capita travel kilometers by Car Passenger in Puebla will continue to decrease due to travel behavior changes towards fewer per capita traveled distances from people 40 and older, which combined with population ageing intensify the decrease of total average per person. In addition, 35 and

younger, which are the diminishing age categories, will stabilize travel distances in the future.

- In Lille, the total average distance per person as Vehicle Passenger will decrease in the future if calibrated with two most recent surveys. In addition to population ageing, this is due to the decrease of per capita travel distance in this mode for age brackets from 30 to 70 years old, coupled with future share increases for age categories 60 years and older.
- Mobility forecasts show a stabilization of the total average traveled kilometers by Public Transport per person in Juarez, which is due to a combined effect of population ageing and different travel behavior changes depending of the age category: 60 and older people will travel fewer kilometers per person in this mode, 30 to 55 years old will travel more kilometers and lastly 25 and younger will travel on average the same number of kilometers per capita over the years.
- In Puebla, people from 30 years and older will increasingly travel more kilometers per capita by Public Transport, while younger generations will stabilize their travel behavior. Consequently, by combining these travel behavior changes with population ageing, the total average kilometers per person traveled by Public Transport will continue to increase in the future.
- The total average travel distance per person by Public Transport will increase in Lille. This increase is practically due to all age categories: people from 20 and younger will stabilize their travel behavior, while older than 20 years will travel more kilometers in Public Transport compared to people from the same age from previous years.

Study findings show that sustainable urban transport has begun to take shape only in French cities, where CO₂ emissions stabilized or declined slightly mostly as a result of:

- population growth stabilization,
- population ageing (changing age pyramids towards higher proportions of older people, who, even if they tend to travel more compared to people with the same age from previous years, they still remain as the less mobile age-group compared to younger people),

- peak demand (in particular less motorized travel of 34-44 year-old individuals and younger adults),
- and vehicle technology improvements (European emission standards applied to passenger vehicles).

However, in Lille, the snowball effect formed by the combination of these structural and travel behavior changes, coupled with vehicle technology implementation on passenger vehicles, has begun to be noticed only during the most recent period (1998-2006), causing a slight diminution of CO₂ emissions[83, 93]. In the Paris Region these changes have not been sufficient to reduce CO₂ emissions between 1991 and 2001. In fact, the decrease of pollutant emissions from urban transport in the Paris Region has also begun in the 2000's. In addition to previously mentioned structural and behavior changes, as well as vehicle technology improvements, the reduction of pollutant emissions from transport in the Paris Region was due to applied urban planning, the development of alternative transportation modes and the reduction of speed limits[163].

Unlike French case studies, results have shown that Mexican cities failed to reverse the trend towards greater GHG emissions. The reasons encountered in this study that explain the great difficulties to reach in the future the established GHG reduction goals in Mexico are that:

- There is a significant delay on vehicle technology democratization compared to the developed world, combined with a more rapid ageing of the vehicle fleet. Consequently, it is not likely to observe in the near future a cleaner vehicle fleet in Mexican cities.
- High population growth in Puebla and increase of average vehicle traveled kilometers per person in Juarez, led to an increase of total vehicle kilometers traveled in the past and will continue to increase in the future.
- Long-term Travel Demand forecasts from Juarez were based on past population growth rates, which are relatively low. However, traffic increase could be much greater if population growth in this city turns out to be higher than expected.
- Yes, population ageing can slow down CO₂ emissions growth but cannot stop it. This is due to the fact that population ageing is far to be strong enough to

significantly decrease the vehicle kilometers traveled in Mexican cities, coupled with the fact that, at least in Juarez, older age categories had similar shifts observed in France towards more use of motorized modes and will continue to play more important roles in the future.

- Occupancy rates of passenger vehicles are very low (less than half its capacity) and remained stable over the years.
- The decentralization effect or “*doughnut effect*”, which is the process of distributing or dispersing people away from the city-center, was observed only in Mexican case studies and with high rates. In fact, city centers are being emptied at the expense of new suburban developments, which are increasing also probably to migrations from outside the urban area. This indicates on the one hand, an increasing attraction of peripheral areas and on the other hand, a lack of interest from Mexican authorities to re-densify city-centers. As a consequence, increasing shares of total travel kilometers and motorized households are observed in the suburbs. In fact, unplanned urban sprawl led to even more pollutant behaviors from suburban individuals. The increase rates in the suburbs are higher for kilometers traveled by private vehicle than by public transport. Yes, in French case studies the shares of city-centers are also relatively low compared to suburbs, accounting only for less than 1/5 of total population, number of trips and traveled kilometers. However, not only the decentralization effect has stabilized in these cities, meaning that the population from recent surveys is distributed almost accordingly to previous years, but in fact population in city-centers has been also increasing. In both countries traveled kilometers and number of trips increase faster in suburbs compared to city-centers, albeit with significantly higher rates in Mexican cities. Traveled kilometers in the suburbs increased faster for private vehicle than for public transport, as well as the shares of household vehicle ownership in suburbs compared to city-centers. The GHG emissions inventories confirm the negative effects of urban sprawl on traffic generation, energy consumption and GHG emissions. In Mexico, it is very likely that cities will continue to expand in a disordered and unplanned manner.
- The trend towards multi-motorization in the household is important in Juarez, Lille and the Paris Region, albeit less pronounced in the latter. On the contrary, Puebla shows increase of car-deprived households and decrease of households with more than one vehicle. This had an “apparent” positive impact towards less

motorized trips and kilometers for both, driver and passenger modes in this city. The downward trend of motorized mode use in this city could be probably due in fact to survey implementation bias, as it is suspected that gated housing communities (generally middle-class and wealthier households) couldn't be properly surveyed. Therefore, data for this city need to be compared and reviewed with new mobility surveys in order to ensure and confirm the representativeness of these results. If representativeness of motorized households is weak or biased, then long-term mobility forecasts will drastically change towards even more motorized travel, which will be an alarming trend in a context of fast ageing car fleet in Mexico, and in particular for this city, high population growth.

- If sustainable urban transport and urban planning implementation continue to be absent in Mexican cities, it is then unlikely to observe in the near future significant changes in travel behavior leading to permanent change towards Public Transport, bicycle or walking modes.

To summarize with respect to France, the same trend towards a decline in mobility can be seen here as in most other developed countries, starting in the early 2000s, while the average distance travelled by households was levelling off and dropped slightly thereafter, with cyclical variations probably linked to fuel price variations, a drop in the percentage of young people holding driving licenses in urban areas and a significant growth in the use of public transport. Given the finding that overall mobility as well as urban car mobility has reached a saturation point, or at the very least has been slowing in the developed countries, what can be concluded in policy terms? With respect to developed countries, there is an encouraging sign that it will be easier to shift the focus of urban transport planning: restrict car usage in the city, while promoting the use of public transport and soft modes. Moreover, it is necessary to find ways to control urban sprawl by making suburbs denser; rethink the construction of toll roads at the periphery of metropolitan areas; rethink our conception of quality-of-life in the city, with less emphasis on the fluidity of car travel; introduce various measures to travel demand management in order to diminish the number of trips and car travel within cities. It would also be necessary to address vehicle technology by imposing stricter standards on manufacturers; nevertheless, the impact on the production cycle and the renewal of cars on the road could take another two decades. The transition must therefore be accelerated (Schipper, 2011).

In Mexico, it is very likely that cities will continue to expand in a way that is disordered and staggered; and socio-economic equality between households in terms of car ownership is probably only beginning, currently the great majority of transport policies favor the use of automobiles, following the US model from the 1970s. In our case studies in Mexico, we can also make out a peak travel phenomenon that could take place probably in roughly 20 years, provided there is a slowdown in population growth. The car fleet is very old and is getting even older, due to lack of purchasing power, but also to policies that encourage ownership of old vehicles, such as the annual vehicle tax from which cars aged 10 years or older are exempt - a tax that was recently abolished at the national level (federal tax) and in certain states (Puebla and Tlaxcala in 2011)-. In Mexico, most Public Transport is rudimentary and not very competitive in relation to travel by car, except in very large cities. In general, it is difficult to modernize it and introduce operating subsidies to make it more competitive. In addition, the public's lack of awareness of environmental issues, coupled with security and safety problems are complicating the introduction of non-motorized modes. What, therefore, would be the most appropriate policies for Mexican cities? First, existing facilities must be strengthened (e.g. bus terminals, bus stations, sidewalks, bikepaths, etc.). Public policies should be crafted to maintain the density of city centers and avoid constructing ring roads without complementary measures to avoid people to move from the center to the periphery, implement smart growth land-use planning, modernize public transport to make it even more competitive compared to cars and to change its image from a mode of transport exclusively for poor people to a mode of transport for everyone. It is important to highlight that in the case of Mexican cities, the increase of Public Transport shares will only bring significant benefits if the infrastructure projects include regulations that assure also the improvement in the bus technologies used. In addition, it is necessary to foster the introduction of pedestrian areas in city centers and in the suburbs; foster the use of bicycles in cities where it has not yet disappeared; promote expansion of bicycle use not only for recreational purposes but also for daily commute; regulate the car fleet in order to make it younger, with cleaner vehicles; disseminate information and facilitate procedures to have access to carbon vouchers that could finance these measures.

In summary, urgent action is needed in particular in Mexican cities, where the trend towards ever-greater generation of GHG emissions is still expected in the future. A comprehensive set of public policies is therefore the key to actually reducing the

transport sector's carbon footprint, as it is not feasible to achieve pollutant emissions reduction goals, especially in emerging economies, solely with advances in motor vehicle technology. It is imperative also to foster permanent changes in travel behavior by facilitating modal shift towards more environmentally friendly modes of transportation. Significant changes towards urban transport sustainability can be only achieved, if applied simultaneously, through a synergistic approach of the following strategies and "carrot-and-stick" policies.

- Yes, promote, but not rely only on vehicle technology advances and democratization, in particular in southern countries; instead to prioritize and invest on alternatives to private vehicle use leading towards permanent travel behavior changes to more use of public transport, cycling and walking modes;
- decrease the age limit of imported vehicles in Mexico, and not foster the purchase of old vehicles with tax exemptions;
- implement travel demand management measures to reduce vehicle kilometers traveled (e.g. telecommuting replacing physical trips, increasing occupancy rates in private vehicles, HOV lanes, taxation, costly parking in city-centers, etc.) and;
- increase density and diversity of land use leading to shorter travel distances and consequently, less motorized trips and a slowdown of urban sprawl.

In the French case studies, which give us an overview of tendencies of motorization in developed countries, we observed encouraging tendencies towards a stabilization or slight reduction of GHG emissions but still far from being sufficient to attain reduction targets necessary to restrain global warming. Even though the poor and emerging countries are very diverse, the Mexican case may give us an insight of tendencies in emerging countries, which are very far from being sustainable and will remain a big challenge in the next two or three decades.

6.4 Future research directions

Present study provides a solid foundation for many research avenues and hence several suggestions are made for further research.

- In this research the limitations of cross-sectional travel surveys for long-term travel projections have been solved through the creation of pseudo-panel data. However, time gap between surveys could lead to a bias from lack of continuity and harmonization; especially when surveys are developed, applied and supervised by different firms or institutions. In France, the comparability between cities and over time is guaranteed by CERTU after checking that the methodology has been implemented correctly, which is a condition for a subsidy from the Ministry. It is not the case in developing countries where Transportation Authorities can drastically change or disappear from one mayor/governor to another based on political interests; and survey methodology is not always harmonized. For instance, Travel Surveys from Puebla are 17-year old apart one to another and are developed by different consultant firms. Surveys from Juarez were developed by the same institute. However, the zone structure changed between surveys; therefore, an important effort was needed in order to harmonize. Possible lack of continuity between Household Travel Surveys could be minimized through the development of new continuous observation instruments (i.e. travel data from a smaller sample interviewed at different points in time over several years) aiming to complete and harmonize current widely separated surveys in terms of time. Finally, travel behavior changes and elasticities could be analyzed easily from continuous or time series data mitigating any time dissociation bias by increasing their comparability. As stated by Ortúzar J. et al [2011]: *“Urban areas over one million inhabitants, should collect mobility data on a continuous basis as part of their efforts to guarantee sustainable development. This would allow them to gain a proper understanding of the pressing environmental and transport-related issues of today’s world, as well as of the effects of economic growth and price volatility (especially for fuel)”*. Consequently, mobility modelling and forecasts could take into account price and income effects.
- This study only emphasized on travel behavior with respect to the most significant variables available, this certainly overlooked the reflection of data at an individual level (e.g. geographic, demographic and micro-socioeconomic variables). Therefore, any future research direction, should be to incorporate macroeconomic variables to compare and contrast the findings. Notably, subject to data availability (continuous data or more than three cross-sectional

surveys), future research should include income and price effects, in particular fuel price.

- Mexican demographic projections at the urban level were specifically developed for this research study due to lack of appropriate data. These population projections were based on official regional data and observed population growth trends from available Household Travel Surveys. Nevertheless, it is recommended to develop various demographic scenarios covering low, middle and high population growth rates.
- There is a paradox with respect to the aggregation of results and their representativity. At more disaggregate/fine zoning, less representative become the results; reciprocally, at more aggregate/grouped zoning the more reliable and robust become the results. In this study the Age-Cohort Travel Demand Forecasts have been developed based on non-spatial projections by city. This was done mainly to minimize bias and also due to data availability, in particular in Mexican cities. Thus, one line of research when data becomes available, should focus on more disaggregated travel projections in terms of zone of residence to follow future impact of travel behavior on urban form. For this, the development of new population projections by micro zone are needed.
- Similarly, travel projections could be also developed at a more disaggregated level in terms of individual's activity, to follow for instance future travel impact exclusively from commuters (active workers and students), which account for most travel activity and pollutant emissions. Likewise, convergence between genders could be studied by observing long-term mobility projections.
- Results have been controlled for study area. City limits have been harmonized and adjusted according to base year's geographic limits. A new path of research could include the study of new developments outside these limits. It would allow a deeper analysis of evolving urban form and urban sprawl, (which were not the interest and would have been too ambitious for the present research), and study their implication of global travel demand, energy expenditure and GHG emissions.

- Finally, another path of research taking into account the Age-Cohort Travel Demand Forecasts and transport-related GHG emissions inventories presented in this research study, is to develop CO₂ emissions forecast scenarios based on different levels of vehicle technology implementation, travel demand management, travel mitigation strategies, shifts towards Public Transport, car pooling or active mode, as well as increases of fuel costs. Mexican CO₂ emissions projections could be based from observed outputs from the developed world by exploiting the fact that developing countries are years behind in terms of vehicle technology implementation and democratization.

This is certainly a substantial research agenda, in which some progress have been already made in developed countries. Yet, developing countries' governments should not undervalue transport research and should give greater priority to the development and implementation of sustainable urban transport plans. This is in particular crucial in mid-sized cities (around 1 million people) from developing countries, as the large part of the world population growth will be observed in these cities and not in large metropolitan areas. Future research leading to the design of public policies, tailored to the implementation capabilities and needs of developed and developing countries, will undoubtedly provide a more compelling basis for specific strategies to reduce the impacts of urban travel demand on Global Climate, achieving reduction targets established by the Kyoto Protocol and the Copenhagen Accord of the 15th session of the Conference of Parties (COP 15, 2009) to the United Nations Framework Convention on Climate Change (UNFCCC).

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Annex 1.

Multinomial Logistic Regression for household vehicle
ownership

1.1. Juarez

		1996				2006			
		Number of obs	3771			Number of obs	1164		
		LR chi2(12)	827.22			LR chi2(12)	294.46		
		Prob > chi2	<0.001			Prob > chi2	<0.001		
		Pseudo R2	0.0885			Pseudo R2	0.0973		
	Vehicles/hh	RRR	P>z	[95% Conf. Interval]	RRR	P>z	[95% Conf. Interval]		
0	(base outcome)	(base)				(base)			
1	Zone (ref: center)								
	Inner sub.	1.22	0.037	1.01	1.47	1.69	0.010	1.13	2.53
	Outer sub.	1.21	0.089	0.97	1.50	1.64	0.023	1.07	2.51
	adults/hh	1.19	<0.001	1.08	1.32	1.09	0.252	0.94	1.28
	income/hh	1.13	<0.001	1.10	1.15	1.22	<0.001	1.14	1.29
	_cons	0.42	<0.001	0.32	0.55	0.27	<0.001	0.17	0.44
2	Zone (ref: center)								
	Inner sub.	1.75	<0.001	1.38	2.23	1.60	0.045	1.01	2.55
	Outer sub.	1.20	0.216	0.90	1.60	1.93	0.008	1.19	3.13
	adults/hh	1.43	<0.001	1.27	1.61	1.08	0.345	0.92	1.28
	income/hh	1.26	<0.001	1.23	1.29	1.40	<0.001	1.31	1.49
	_cons	0.06	<0.001	0.04	0.08	0.08	<0.001	0.05	0.15
≥3	Zone (ref: center)								
	Inner sub.	3.01	<0.001	1.97	4.59	1.63	0.128	0.87	3.08
	Outer sub.	1.22	0.481	0.70	2.10	1.10	0.805	0.53	2.28
	adults/hh	2.22	<0.001	1.91	2.58	1.46	<0.001	1.20	1.79
	income/hh	1.29	<0.001	1.25	1.33	1.49	<0.001	1.39	1.60
	_cons	0.003	<0.001	0.001	0.005	0.01	<0.001	0.00	0.02

1.2. Puebla

	1994				2011			
	Number of obs	3487			Number of obs	4087		
	LR chi2(27)	523877.29			LR chi2(27)	575451.61		
	Prob > chi2	<0.001			Prob > chi2	<0.001		
	Pseudo R2	0.9885			Pseudo R2	0.9903		
	Log likelihood =	-3035.593			Log likelihood	-2820.2874		
Vehicles/hh	RRR	P>z	[95% Conf.	Interval]	RRR	P>z	[95% Conf.	Interval]
0 (base outcome)	(base outcome)				(base outcome)			
Zone (ref: center)								
Inner sub.	0.92	0.330	0.77	1.09	0.93	0.488	0.77	1.13
Outer sub.	0.77	0.015	0.62	0.95	1.05	0.624	0.88	1.25
adults/hh	1.03	0.255	0.98	1.09	1.00	0.961	0.94	1.06
1 type_hh (rf: house)								
Multiple dwelling/other	0.61	<0.001	0.51	0.74	0.75	0.004	0.61	0.91
total_rooms	1.30	<0.001	1.24	1.36	1.24	<0.001	1.18	1.31
income/hh	• NA				1.87	<0.001	1.71	2.04
_cons	0.17	<0.001	0.12	0.23	0.10	<0.001	0.07	0.13
Zone (ref: center)								
Inner sub.	0.93	0.631	0.68	1.27	0.31	<0.001	0.18	0.53
Outer sub.	0.87	0.495	0.58	1.30	0.55	0.003	0.36	0.82
adults/hh	1.00	0.956	0.91	1.11	1.20	0.005	1.06	1.37
2 type_hh (rf: house)								
Multiple dwelling/other	0.38	<0.001	0.24	0.58	0.17	<0.001	0.06	0.45
total_rooms	1.60	<0.001	1.49	1.73	1.37	<0.001	1.22	1.54
income/hh	• NA				2.70	<0.001	2.23	3.27
_cons	0.01	<0.001	0.01	0.03	0.00	<0.001	0.00	0.01
Zone (ref: center)								
Inner sub.	0.93	0.775	0.58	1.50	0.61	0.486	0.15	2.46
Outer sub.	0.98	0.948	0.53	1.80	0.85	0.767	0.28	2.54
adults/hh	1.20	0.004	1.06	1.37	1.48	0.007	1.11	1.97
≥3 type_hh (rf: house)								
Multiple dwelling/other	0.44	0.021	0.22	0.88	0.37	0.339	0.05	2.86
total_rooms	1.87	<0.001	1.68	2.08	1.36	0.043	1.01	1.83
income/hh	• NA				5.08	<0.001	3.11	8.28
_cons	0	<0.001	0	0	0.00	<0.001	0.00	0.00

• NA: Not available data in HTS

1.3. Lille

	1987				1998				2006			
	RRR	St	P>z	[95% Conf. Interval]	RRR	P>z	[95% Conf. Interval]	RRR	P>z	[95% Conf. Interval]		
	Number of obs 4084				Number of obs 3971				Number of obs 6965			
	LR chi2(27) 809109.07				LR chi2(27) 888574.8				LR chi2(27) 1784447.74			
	Prob > chi2 <0.001				Prob > chi2 <0.001				Prob > chi2 <0.001			
	Pseudo R2 0.9905				Pseudo R2 0.9925				Pseudo R2 0.9922			
	Log likelihood -3898.7				Log likelihood -3931.3498				Log likelihood -6974.89			
Vehicles/hh	RRR	St	P>z	[95% Conf. Interval]	RRR	P>z	[95% Conf. Interval]	RRR	P>z	[95% Conf. Interval]		
0	(base outcome)											
1 Zone (center)												
Inner suburbs	1.30		0.012	1.06 1.59	1.38		0.007	1.09 1.75	1.66		<0.001	1.39 1.93
Outer suburbs	1.17		0.176	0.93 1.47	1.89		<0.001	1.43 2.48	2.29		<0.001	1.84 2.72
adults/hh	3.47		<0.001	3.11 3.88	2.48		<0.001	2.18 2.84	1.44		<0.001	1.16 1.62
type_hh (house)												
*Multiple dwelling (LRH)	1.21		0.057	0.99 1.48	1.49		0.003	1.15 1.92	0.80		0.017	0.68 0.95
residential status (owner)												
‡ Tenant (LRH)	0.41		<0.001	0.33 0.50	0.38		<0.001	0.28 0.51	0.40		<0.001	0.36 0.54
Other tenant			• NA		0.44		<0.001	0.33 0.57	0.39		<0.001	0.36 0.54
Free housing			• NA		0.84		0.638	0.42 1.71	0.60		0.120	0.32 1.14
Other	0.54		0.030	0.31 0.94	0.43		0.084	0.16 1.12	0.23		<0.001	0.12 0.51
income_hh			• NA		1.92		0.000	1.79 2.05	1.04		<0.001	1.02 1.07
_cons	0.33		<0.001	0.25 0.42	0.07		<0.001	0.05 0.1	0.82		0.308	0.55 1.2
2 Zone (center)												
Inner suburbs	1.38		0.048	1.00 1.89	2.20		<0.001	1.53 3.15	2.13		<0.001	1.69 2.68
Outer suburbs	1.51		0.015	1.09 2.11	3.83		<0.001	2.59 5.68	4.24		<0.001	3.3 5.45
adults/hh	6.98		<0.001	6.01 8.11	5.90		<0.001	4.94 7.05	4.64		<0.001	3.53 5.76
type_hh (house)												
*Multiple dwelling (LRH)	0.91		0.545	0.67 1.23	1.19		0.351	0.83 1.71	0.62		0.027	0.49 0.76
residential status (owner)												
‡ Tenant (LRH)	0.19		<0.001	0.14 0.26	0.31		<0.001	0.20 0.48	0.12		<0.001	0.10 0.18
Other tenant			• NA		0.39		<0.001	0.27 0.56	0.15		<0.001	0.13 0.24
Free housing			• NA		0.84		0.713	0.33 2.14	0.20		<0.001	0.09 0.51
Other	0.40		0.015	0.19 0.84	0.09		0.021	0.01 0.69	0.15		<0.001	0.07 0.46
income_hh			• NA		3.16		<0.001	2.90 3.44	1.13		<0.001	1.1 1.16
_cons	0.03		<0.001	0.02 0.05	0.00		<0.001	0.00 0.00	0.18		<0.001	0.11 0.28
3 Zone (center)												
Inner suburbs	2.25		0.086	0.89 5.71	1.45		0.305	0.71 2.92	3.36		<0.001	1.94 5.99
Outer suburbs	2.77		0.034	1.08 7.11	3.34		<0.001	1.63 6.83	8.42		<0.001	4.80 14.9
adults/hh	16.26		<0.001	12.79 20.66	14.16		<0.001	10.99 18.25	12.1		<0.001	10.92 14.3
type_hh (house)												
*Multiple dwelling (LRH)	1.77		0.149	0.82 3.83	1.34		0.481	0.59 3.03	0.54		<0.001	0.33 0.88
residential status (owner)												
‡ Tenant (LRH)	0.05		<0.001	0.02 0.12	0.17		0.003	0.05 0.55	0.06		<0.001	0.04 0.15
Other tenant			• NA		0.20		<0.001	0.09 0.45	0.10		<0.001	0.07 0.17
Free housing			• NA		0.00		0.985	0.00 .	0.50		0.252	0.15 1.64
Other	0.37		0.230	0.07 1.89	0.25		0.392	0.01 5.89	0.00		0.982	0.00 .
income_hh			• NA		4.23		<0.001	3.68 4.86	1.19		<0.001	1.12 1.23
_cons	0.01		<0.001	0.00 0.04	0.00		<0.001	0.00 0.00	0.01		<0.001	0.00 0.01

* LRH (low rental housing); • NA: Not available data in HTS

‡ 1987: Tenant; 1998, 2006: Tenant LRH

1.4. Paris Region

	1991					2001			
	Number of obs 9812 LR chi2(33) 8414919 Prob > chi2 <0.001 Pseudo R2 0.9982 Log likelihood -7771.0838					Number of obs 10318 LR chi2(33) 1.06E+07 Prob > chi2 <0.001 Pseudo R2 0.9983 Log likelihood -8986.506			
Vehicles/hh	RRR	St	P>z	[95% Conf. Interval]		RRR	P>z	[95% Conf. Interval]	
0									
1 Zone (center)									
Inner suburbs	2.16		<0.001	1.87 2.49		2.30	<0.001	2.02 2.61	
Outer suburbs	3.96		<0.001	3.35 4.69		3.27	<0.001	2.82 3.80	
adults/hh	2.04		<0.001	1.88 2.21		2.24	<0.001	2.08 2.41	
type_hh (house)									
*Multiple dwelling (LRH)	0.73		0.001	0.60 0.88		0.87	0.121	0.73 1.04	
residential status (owner)									
Tenant LRH	0.83		0.028	0.70 0.98		0.47	<0.001	0.41 0.55	
Other tenant	0.73		<0.001	0.63 0.86		0.64	<0.001	0.55 0.73	
Subsidized ‡	1.86		0.005	1.21 2.87		1.19	0.391	0.80 1.80	
Free housing	1.11		0.490	0.82 1.50		0.60	<0.001	0.45 0.81	
Other	1.76		0.088	0.92 3.38		0.62	0.148	0.33 1.18	
hh_area	1.17		<0.001	1.09 1.26		1.50	<0.001	1.40 1.60	
income_hh	1.64		<0.001	1.59 1.70		1.11	<0.001	1.09 1.14	
_cons	0.04		<0.001	0.03 0.05		0.10	<0.001	0.08 0.13	
2 Zone (center)									
Inner suburbs	4.38		<0.001	3.44 5.57		4.97	<0.001	3.93 6.27	
Outer suburbs	12.13		<0.001	9.35 15.75		10.56	<0.001	8.25 13.52	
adults/hh	3.86		<0.001	3.45 4.31		4.64	<0.001	4.22 5.12	
type_hh (house)									
*Multiple dwelling (LRH)	0.40		<0.001	0.32 0.51		0.51	<0.001	0.41 0.64	
residential status (owner)									
Tenant LRH	0.68		0.003	0.53 0.88		0.27	<0.001	0.22 0.34	
Other tenant	0.67		<0.001	0.54 0.83		0.52	<0.001	0.42 0.64	
Subsidized ‡	1.24		0.470	0.69 2.23		1.07	0.805	0.62 1.83	
Free housing	0.97		0.900	0.59 1.59		0.53	0.009	0.33 0.85	
Other	1.23		0.694	0.44 3.42		0.80	0.642	0.31 2.05	
hh_area	1.46		<0.001	1.33 1.61		2.10	<0.001	1.93 2.28	
income_hh	2.43		<0.001	2.31 2.56		1.26	<0.001	1.23 1.30	
_cons	0.00		<0.001	0.00 0.00		0.00	<0.001	0.00 0.00	
3 Zone (center)									
Inner suburbs	11.00		<0.001	5.29 22.85		6.33	<0.001	3.19 12.56	
Outer suburbs	27.60		<0.001	13.07 58.28		15.07	<0.001	7.54 30.12	
adults/hh	9.22		<0.001	7.76 10.95		10.30	<0.001	8.89 11.93	
type_hh (house)									
*Multiple dwelling (LRH)	0.23		<0.001	0.15 0.35		0.21	<0.001	0.14 0.32	
residential status (owner)									
Tenant LRH	0.46		0.020	0.24 0.88		0.15	<0.001	0.09 0.27	
Other tenant	0.56		0.023	0.34 0.92		0.58	0.013	0.38 0.89	
Subsidized ‡	1.74		0.292	0.62 4.89		0.83	0.744	0.27 2.57	
Free housing	1.44		0.493	0.51 4.07		0.62	0.411	0.20 1.92	
Other	5.55		0.031	1.17 26.24		0.00	0.986	0.00 .	
hh_area	1.81		<0.001	1.51 2.17		2.79	<0.001	2.39 3.26	
income_hh	2.95		<0.001	2.66 3.27		1.31	<0.001	1.24 1.39	
_cons	0.00		<0.001	0.00 0.00		0.00	<0.001	0.00 0.00	

‡ Housing cost subsidized by the employer

Annex 2.

Logistic regression for vehicle driver trips

2.1. Juarez

	1996				2006			
	Number of obs				Number of obs			
	9151				3005			
	LR chi2(33)		3973.92		LR chi2(30)		945.01	
	Prob > chi2		<0.001		Prob > chi2		<0.001	
	Pseudo R2		0.3439		Pseudo R2		0.2644	
	Log likelihood		-3790.718		Log likelihood		-1314.585	
VD_trips (0/1)	Odds Ratio	P>z	[95% Conf. Interval]		Odds Ratio	P>z	[95% Conf. Interval]	
zone								
Center	1 (ref)							* NS
Inner suburbs	1.33	<0.001	1.16	1.54				
Outer suburbs	1.05	0.564	0.88	1.26				
class_vehicle/hh								
0	1 (ref)				1 (ref)			
1	12.88	<0.001	7.07	23.48	2.11	<0.001	1.13	3.93
2	36.44	<0.001	19.89	66.73	5.01	<0.001	2.68	9.34
≥ 3	50.18	<0.001	27.01	93.23	6.17	<0.001	3.22	11.82
age								
18 – 23 years	0.56	<0.001	0.45	0.70	0.66	0.019	0.46	0.93
24 – 33 years	0.93	0.346	0.81	1.08	1.09	0.520	0.84	1.41
34 – 43 years	1 (ref)				1 (ref)			
44 – 53 years	0.57	<0.001	0.47	0.69	0.63	0.003	0.47	0.86
54 – 63 years	0.42	<0.001	0.32	0.54	0.52	0.002	0.34	0.79
64 – 73 years	0.30	<0.001	0.21	0.45	0.29	<0.001	0.17	0.50
≥ 74 years	0.27	<0.001	0.15	0.50	0.31	0.009	0.13	0.74
Gender								
Male	1 (ref)				1 (ref)			
Female	0.62	<0.001	0.54	0.71	0.58	<0.001	0.45	0.75
family_role								
Head of HH	1 (ref)				1			
Wife/husband	0.42	<0.001	0.35	0.50	0.74	0.065	0.54	1.02
Son/Daughter	0.36	<0.001	0.29	0.44	0.66	0.007	0.48	0.89
Other relatives	0.21	<0.001	0.16	0.29	0.29	<0.001	0.19	0.45
Housemaid	0.10	<0.001	0.03	0.29	0.31	0.319	0.03	3.08
Guest	0.24	0.001	0.10	0.56	0.13	0.201	0.01	3.04
Other non-relatives	0.31	0.011	0.13	0.77	0.15	<0.001	0.05	0.41
activity								
		* NS				* NS		
profession								
Currently not working	1 (ref)				1 (ref)			
Industry	1.06	0.694	0.80	1.39	1.46	0.225	0.79	2.67
Trade/commerce	1.28	0.085	0.97	1.70	1.96	0.033	1.06	3.64
Bank/finance	1.40	0.195	0.84	2.31	3.11	0.059	0.96	10.11
Other services	1.44	0.020	1.06	1.97	1.65	0.118	0.88	3.08
Retired	1.67	0.002	1.22	2.28	3.52	0.001	1.73	7.17
Freelance Professional	1.46	0.027	1.04	2.05	2.64	0.008	1.29	5.41
Other	0.89	0.379	0.68	1.16	1.49	0.219	0.79	2.81
income_per (min. wage)								
0	1 (ref)				1 (ref)			
1	1.13	0.428	0.84	1.52	0.49	0.078	0.23	1.08
2	1.34	0.033	1.02	1.76	0.72	0.289	0.39	1.33
3 – 4	1.91	<0.001	1.45	2.52	1.05	0.880	0.57	1.91
5 – 6	2.14	<0.001	1.58	2.89	1.54	0.197	0.80	2.96
7 – 8	2.34	<0.001	1.64	3.34	2.93	0.012	1.27	6.77
9 – 10	2.49	<0.001	1.67	3.72	1.39	0.443	0.60	3.26
11 – 12	2.49	<0.001	1.59	3.91	1.36	0.523	0.53	3.53
13 – 14	1.85	<0.001	1.31	2.61	1.80	0.176	0.77	4.21
_cons	0.01	<0.001	0.00	0.01	0.02	<0.001	0.01	0.05

* NS: Not statistically significant (p-value <0.05)

2.2. Puebla

1994					2011						
Number of obs					10329	Number of obs					1383
Wald chi2(22)					1369.72	Wald chi2(20)					1527.92
Prob > chi2					<0.001	Prob > chi2					<0.001
Pseudo R2					0.421	Pseudo R2					0.3325
Log pseudolikelihood					-153501.67	Log pseudolikelihood					-245067.33
VD_trips	Odds Ratio	P>z	[95% Conf.	Interval]		Odds Ratio	P>z	[95% Conf.	Interval]		
zone						zone					
Center	1					* NS					
Inner suburbs	0.99	0.948	0.82	1.21							
Outer suburbs	0.65	0.001	0.50	0.84							
mot						mot					
0	1				0	1					
1	7.99	<0.001	6.02	10.61	1	8.12	<0.001	6.59	10.02		
2	15.62	<0.001	13.92	27.24	2	15.16	<0.001	11.33	20.29		
≥3	16.07	<0.001	10.61	24.33	≥3	14.86	<0.001	8.79	25.10		
dr_license						dr_license					
No	1				No	1					
Yes	14.25	<0.001	10.39	19.56	Yes	4.75	<0.001	3.97	5.70		
gender						gender					
					* NS						
age_cat						age_cat					
18 – 23 years	0.94	0.850	0.48	1.83							
24 – 33 years	0.68	0.002	0.53	0.87							
34 – 43 years	1				* NS						
44 – 53 years	0.84	0.203	0.65	1.10							
54 – 63 years	0.73	0.072	0.51	1.03							
64 – 73 years	0.62	0.087	0.36	1.07							
≥ 74 years	0.27	0.011	0.10	0.74							
family_role						family_role					
Head of HH	1				Father	1					
Wife/husband	0.71	0.031	0.51	0.97	Mother	0.69	0.004	0.54	0.89		
Son/Daughter	0.51	<0.001	0.37	0.70	Son/Daughter	0.46	<0.001	0.38	0.57		
Other relatives	0.42	0.003	0.23	0.75	Other relatives	0.75	0.213	0.47	1.18		
Housemaid	0.22	0.297	0.01	3.76	• NA						
Other relationship	0.41	0.037	0.18	0.95	Other relationship	0.75	0.248	0.46	1.22		
Other non-relatives	0.06	0.003	0.03	1.98	Other non-relatives	0.48	<0.001	0.36	0.65		
activity						activity					
Worker	1				Worker	1					
Unemployed	0.42	0.020	0.29	1.27	Unemployed	0.57	0.023	0.35	0.93		
Stay-at-home housewife	0.61	0.006	0.43	1.19	Maid	0.53	<0.001	0.41	0.70		
Student	0.67	0.173	0.38	7.71	Full time student	0.49	<0.001	0.35	0.67		
Military service	0.33	0.492	0.01	0.86	Working student	0.86	0.664	0.42	1.73		
Retired	0.52	0.012	0.31	0.86	Retired	0.44	<0.001	0.30	0.64		
Other	0.35	0.336	0.04	3.00	Other	0.95	0.876	0.48	1.88		
education						education					
None	1				None	1					
Elementary NC ‡	1.35	0.534	0.52	3.52	Kinder garden	3.58	0.154	0.62	20.60		
Elementary C †	1.20	0.685	0.50	2.90	Elementary school	1.21	0.565	0.64	2.28		
Technical 3 years	2.62	0.044	1.02	6.68	• NA						
Middle school	1.65	0.263	0.69	3.96	Middle school	1.53	0.189	0.81	2.88		
Technical 5 years	2.60	0.043	1.03	6.55	• NA						
High school	2.87	0.018	1.20	6.89	High school	2.03	0.027	1.08	3.82		
Teacher training system	1.88	0.200	0.72	4.95	• NA						
Higher education	3.24	0.008	1.36	7.73	Higher education	2.67	0.002	1.42	5.01		
Income						Income					
• NA					* NS						
_cons	0.01	<0.001	0.01	0.01	_cons	0.01	<0.001	0.01	0.02		

‡ NC: Not completed; † C: Completed.

* NS: No statistically significant (p-value <0.05)

• NA: Not available data in HTS

2.3. Lille

	1987				1998				2006			
	Number of obs		7804		Number of obs		8133		Number of obs		7485	
	Wald chi2(30)		902.65		Wald chi2(36)		697.58		Wald chi2(26)		655.02	
	Prob > chi2		<0.001		Prob > chi2		<0.001		Prob > chi2		<0.001	
	Pseudo R2		0.4484		Pseudo R2		0.4238		Pseudo R2		0.4252	
	Log pseudolikelihood		-266490		Log pseudolikelihood		-316295		Log pseudolikelihood		-323676	
VD_trips	Odds Ratio	P>z	[95% Conf. Interval]		Odds Ratio	P>z	[95% Conf. Interval]		Odds Ratio	P>z	[95% Conf. Interval]	
zone												
Center	1				1				1			
Inner suburbs	1.44	<0.000	1.20	1.73	1.50	<0.000	1.25	1.81	1.66	<0.000	1.35	2.03
Outer suburbs	1.39	0.001	1.15	1.68	1.38	0.001	1.15	1.65	1.76	<0.000	1.43	2.17
vehicles/hh												
0	1				1				1			
1	21.01	<0.000	13.58	32.49	68.92	<0.000	34.81	136.48	102.20	<0.000	45.82	227.99
2	45.47	<0.000	28.62	72.25	145.80	<0.000	72.57	292.90	179.97	<0.000	79.77	406.04
≥3	65.86	<0.000	38.11	113.81	156.28	<0.000	74.54	327.67	210.08	<0.000	89.22	494.64
dr_license												
No	1				1				1			
Supervised_dr	• NA				101.97	0.001	6.07	1712.18	47.90	0.001	4.89	468.99
Yes	166.66	<0.000	83.38	333.12	1095.82	<0.000	153.28	7834.09	936.22	<0.000	131.14	6683.71
transport_card												
No			• NA		1				1			
Yes, paid					0.38	<0.000	0.28	0.53	0.37	<0.000	0.29	0.49
Yes, free					0.45	<0.000	0.30	0.66	0.66	0.016	0.47	0.92
age_cat												
18-23 years	0.85	0.296	0.62	1.16	0.80	0.203	0.57	1.13	0.86	0.424	0.59	1.25
24-33 years	0.94	0.537	0.77	1.14	0.92	0.426	0.75	1.13	0.77	0.017	0.62	0.95
34-43 years	1				1				1			
44-53 years	0.53	<0.000	0.42	0.67	0.71	0.001	0.58	0.87	0.66	<0.000	0.53	0.83
54-63 years	0.56	<0.000	0.43	0.72	0.61	<0.000	0.47	0.79	0.52	<0.000	0.40	0.67
64-73 years	0.35	<0.000	0.23	0.52	0.61	0.012	0.42	0.90	0.42	<0.000	0.28	0.63
≥74 years	0.26	<0.000	0.15	0.44	0.52	0.004	0.34	0.82	0.25	<0.000	0.17	0.39
gender	*NS				*NS				*NS			
family_role												
Head of HH	1				1				1			
Wife/husband	0.38	<0.000	0.32	0.46	0.44	<0.000	0.37	0.51	0.57	<0.000	0.49	0.67
Son/Daughter	0.41	<0.000	0.31	0.55	0.47	<0.000	0.35	0.63	0.59	0.006	0.41	0.86
Other relatives	0.19	<0.000	0.10	0.35	0.55	0.032	0.32	0.95	0.38	0.001	0.22	0.66
activity												
Full time worker	1				1				1			
Part-time worker	0.99	0.924	0.74	1.31	0.98	0.882	0.78	1.23	1.15	0.280	0.89	1.50
Internship training	• NA				2.97	0.004	1.41	6.23	0.47	0.028	0.24	0.92
Student	0.86	0.864	0.15	4.84	0.86	0.381	0.61	1.21	0.53	0.002	0.36	0.80
School (until bac)	0.02	<0.000	0.00	0.12	0.41	0.027	0.19	0.90	0.20	0.001	0.08	0.49
Unemployed	0.52	<0.000	0.39	0.71	0.58	<0.000	0.44	0.75	0.54	<0.000	0.41	0.71
Retired	0.74	0.074	0.53	1.03	0.56	<0.000	0.41	0.77	0.80	0.179	0.58	1.11
Stay-at-home	0.76	0.047	0.57	1	0.65	0.001	0.50	0.84	0.48	<0.000	0.35	0.67
Other	0.44	0.003	0.25	0.75	0.42	0.001	0.25	0.71	0.47	0.001	0.31	0.73
profession												
Unemployed	1											
Small-medium business	0.68	0.085	0.44	1.05								
Freelance	1.42	0.095	0.94	2.15			*NS				*NS	
Technicians	1.41	0.074	0.97	2.07								
Employees	1.24	0.243	0.86	1.78								
Working class	1.14	0.490	0.79	1.65								
School (until bac)	10.49	0.007	1.91	57.48								
Student	0.65	0.632	0.11	3.83								
education												
No education					1							
Still at school					2.55	0.039	1.05	6.19				
Elementary			×		1.25	0.453	0.70	2.26			*NS	
Middle school					1.40	0.251	0.79	2.50				
High-school					1.68	0.083	0.93	3.00				
Higher school					1.78	0.055	0.99	3.21				
Professional training					1.26	0.531	0.61	2.59				
income_hh												
1					1							
2					1.55	0.048	1.01	2.40				
3					1.02	0.937	0.68	1.53				
4					0.97	0.881	0.65	1.45				
5			• NA		1.01	0.988	0.67	1.50			*NS	
6					1.06	0.790	0.70	1.60				
7					1.12	0.600	0.74	1.68				
8					1.25	0.309	0.81	1.93				
9					1.56	0.104	0.91	2.65				
10					1.61	0.256	0.71	3.67				
_cons	0.11	<0.000	0.06	0.19	0.00	<0.000	0.00	0.00	0.00	<0.000	0.00	0.00

• NA: Not available data in HTS; * NS: No statistically significant (p-value <0.05); × : Not included due to collinearity

2.4. Paris Region

	1991				2001					
	Number of obs	Wald chi2(27)	Prob > chi2	Pseudo R2	Log pseudolikelihood	Number of obs	Wald chi2(41)	Prob > chi2	Pseudo R2	Log pseudolikelihood
	20678	2715.25	0	0.4438	-2826345.8	15153	2940.06	0	0.3032	-3097958.9
VD_trips	Odds Ratio	P>z	[95% Conf. Interval]		Odds Ratio	P>z	[95% Conf. Interval]			
zone										
Center	1.00				1.00					
Inner suburbs	2.00	<0.001	1.75	2.27	1.83	<0.001	1.59	2.11		
Outer suburbs	2.72	<0.001	2.39	3.09	2.41	<0.001	2.10	2.76		
mot										
0	1.00				1.00					
1	33.31	<0.001	22.95	48.33	32.25	<0.001	22.95	45.31		
2	77.70	<0.001	52.87	114.20	79.96	<0.001	56.02	114.14		
≥3	112.77	<0.001	73.94	171.99	99.63	<0.001	67.83	146.35		
dr_license										
No	1.00				1.00					
Supervised_dr	•NA				0.26	<0.001	0.13	0.51		
Yes	343.83	<0.001	136.18	868.09	1.00					
transport_card										
No	1.00				1.00					
Regular paid card	0.15	<0.001	0.13	0.17	0.12	<0.001	0.11	0.14		
Solidarity card	0.13	<0.001	0.07	0.24	0.33	0.023	0.13	0.86		
Student card	•NA				0.18	<0.001	0.12	0.25		
Other	0.40	<0.001	0.30	0.54	0.44	<0.001	0.34	0.57		
age_cat										
18-23 years	0.88	0.273	0.70	1.11	1.18	0.205	0.91	1.54		
24-33 years	0.93	0.272	0.83	1.06	1.04	0.572	0.91	1.18		
34-43 years	1.00				1.00					
44-53 years	0.74	<0.001	0.65	0.84	0.80	<0.001	0.70	0.90		
54-63 years	0.59	<0.001	0.51	0.69	0.65	<0.001	0.56	0.75		
64-73 years	0.50	<0.001	0.40	0.63	0.47	<0.001	0.37	0.58		
≥74 years	0.33	<0.001	0.24	0.45	0.34	<0.001	0.26	0.45		
gender										
Male	* NS				* NS					
Female										
family_role										
Reference person	1.00				1.00					
Wife/Husband	0.37	<0.001	0.33	0.41	0.32	<0.001	0.28	0.37		
Child	0.33	<0.001	0.27	0.42	0.32	<0.001	0.26	0.40		
Other relative	0.38	<0.001	0.23	0.64	0.32	<0.001	0.19	0.53		
Housemaid	0.02	0.014	0.01	0.47	1.13	0.905	0.15	8.83		
Other non relative	0.43	0.001	0.26	0.71	0.33	0.001	0.17	0.64		
activity										
Active worker	1.00				1.00					
Student	0.36	<0.001	0.23	0.56	0.66	0.005	0.50	0.89		
Retired	0.58	<0.001	0.48	0.71	0.62	<0.001	0.52	0.75		
Unemployed	0.49	<0.001	0.39	0.61	0.58	<0.001	0.47	0.71		
Other inactive	0.60	<0.001	0.52	0.70	0.50	<0.001	0.42	0.59		
education										
No education	1.00									
Elementary school	1.01	0.937	0.76	1.36						×
Secondary school	1.35	0.039	1.01	1.80						
Higher education	1.74	<0.001	1.29	2.33						
Still at school	3.00	<0.001	1.77	5.08						
Income/hh										
0										
1										
2	0.82	0.155	0.63	1.08						
3	0.80	0.100	0.61	1.04						
4	0.83	0.181	0.62	1.09						
5	0.78	0.086	0.58	1.04						×
6	0.70	0.023	0.51	0.95						
7	0.88	0.544	0.58	1.34						
8	0.66	0.005	0.50	0.88						
_cons	0.00	<0.001	0.00	0.00	0.08	<0.001	0.03	0.20		

× : Not included due to collinearity ; * NS: No statistically significant (p-value <0.05); • NA: Not available data in HTS

Annex 3.

Logistic regression for vehicle passenger trips

3.1. Juarez

	1996				2006			
	Number of obs				Number of obs			
	13969				4306			
	LR chi2(34)		1645.36		LR chi2(20)		589.98	
	Prob > chi2		<0.001		Prob > chi2		<0.001	
	Pseudo R2		0.118		Pseudo R2		0.1557	
	Log likelihood		-6146.87		Log likelihood		-1599.95	
VP_trips (0/1)	Odds Ratio	P>z	[95% Conf. Interval]		Odds Ratio	P>z	[95% Conf. Interval]	
zone								
Center	1 (ref)				1 (ref)			
Inner suburbs	1.20	0.002	1.07 1.35		0.84	0.163	0.65 1.07	
Outer suburbs	0.97	0.688	0.84 1.12		0.63	0.001	0.48 0.83	
class_vehicle/hh								
0	1 (ref)				1 (ref)			
1	2.81	<0.001	2.45 3.22		4.33	<0.001	3.15 5.96	
2	4.39	<0.001	3.80 5.06		6.03	<0.001	4.37 8.32	
≥ 3	4.38	<0.001	3.66 5.24		5.40	<0.001	3.69 7.91	
age								
5 – 10 years	2.65	<0.001	2.00 3.52		3.00	<0.001	1.79 5.01	
11 – 17 years	2.74	<0.001	2.09 3.59		2.66	<0.001	1.63 4.32	
18 – 23 years	1.63	<0.001	1.29 2.05		1.48	0.070	0.97 2.25	
24 – 33 years	1.38	<0.001	1.17 1.64		1.47	0.034	1.03 2.10	
34 – 43 years	1 (ref)				1 (ref)			
44 – 53 years	1.08	0.494	0.86 1.37		0.79	0.311	0.49 1.25	
54 – 63 years	1.65	0.001	1.24 2.19		0.95	0.853	0.53 1.70	
64 – 73 years	1.40	0.108	0.93 2.13		1.48	0.202	0.81 2.70	
≥ 74 years	1.35	0.321	0.75 2.43		1.29	0.573	0.53 3.12	
gender								
Male	1 (ref)				1 (ref)			
Female	1.24	<0.001	1.12 1.37		1.59	<0.001	1.31 1.92	
family_role								
Head of HH	1 (ref)							
Wife/husband	1.70	<0.001	1.40 2.05					
Son/Daughter	1.30	0.025	1.03 1.63					*NS
Other relatives	1.16	0.286	0.88 1.54					
Housemaid	0.50	0.159	0.19 1.31					
Guest	0.68	0.367	0.30 1.56					
Other non-relatives	1.51	0.242	0.76 3.01					
activity								
Worker	1 (ref)				1 (ref)			
Unemployed	1.22	0.323	0.82 1.80		0.53	0.065	0.27 1.04	
Stay-at-home housewife	1.30	0.073	0.98 1.72		0.76	0.114	0.55 1.07	
Full time student	2.68	<0.001	1.98 3.62		2.27	<0.001	1.51 3.41	
Working student	0.96	0.823	0.69 1.35		2.10	0.027	1.09 4.06	
Retired	1.21	0.391	0.78 1.89		1.20	0.634	0.57 2.52	
Other	1.38	0.102	0.94 2.02		0.66	0.305	0.29 1.47	
profession								
			* NS					* NS
income_per (min. wage)								
0	1 (ref)							
1	1.45	0.013	1.08 1.96					
2	1.62	0.001	1.23 2.14					
3 – 4	1.70	<0.001	1.28 2.28					
5 – 6	1.56	0.009	1.12 2.17					*NS
7 – 8	1.02	0.937	0.65 1.59					
9 – 10	1.13	0.627	0.69 1.84					
11 – 12	1.22	0.481	0.70 2.13					
13 – 14	0.88	0.564	0.58 1.34					
_cons	0.02	<0.001	0.01 0.02		0.02	<0.001	0.01 0.03	

* NS: No statistically significant (p-value <0.05)

3.2. Puebla

1994					2011				
Number of obs		14674			Number of obs		16676		
Wald chi2(34)		610.74			Wald chi2(28)		535.11		
Prob > chi2		<0.001			Prob > chi2		<0.001		
Pseudo R2		0.1384			Pseudo R2		0.176		
Log pseudolikelihood		-238173			Log pseudolikelihood		-244091		
VP_trips	Odds Ratio	P>z	[95% Conf. Interval]		VP_trips	Odds Ratio	P>z	[95% Conf. Interval]	
zone					zone				
Center	1				* NS				
Inner suburbs	0.94	0.444	0.80	1.10					
Outer suburbs	0.55	<0.001	0.44	0.70					
mot					mot				
0	1				0	1			
1	5.16	<0.001	4.25	6.27	1	4.29	<0.001	3.58	5.14
2	7.42	<0.001	5.78	9.54	2	6.64	<0.001	4.88	9.04
≥3	6.37	<0.001	4.60	8.83	≥3	6.66	<0.001	3.52	12.60
dr_license					dr_license				
No	1				* NS				
Yes	1.57	<0.001	1.22	2.02					
age_cat					age_cat				
5 - 10 years	2.43	<0.001	1.49	3.97	5 - 10 years	3.76	<0.001	2.29	6.17
11 - 17 years	2.74	<0.001	1.77	4.24	11 - 17 years	3.45	<0.001	2.20	5.41
18 - 23 years	1.07	0.752	0.71	1.60	18 - 23 years	1.55	0.027	1.05	2.28
24 - 33 years	0.72	0.047	0.52	1.00	24 - 33 years	1.08	0.644	0.79	1.48
34 - 43 years	1				34 - 43 years	1.00			
44 - 53 years	1.01	0.951	0.72	1.42	44 - 53 years	0.76	0.107	0.54	1.06
54 - 63 years	1.34	0.153	0.90	1.99	54 - 63 years	0.68	0.060	0.46	1.02
64 - 73 years	1.23	0.492	0.68	2.20	64 - 73 years	0.78	0.393	0.44	1.38
≥ 74 years	1.67	0.207	0.75	3.67	≥ 74 years	1.02	0.963	0.49	2.09
gender					gender				
Male	1					1			
Female	1.28	0.005	1.08	1.52		1.32	0.003	1.10	1.60
family_role					family_role				
Head of HH	1				Father	1			
Wife/husband	2.09	<0.001	1.45	3.03	Mother	1.81	0.002	1.24	2.63
Son/Daughter	1.51	0.023	1.06	2.14	Son/Daughter	1.05	0.804	0.73	1.51
Other relatives	0.95	0.833	0.59	1.53	Other relatives	0.69	0.328	0.33	1.44
Housemaid	0.13	0.152	0.08	2.14	• NA				
Other relation	1.12	0.751	0.56	2.22	Other relation	2.03	0.031	1.07	3.88
Other no-relative	0.67	0.575	0.16	2.75	Other no relative	1.08	0.699	0.73	1.61
activity					activity				
Worker	1				Worker	1			
Unemployed	0.72	0.410	0.33	1.57	Unemployed	0.34	0.040	0.12	0.95
Stay-at home	0.67	0.022	0.48	0.94	Maid	0.64	0.002	0.48	0.85
Student	1.14	0.363	0.86	1.52	Full time student	0.75	0.097	0.53	1.05
Military service	5.82	0.047	1.02	33.15	Working student	1.12	0.812	0.44	2.89
Retired	0.56	0.083	0.29	1.08	Retired	0.86	0.652	0.45	1.64
Other	0.82	0.625	0.37	1.81	Other	0.75	0.522	0.30	1.83
education					education				
None	1				None	1			
Elementary NC ‡	1.52	0.032	1.04	2.22	Kinder garden	0.61	0.136	0.32	1.17
Elementary C †	1.45	0.084	0.95	2.21	Elementary	0.79	0.410	0.46	1.38
Technical 3 years	2.52	0.001	1.47	4.31	• NA				
Middle school	1.17	0.475	0.76	1.81	Middle school	0.77	0.377	0.43	1.37
Technical 5 years	2.08	0.014	1.16	3.71	• NA				
High school	1.59	0.054	0.99	2.54	High school	0.54	0.041	0.30	0.97
Teacher training	1.81	0.111	0.87	3.75	• NA				
Higher education	2.04	0.003	1.27	3.27	Higher education	0.95	0.877	0.53	1.73
Income/hh					Income/hh				
• NA					1	1			
					2	1.10	0.478	0.84	1.44
					3	1.99	<0.001	1.51	2.62
					4	2.00	<0.001	1.41	2.85
					5	2.24	0.001	1.38	3.62
cons	0.01	<0.001	0.00	0.01	cons	0.01	<0.001	0.01	0.02

‡ NC: Not completed; † C: Completed; • NA: Not available data in HTS

* NS: No statistically significant (p-value <0.05)

3.3. Lille

	1987				1998				2006			
	Number of obs 10002.00				Number of obs 10301				Number of obs 8990			
	Wald chi2(33) 1031.79				Wald chi2(35) 1159.07				Wald chi2(25) 1071.39			
	Prob > chi2 <0.001				Prob > chi2 <0.001				Prob > chi2 <0.001			
	Pseudo R2 0.15				Pseudo R2 0.1412				Pseudo R2 0.1722			
	Log pseudolikelihood -401792				Log pseudolikelihood -482734				Log pseudolikelihood -421712			
VP_trips	Odds Ratio	P>z	[95% Conf. Interval]	Odds Ratio	P>z	[95% Conf. Interval]	Odds Ratio	P>z	[95% Conf. Interval]			
zone												
Center	1				*NS				1			
Inner suburbs	1.20	0.038	1.01	1.42					1.20	0.083	0.98	1.47
Outer suburbs	1.37	<0.001	1.16	1.62					1.37	0.003	1.11	1.68
vehicles/hh												
0	1				1				1			
1	2.72	<0.001	2.25	3.30	2.15	<0.001	1.75	2.65	2.17	<0.001	1.71	2.74
2	3.56	<0.001	2.85	4.45	2.37	<0.001	1.87	3.01	2.70	<0.001	2.06	3.55
≥3	3.32	<0.001	2.29	4.82	2.17	<0.001	1.58	2.97	2.89	<0.001	2.00	4.17
dr_license												
No	1				1				1			
Supervised_dr	• NA				1.46 0.178 0.84 2.54				0.80 0.407 0.47 1.36			
Yes	0.39	<0.001	0.32	0.478	0.40	<0.001	0.33	0.48	0.24	<0.001	0.19	0.29
transport_card	• NA				*NS				*NS			
age_cat												
5-10 years	4.76	<0.001	2.97	7.62	8.00	<0.001	5.12	12.49	4.19	<0.001	2.79	6.28
11-17 years	2.18	0.001	1.37	3.46	4.31	<0.001	2.79	6.66	2.16	<0.001	1.45	3.21
18-23 years	2.02	<0.001	1.46	2.78	2.64	<0.001	1.92	3.63	1.59	0.009	1.12	2.24
24-33 years	1.58	<0.001	1.27	1.96	1.60	<0.001	1.30	1.98	1.17	0.239	0.90	1.51
34-43 years	1				1				1			
44-53 years	1.03	0.833	0.79	1.34	0.96	0.716	0.77	1.20	1.02	0.906	0.77	1.34
54-63 years	1.23	0.136	0.94	1.61	1.26	0.058	0.99	1.59	1.20	0.192	0.91	1.58
64-73 years	1.98	0.002	1.30	3.03	0.98	0.859	0.74	1.28	1.27	0.134	0.93	1.75
≥74 years	1.15	0.590	0.70	1.87	0.76	0.123	0.54	1.08	0.97	0.866	0.67	1.39
gender												
Male	1				1				1			
Female	1.33	<0.001	1.15	1.54	1.40	<0.001	1.23	1.59	1.71	<0.001	1.48	1.99
family_role												
Head of HH	1				1				1			
Wife/husband	2.79	<0.001	2.25	3.46	1.84	<0.001	1.54	2.19	1.37	0.001	1.13	1.65
Son/Daughter	0.77	0.117	0.55	1.07	0.79	0.097	0.60	1.04	0.95	0.769	0.68	1.33
Other relatives	1.08	0.784	0.64	1.81	0.98	0.937	0.67	1.46	0.63	0.168	0.33	1.22
activity												
Full time worker	1											
Part-time worker	0.82	0.160	0.62	1.08								
Student	1.09	0.933	0.16	7.35								
School (until bac)	2.53	0.222	0.57	11.23	*NS				*NS			
Unemployed	0.69	0.031	0.49	0.97								
Retired	0.56	0.002	0.38	0.81								
Stay-at-home	0.49	<0.001	0.38	0.65								
Other	0.33	0.005	0.15	0.71								
profession												
Unemployed	1				1							
Small-medium business	0.58	0.032	0.36	0.95	1.29	0.238	0.84	1.98				
Freelance profession	0.74	0.206	0.47	1.18	0.93	0.687	0.65	1.33				
Technicians	1.02	0.921	0.70	1.47	0.99	0.971	0.74	1.34	*NS			
Employees	1.36	0.058	0.99	1.86	1.32	0.035	1.02	1.72				
Working class	1.47	0.017	1.07	2.01	1.46	0.006	1.11	1.93				
School (until bac)	0.66	0.581	0.15	2.90	1.02	0.924	0.68	1.53				
Student	1.56	0.650	0.23	10.75	1.32	0.134	0.92	1.91				
education	x				*NS				*NS			
income_hh												
1	1				1				1			
2					1.13	0.452	0.82	1.54	1.17	0.193	0.92	1.48
3					1.26	0.154	0.92	1.74	1.45	0.004	1.13	1.88
4					1.44	0.025	1.05	1.98	1.62	0.001	1.22	2.15
5	•NA				1.57	0.006	1.14	2.16	1.89	<0.001	1.38	2.60
6					1.55	0.009	1.11	2.17	1.88	0.001	1.30	2.71
7					1.80	<0.001	1.29	2.49				
8					2.09	<0.001	1.49	2.93				
9					1.91	0.002	1.27	2.85				
10					2.06	0.023	1.11	3.84				
_cons	0.02	<0.001	0.01	0.03	0.06	<0.001	0.04	0.09	0.07	<0.001	0.05	0.10

• NA: Not available data in HTS; * NS: No statistically significant (p-value <0.05)

x: Not included due to collinearity

3.4. Paris Region

	1991				2001			
			25350.00				23505.00	
	Wald chi2(37)		1715.08		Wald chi2(43)		1924.86	
	Prob > chi2		0.00		Prob > chi2		0.00	
	Pseudo R2		0.11		Pseudo R2		0.13	
	Log pseudolikelihood		-3526121.20		Log pseudolikelihood		-3620508.60	
VP_trips	Odds Ratio	P>z	[95% Conf. Interval]		Odds Ratio	P>z	[95% Conf. Interval]	
zone								
Center	1.00				1.00			
Inner suburbs	1.33	<0.001	1.17	1.52	1.35	<0.001	1.16	1.57
Outer suburbs	1.64	<0.001	1.45	1.86	1.62	<0.001	1.40	1.88
mot								
0	1.00				1.00			
1	2.09	<0.001	1.81	2.43	2.55	<0.001	2.21	2.95
2	2.62	<0.001	2.21	3.10	3.69	<0.001	3.15	4.32
≥3	2.56	<0.001	2.02	3.24	3.80	<0.001	3.11	4.66
dr_license								
No	1.00				1.00			
Supervised_dr	• NA				1.53	0.049	1.00	2.35
Yes	0.52	<0.001	0.46	0.59	0.47	<0.001	0.41	0.54
transport_card								
No	1.00				1.00			
Regular paid card	0.83	0.001	0.74	0.93	1.03	0.597	0.91	1.17
Solidarity card	0.72	0.298	0.38	1.34	1.55	0.333	0.64	3.77
Student card	• NA				0.73	<0.001	0.61	0.87
Other	1.09	0.379	0.90	1.31	0.87	0.160	0.72	1.06
age_cat								
5-10 years	5.81	<0.001	4.32	7.83	6.79	<0.001	4.91	9.39
11-17 years	2.77	<0.001	2.07	3.70	4.37	<0.001	3.19	5.98
18-23 years	2.26	<0.001	1.81	2.82	2.60	<0.001	2.00	3.38
24-33 years	1.56	<0.001	1.35	1.80	1.82	<0.001	1.54	2.15
34-43 years	1.00				1.00			
44-53 years	0.89	0.163	0.75	1.05	1.04	0.686	0.87	1.23
54-63 years	1.20	0.053	1.00	1.43	1.43	<0.001	1.19	1.72
64-73 years	1.69	<0.001	1.30	2.19	1.62	0.001	1.22	2.13
≥74 years	1.37	0.050	1.00	1.87	1.63	0.001	1.21	2.21
gender								
Male	1.00				1.00			
Female	1.50	<0.001	1.35	1.66	1.39	<0.001	1.25	1.53
family_role								
Reference person	1.00				1.00			
Wife/Husband	1.95	<0.001	1.70	2.24	2.08	<0.001	1.82	2.39
Child	1.01	0.947	0.81	1.26	1.07	0.576	0.85	1.35
Other relative	0.61	0.024	0.40	0.94	0.95	0.794	0.63	1.42
Housemaid	0.62	0.678	0.07	5.90	1.00			
Other non relative	1.41	0.133	0.90	2.20	1.35	0.327	0.74	2.49
activity								
Active worker	1.00				1.00			
Student	0.83	0.107	0.67	1.04	0.91	0.517	0.68	1.21
Retired	0.93	0.549	0.74	1.17	1.45	0.001	1.15	1.82
Unemployed	1.32	0.012	1.06	1.64	0.98	0.854	0.77	1.25
Other inactive	0.90	0.163	0.77	1.04	1.17	0.079	0.98	1.39
education								
No education					1.00			
Elementary school		*NS			1.53	0.008	1.12	2.09
Secondary school					1.58	0.004	1.16	2.14
Higher education					1.50	0.012	1.09	2.06
Still at school					1.52	0.016	1.08	2.13
Income/hh								
0								
1	1.00							
2	0.95	0.627	0.77	1.17				
3	1.04	0.751	0.84	1.28				
4	1.28	0.032	1.02	1.60		×		
5	1.31	0.021	1.04	1.65				
6	1.47	0.003	1.14	1.88				
7	1.47	0.043	1.01	2.14				
8	1.06	0.598	0.85	1.34				
_cons	0.04	<0.001	0.03	0.07	0.03	<0.001	0.01	0.07

• NA: Not available data in HTS; * NS: No statistically significant (p-value <0.05) ; ×: Not included due to collinearity

Annex 4.

Logistic regression for public transport trips

4.1. Juarez

	1996				2006				
	Number of obs 13969 LR chi2(34) 2098.65 Prob > chi2 <0.001 Pseudo R2 0.1391 Log likelihood -6496.0477				Number of obs 4306 LR chi2(24) 457.79 Prob > chi2 <0.001 Pseudo R2 0.1194 Log likelihood -1687.43				
PT_trips (0/1)	Odds Ratio	P>z	[95% Conf. Interval]	Odds Ratio	P>z	[95% Conf. Interval]	Odds Ratio	P>z	[95% Conf. Interval]
zone									
Center	1 (ref)				*NS				
Inner suburbs	0.87	0.011	0.79	0.97					
Outer suburbs	0.85	0.010	0.75	0.96					
class_vehicle/hh									
0	1 (ref)				1 (ref)				
1	0.39	<0.001	0.35	0.42	0.47	<0.001	0.39	0.57	
2	0.19	<0.001	0.16	0.21	0.20	<0.001	0.15	0.25	
≥ 3	0.13	<0.001	0.10	0.16	0.11	<0.001	0.07	0.17	
age									
5 – 10 years	0.34	<0.001	0.26	0.43	0.16	<0.001	0.09	0.28	
11 – 17 years	1.26	0.025	1.03	1.55	1.10	0.660	0.72	1.68	
18 – 23 years	1.35	0.001	1.13	1.62	1.71	0.001	1.24	2.35	
24 – 33 years	1.13	0.086	0.98	1.29	1.07	0.656	0.80	1.43	
34 – 43 years	1 (ref)				1 (ref)				
44 – 53 years	1.19	0.061	0.99	1.44	1.20	0.287	0.86	1.70	
54 – 63 years	0.97	0.825	0.76	1.24	1.13	0.583	0.73	1.74	
64 – 73 years	0.91	0.547	0.66	1.25	0.71	0.216	0.41	1.22	
≥ 74 years	0.51	0.010	0.30	0.85	0.55	0.161	0.24	1.26	
gender	*NS				*NS				
family_role									
Head of HH	1 (ref)				*NS				
Wife/husband	1.17	0.026	1.02	1.34					
Son/Daughter	1.42	<0.001	1.20	1.69					
Other relatives	1.59	<0.001	1.27	1.98					
Housemaid	0.87	0.744	0.39	1.96					
Guest	1.26	0.437	0.71	2.24					
Other non-relatives	0.54	0.132	0.24	1.21					
activity									
Worker					1 (ref)				
Unemployed					0.57	0.203	0.24	1.35	
Stay-at-home housewife	×				0.71	0.378	0.33	1.51	
Full time student					2.53	0.020	1.16	5.53	
Working student					3.47	<0.001	1.92	6.28	
Retired					1.20	0.702	0.47	3.06	
Other					0.58	0.246	0.23	1.46	
profession									
Currently not working	1 (ref)				1 (ref)				
Industry	2.02	<0.001	1.62	2.52	1.21	0.612	0.57	2.57	
Trade/commerce	1.10	0.466	0.85	1.41	2.19	0.045	1.02	4.70	
Bank/finance	1.11	0.662	0.69	1.79	3.68	0.031	1.12	12.03	
Other services	1.43	0.009	1.10	1.87	1.45	0.342	0.67	3.12	
Retired	1.04	0.820	0.76	1.42	1.30	0.579	0.52	3.23	
Freelance Professional	1.03	0.871	0.74	1.43	1.02	0.962	0.40	2.64	
Other	1.31	0.012	1.06	1.61	1.81	0.118	0.86	3.79	
income_per (min. wage)									
0	1 (ref)				×				
1	1.47	0.001	1.16	1.85					
2	1.54	<0.001	1.23	1.93					
3 – 4	1.21	0.118	0.95	1.54					
5 – 6	0.89	0.424	0.67	1.19					
7 – 8	0.56	0.005	0.37	0.83					
9 – 10	0.58	0.021	0.37	0.92					
11 – 12	0.23	<0.001	0.11	0.49					
13 – 14	0.32	<0.001	0.20	0.51					
_cons	0.50	<0.001	0.42	0.60	0.31	0.00	0.15	0.67	

* NS: No statistically significant (p-value <0.05); ×: Not included due to collinearity

4.2. Puebla

1994					2011				
		Number of obs	14718				Number of obs	16651	
		Wald chi2(34)	1784.21				Wald chi2(30)	1456.69	
		Prob > chi2	<0.001				Prob > chi2	<0.001	
		Pseudo R2	0.1268				Pseudo R2	0.0793	
		Log pseudolikelihood	-682049.27				Log pseudolikelihood	-993372.1	
PT_trips	Odds Ratio	P>z	[95% Conf.	Interval]	PT_trips	Odds Ratio	P>z	[95% Conf.	Interval]
zone					zone				
Center	1				Center	1			
Inner suburbs	1.16	0.001	1.06	1.26	Inner suburbs	1.12	0.007	1.03	1.22
Outer suburbs	0.59	<0.001	0.53	0.65	Outer suburbs	0.94	0.208	0.87	1.03
mot					mot				
0	1				0	1.00			
1	0.70	<0.001	0.64	0.76	1	0.63	<0.001	0.58	0.68
2	0.53	<0.001	0.45	0.63	2	0.42	<0.001	0.34	0.51
≥3	0.30	<0.001	0.23	0.38	≥3	0.20	<0.001	0.12	0.36
dr_license					dr_license				
No	1				No	1.00			
Yes	0.43	<0.001	0.38	0.49	Yes	0.54	<0.001	0.49	0.61
age_cat					age_cat				
5 - 10 years	0.18	<0.001	0.14	0.24	5 - 10 years	0.25	<0.001	0.20	0.31
11 - 17 years	0.37	<0.001	0.30	0.45	11 - 17 years	0.51	<0.001	0.42	0.62
18 - 23 years	0.83	0.027	0.70	0.98	18 - 23 years	1.26	0.002	1.09	1.46
24 - 33 years	1.02	0.808	0.89	1.16	24 - 33 years	1.19	0.003	1.06	1.33
34 - 43 years	1				34 - 43 years	1.00			
44 - 53 years	0.79	0.005	0.67	0.93	44 - 53 years	1.10	0.134	0.97	1.24
54 - 63 years	0.72	0.001	0.59	0.88	54 - 63 years	1.26	0.002	1.09	1.45
64 - 73 years	0.60	<0.001	0.46	0.78	64 - 73 years	0.97	0.768	0.80	1.18
≥ 74 years	0.27	<0.001	0.17	0.41	≥ 74 years	0.71	0.010	0.54	0.92
gender					gender				
*NS					*NS				
family_role					family_role				
Head of HH	1				Father	1			
Wife/husband	1.20	0.024	1.02	1.41	Mother	1.13	0.057	1.00	1.29
Son/Daughter	1.36	<0.001	1.18	1.56	Son/Daughter	1.17	0.015	1.03	1.32
Other relatives	1.35	0.002	1.12	1.64	Other relatives	0.65	<0.001	0.52	0.80
Housemaid	0.58	0.195	0.25	1.33	• NA				
Other relationship	1.13	0.406	0.85	1.49	Other relationship	1.28	0.068	0.98	1.66
Other non-relatives	1.23	0.369	0.78	1.93	Other non-relatives	1.14	0.083	0.98	1.31
activity					activity				
Worker	1				Worker	1			
Unemployed	0.46	<0.001	0.35	0.62	Unemployed	0.52	<0.001	0.41	0.66
Stay-at-home	0.27	<0.001	0.24	0.31	Maid	0.54	<0.001	0.49	0.61
Student	1.62	<0.001	1.39	1.89	Full time student	1.36	<0.001	1.17	1.59
Military service	1.66	0.559	0.30	9.11	Working student	1.07	0.774	0.68	1.68
Retired	0.64	0.002	0.49	0.85	Retired	0.68	0.001	0.54	0.86
Other	0.19	<0.001	0.12	0.30	Other	0.43	<0.001	0.29	0.63
education					education				
None	1				None	1.00			
Elementary NC ‡	1.01	0.966	0.83	1.22	Kinder garden	0.59	<0.001	0.44	0.79
Elementary C †	1.58	<0.001	1.30	1.91	Elementary school	1.27	0.016	1.04	1.54
Technical 3 years	2.47	<0.001	1.88	3.24	• NA				
Middle school	2.28	<0.001	1.87	2.78	Middle school	1.51	<0.001	1.23	1.84
Technical 5 years	2.45	<0.001	1.85	3.24	• NA				
High school	2.19	<0.001	1.76	2.72	High school	1.95	<0.001	1.59	2.40
Teacher trainin	2.27	<0.001	1.59	3.25	• NA				
Higher education	1.62	<0.001	1.29	2.04	Higher education	2.03	<0.001	1.63	2.51
income_hh					income_hh				
• NA					1	1.00			
					2	1.01	0.779	0.92	1.11
					3	0.84	0.001	0.75	0.93
					4	0.68	<0.001	0.57	0.80
					5	0.65	0.003	0.49	0.86
_cons	0.86	0.178	0.69	1.07	_cons	0.96	0.697	0.77	1.19

‡ NC: Not completed; † C: Completed; • NA: Not available data in HTS; * NS: No statistically significant (p-value <0.05)

4.3. Lille

	1987				1998				2006			
	Number of obs			10002.00	Number of obs			10312	Number of obs			8984
	Prob > chi2			<0.001	Prob > chi2			<0.001	Prob > chi2			<0.001
	Pseudo R2			0.14	Pseudo R2			0.3092	Pseudo R2			0.2817
	Log pseudolikelihood			-258685	Log pseudolikelihood			-270214	Log pseudolikelihood			-331351
PT_trip	Odds Ratio	P>z	[95% Conf. Interval]		Odds Ratio	P>z	[95% Conf. Interval]		Odds Ratio	P>z	[95% Conf. Interval]	
zone												
Center	1				1				1			
Inner suburbs	0.82	0.041	0.67	0.99	0.71	0.001	0.58	0.87	0.63	<0.001	0.52	0.77
Outer suburbs	0.59	<0.001	0.48	0.72	0.66	<0.001	0.54	0.81	0.57	<0.001	0.46	0.70
vehicles/hh												
0	1				1				1			
1	0.51	<0.001	0.41	0.62	0.57	<0.001	0.45	0.73	0.57	<0.001	0.46	0.70
2	0.28	<0.001	0.21	0.37	0.42	<0.001	0.31	0.57	0.42	<0.001	0.33	0.53
≥3	0.19	<0.001	0.11	0.33	0.29	<0.001	0.19	0.46	0.33	<0.001	0.23	0.49
dr_license												
No	1				1				1			
Supervised_dr	• NA				1.73	0.045	1.01	2.96	2.39	0.001	1.41	4.03
Yes	0.52	<0.001	0.41	0.66	0.45	<0.001	0.35	0.58	0.56	<0.001	0.46	0.68
transport_card												
No	•NA				1				1			
Yes. paid					12.89	<0.001	10.41	15.97	8.60	<0.001	7.19	10.29
Yes. free					11.41	<0.001	9.25	14.08	8.12	<0.001	6.53	10.10
age_cat												
5-10 years	0.04	<0.001	0.02	0.07	0.24	<0.001	0.13	0.44	0.32	0.001	0.17	0.61
11-17 years	0.35	<0.001	0.21	0.61	0.90	0.696	0.53	1.52	0.97	0.926	0.56	1.71
18-23 years	1.58	0.014	1.10	2.27	1.47	0.034	1.02	2.09	1.53	0.019	1.07	2.19
24-33 years	1.09	0.566	0.82	1.44	1.14	0.402	0.84	1.53	1.15	0.291	0.89	1.48
34-43 years	1				1				1			
44-53 years	1.21	0.258	0.87	1.68	0.95	0.773	0.69	1.31	1.01	0.953	0.76	1.33
54-63 years	1.17	0.407	0.81	1.68	0.61	0.050	0.37	1	0.69	0.046	0.48	0.99
64-73 years	0.93	0.786	0.53	1.62	0.26	<0.001	0.14	0.50	0.49	0.039	0.25	0.97
≥74 years	1.18	0.584	0.65	2.14	0.19	<0.001	0.09	0.37	0.38	0.004	0.20	0.73
gender												
Male	1				*NS				*NS			
Female	1.21	0.041	1.01	1.45								
family_role												
Head of HH	1				*NS				*NS			
Wife/husband	0.91	0.436	0.71	1.16								
Son/Daughter	1.56	0.006	1.14	2.13								
Other relatives	1.38	0.211	0.83	2.28								
activity												
Full time worker	1											
Part-time worker	1.34	0.087	0.96	1.87								
Internship training	• NA											
Student	2.06	0.441	0.33	13.05								
School (until bac)	5.45	0.044	1.04	28.39	*NS							
Unemployed	0.75	0.155	0.51	1.11								
Retired	0.48	0.002	0.30	0.76								
Stay-at-home	0.32	<0.001	0.20	0.52								
Other	0.25	0.001	0.11	0.57								
education												
No education	x				1							
Still at school					2.24	0.013	1.19	4.22				
Elementary					0.92	0.777	0.51	1.66				
Middle school					1.31	0.366	0.73	2.32	*NS			
High-school					1.22	0.515	0.67	2.23				
Higher school					1.31	0.380	0.72	2.41				
P. training					1.23	0.645	0.51	3.00				
profession												
Unemployed/inactives	1											
Small-medium business	0.69	0.311	0.33	1.42								
Freelance profession	1.32	0.376	0.72	2.42								
Technicians	1.26	0.417	0.72	2.20	*NS				*NS			
Employees	1.96	0.006	1.22	3.18								
Working class	1.08	0.760	0.67	1.73								
School (until bac)	0.67	0.632	0.13	3.46								
Student	1.80	0.540	0.27	11.83								
income_hh												
1	•NA				1							
2					0.89	0.512	0.63	1.26				
3					1.01	0.952	0.70	1.45				
4					1.29	0.189	0.88	1.88				
5					1.21	0.337	0.82	1.78				
6					1.59	0.022	1.07	2.36	*NS			
7					1.77	0.006	1.18	2.65				
8					1.54	0.047	1.01	2.37				
9					1.49	0.157	0.86	2.59				
10					2.69	0.006	1.32	5.48				
_cons	0.13	<0.001	0.07	0.23	0.21	<0.001	0.13	0.32	0.39	<0.001	0.29	0.53

4.4. Paris Region

	1991				2001			
			25301.00				23519.00	
	Wald chi2(36)		6774.44		Wald chi2(38)		6492.11	
	Prob > chi2		0.00		Prob > chi2		0.00	
	Pseudo R2		0.39		Pseudo R2		0.42	
	Log pseudolikelihood		-3585100.20		Log pseudolikelihood		-3602892.20	
PT_trip	Odds Ratio	P>z	[95% Conf. Interval]		Odds Ratio	P>z	[95% Conf. Interval]	
zone								
Center	1.00				1.00			
Inner suburbs	0.64	<0.001	0.57	0.72	0.64	<0.001	0.56	0.73
Outer suburbs	0.54	<0.001	0.48	0.60	0.46	<0.001	0.40	0.52
mot								
0	1.00				1.00			
1	0.58	<0.001	0.51	0.65	0.62	<0.001	0.54	0.70
2	0.41	<0.001	0.35	0.48	0.45	<0.001	0.39	0.52
≥3	0.35	<0.001	0.28	0.44	0.38	<0.001	0.31	0.46
dr_license								
No	1.00				1.00			
Supervised_dr	• NA				1.15	0.673	0.60	2.23
Yes	0.76	<0.001	0.67	0.86	0.69	<0.001	0.60	0.79
transport_card								
No	1.00				1.00			
Regular paid card	27.43	<0.001	24.93	30.18	29.15	<0.001	26.19	32.44
Solidarity card	44.73	<0.001	25.65	78.01	25.49	<0.001	10.77	60.34
Student card	• NA				31.32	<0.001	25.60	38.31
Other	9.97	<0.001	8.59	11.57	8.94	<0.001	7.65	10.44
age_cat								
5-10 years	0.24	<0.001	0.17	0.33	0.27	<0.001	0.19	0.38
11-17 years	0.82	0.165	0.61	1.09	0.80	0.136	0.59	1.07
18-23 years	0.96	0.731	0.78	1.19	0.85	0.193	0.67	1.08
24-33 years	0.99	0.828	0.87	1.12	0.88	0.087	0.76	1.02
34-43 years	1.00				1.00			
44-53 years	1.05	0.529	0.91	1.20	1.04	0.571	0.90	1.20
54-63 years	1.16	0.082	0.98	1.38	1.01	0.910	0.85	1.20
64-73 years	0.86	0.281	0.65	1.13	0.85	0.330	0.61	1.18
≥74 years	0.59	0.001	0.43	0.81	0.52	<0.001	0.37	0.75
gender								
Male	1.00				* NS			
Female	1.13	0.003	1.05	1.23				
family_role	* NS				* NS			
activity								
Active worker	1.00				1.00			
Student	1.65	0.002	1.20	2.27	1.82	<0.001	1.32	2.50
Retired	0.84	0.142	0.67	1.06	0.82	0.180	0.62	1.09
Unemployed	1.01	0.950	0.78	1.30	1.24	0.078	0.98	1.59
Other inactive	0.68	<0.001	0.56	0.83	0.78	0.031	0.62	0.98
education								
No education	1.00				1.00			
Elementary school	0.97	0.771	0.76	1.22	0.81	0.170	0.60	1.10
Secondary school	1.22	0.095	0.97	1.55	1.11	0.463	0.83	1.49
Higher education	1.48	0.002	1.15	1.90	1.40	0.028	1.04	1.88
Still at school	1.59	0.009	1.12	2.24	1.07	0.723	0.74	1.54
Income/hh								
0								
1	1.00							
2	1.20	0.072	0.98	1.46				
3	1.29	0.017	1.05	1.58				
4	1.39	0.004	1.11	1.73				
5	1.48	0.001	1.18	1.86				
6	1.75	<0.001	1.35	2.27				
7	1.68	0.010	1.13	2.48				
8	1.10	0.416	0.88	1.37				
_cons	0.24	<0.001	0.15	0.38	0.36	0.024	0.15	0.87

• NA: Not available data in HTS; * NS: No statistically significant (p-value <0.05); ×: Not included due to collinearity

Annex 5.

Logistic regression for all modes trips

5.1. Juarez

	1996					2006				
	Number of obs = 13969					Number of obs = 4286				
LR chi2(41) = 729.36					LR chi2(41) = 662.16					
Prob > chi2 = <0.001					Prob > chi2 = <0.001					
Pseudo R2 = 0.0562					Pseudo R2 = 0.1356					
Total_trips (0/1)	Odds Ratio	P>z	[95% Conf.	Interval]	Odds Ratio	P>z	[95% Conf.	Interval]		
zone										
Center	*NS				*NS					
Inner suburbs										
Outer suburbs										
class_vehicle/hh										
0	1 (ref)				*NS					
1	1.05	0.391	0.94	1.18						
2	1.19	0.008	1.05	1.36						
≥ 3	1.13	0.166	0.95	1.36						
age										
5 – 10 years	1.17	0.259	0.89	1.54	1.72	0.026	1.07	2.79		
11 – 17 years	1.59	0.001	1.22	2.06	1.46	0.082	0.95	2.24		
18 – 23 years	0.90	0.295	0.74	1.10	1.14	0.442	0.82	1.57		
24 – 33 years	1.02	0.806	0.88	1.18	1.03	0.795	0.80	1.34		
34 – 43 years	1 (ref)				1 (ref)					
44 – 53 years	0.80	0.019	0.67	0.96	0.63	0.001	0.48	0.83		
54 – 63 years	0.67	<0.001	0.53	0.83	0.48	<0.001	0.35	0.68		
64 – 73 years	0.49	<0.001	0.37	0.66	0.35	<0.001	0.24	0.52		
≥ 74 years	0.29	<0.001	0.20	0.43	0.27	<0.001	0.16	0.46		
gender										
Male	*NS				*NS					
Female										
family_role										
Head of HH	1 (ref)				1 (ref)					
Wife/husband	0.87	0.116	0.74	1.03	0.79	0.090	0.60	1.04		
Son/Daughter	0.69	<0.001	0.56	0.84	0.70	0.013	0.53	0.93		
Other relatives	0.59	<0.001	0.47	0.74	0.64	0.004	0.47	0.87		
Housemaid	0.19	<0.001	0.10	0.36	0.07	0.020	0.01	0.66		
Guest	0.55	0.056	0.30	1.02	0.31	0.226	0.05	2.05		
Other non-relatives	0.50	0.035	0.27	0.95	0.67	0.289	0.32	1.40		
Activity										
Worker	1 (ref)				1 (ref)					
Unemployed	0.61	0.001	0.44	0.82	0.69	0.336	0.32	1.47		
Stay-at-home housewife	0.73	0.023	0.56	0.96	1.25	0.543	0.61	2.60		
Full time student	1.70	0.001	1.26	2.29	4.06	<0.001	1.92	8.57		
Working student	1.23	0.269	0.85	1.78	3.11	0.020	1.19	8.10		
Retired	0.69	0.037	0.48	0.98	0.89	0.778	0.40	1.98		
Other	0.48	<0.001	0.35	0.66	0.60	0.176	0.28	1.26		
profession										
Currently not working	1 (ref)				1 (ref)					
Industry	1.41	0.012	1.08	1.83	3.29	0.002	1.56	6.93		
Trade/commerce	1.02	0.897	0.77	1.34	1.91	0.093	0.90	4.05		
Bank/finance	1.08	0.770	0.66	1.76	2.68	0.127	0.76	9.51		
Other services	1.67	0.002	1.20	2.32	1.24	0.572	0.59	2.63		
Retired	1.79	0.002	1.25	2.57	6.45	<0.001	2.46	16.88		
Freelance Professional	1.08	0.672	0.77	1.51	2.31	0.095	0.98	5.43		
Other	1.00	0.973	0.80	1.24	1.53	0.247	0.75	3.12		
income_per (min. wage)										
0	1 (ref)				1 (ref)					
1	1.48	0.005	1.13	1.95	1.63	0.176	0.80	3.30		
2	1.78	<0.001	1.36	2.33	1.71	0.124	0.86	3.39		
3 – 4	1.68	<0.001	1.27	2.23	2.03	0.041	1.03	4.00		
5 – 6	1.59	0.005	1.15	2.19	1.47	0.313	0.70	3.08		
7 – 8	1.12	0.565	0.77	1.63	2.71	0.046	1.02	7.23		
9 – 10	1.56	0.050	1.00	2.45	0.72	0.489	0.29	1.81		
11 – 12	1.31	0.278	0.80	2.14	1.09	0.868	0.39	3.07		
13 – 14	1.17	0.398	0.81	1.68	1.44	0.451	0.56	3.69		
_cons	3.48	<0.001	2.58	4.68	1.55	0.268	0.72	3.34		

* NS: No statistically significant (p-value <0.05)

5.2. Puebla

1994					2011				
	Number of obs			14718		Number of obs			16676
	Wald chi2(34)			1749.21		Wald chi2(29)			1200.09
	Prob > chi2			<0.001		Prob > chi2			<0.001
	Pseudo R2			0.124		Pseudo R2			0.0778
	Log pseudolikelihood			-626314.01		Logistic regression			-767010.60
Total_trips	Odds Ratio	P>z	[95% Conf.	Interval]	Total_trip	Odds Ratio	P>z	[95% Conf.	Interval]
zone					zone				
Center	1				Center	1			
Inner suburbs	0.86	0.003	0.79	0.95	Inner suburbs	0.84	0.001	0.76	0.93
Outer suburbs	0.63	<0.001	0.57	0.70	Outer suburbs	0.77	<0.001	0.70	0.86
mot					mot				
0	1								
1	0.94	0.172	0.86	1.03					*NS
2	1.22	0.022	1.03	1.46					
≥3	0.83	0.106	0.66	1.04					
dr_license					dr_license				
		*NS					*NS		
age_cat					age_cat				
5 - 10 years	1.14	0.314	0.88	1.49	5 - 10 years	0.99	0.953	0.76	1.30
11 - 17 years	1.17	0.178	0.93	1.46	11 - 17 years	1.44	0.004	1.13	1.85
18 - 23 years	0.95	0.536	0.80	1.12	18 - 23 years	1.41	<0.001	1.19	1.67
24 - 33 years	1.04	0.563	0.90	1.20	24 - 33 years	1.34	<0.001	1.16	1.53
34 - 43 years	1				34 - 43 years	1			
44 - 53 years	0.82	0.018	0.70	0.97	44 - 53 years	0.90	0.152	0.79	1.04
54 - 63 years	0.74	0.001	0.61	0.89	54 - 63 years	0.86	0.074	0.73	1.01
64 - 73 years	0.64	<0.001	0.50	0.81	64 - 73 years	0.75	0.004	0.61	0.91
≥ 74 years	0.35	<0.001	0.26	0.49	≥ 74 years	0.44	<0.001	0.34	0.56
gender					gender				
Male	1								
Female	1.14	0.012	1.03	1.27					*NS
family_role					family_role				
Head of HH	1				Father	1			
Wife/husband	1.09	0.320	0.92	1.28	Mother	1.18	0.033	1.01	1.37
Son/Daughter	0.83	0.013	0.71	0.96	Son/Daughter	0.83	0.012	0.72	0.96
Other relatives	0.77	0.010	0.64	0.94	Other relatives	0.53	<0.001	0.43	0.65
Housemaid	0.12	<0.001	0.06	0.25	• NA				
Other relationship	0.70	0.012	0.53	0.92	Other relationship	1.54	0.014	1.09	2.18
Other non-relatives	0.88	0.614	0.53	1.46	Other non-relatives	0.79	0.004	0.67	0.93
activity					activity				
Worker	1				Worker	1			
Unemployed	0.27	<0.001	0.21	0.36	Unemployed	0.35	<0.001	0.28	0.44
Stay-at-home	0.26	<0.001	0.23	2.09	Maid	0.45	<0.001	0.40	0.51
Student	1.76	<0.001	1.48	10.25	Full time student	1.74	<0.001	1.42	2.13
Military service	1.12	0.922	0.12	0.47	Working student	2.00	0.072	0.94	4.25
Retired	0.37	<0.001	0.29	0.30	Retired	0.54	<0.001	0.43	0.68
Other	0.13	<0.001	0.09	0.18	Other	0.34	<0.001	0.25	0.47
education					education				
None	1				None	1			
Elementary NC ‡	1.41	<0.001	1.18	1.69	Kinder garden	0.39	<0.001	0.30	0.52
Elementary C †	1.40	<0.001	1.17	1.67	Elementary school	1.67	<0.001	1.37	2.05
Technical 3 years	2.10	<0.001	1.59	2.77	• NA				
Middle school	1.64	<0.001	1.36	1.98	Middle school	1.63	<0.001	1.32	2.00
Technical 5 years	2.23	<0.001	1.67	2.96	• NA				
High school	1.85	<0.001	1.50	2.29	High school	1.77	<0.001	1.43	2.20
Teacher training	1.75	0.004	1.20	2.56	• NA				
Higher education	1.85	<0.001	1.48	2.31	Higher education	2.09	<0.001	1.66	2.63
income_hh					income_hh				
					1	1			
					2	0.79	<0.001	0.71	0.88
					3	0.76	<0.001	0.67	0.86
					4	0.71	<0.001	0.59	0.86
					5	0.65	0.010	0.47	0.90
		• NA							
_cons	2.55	<0.001	2.06	3.15	_cons	3.10	<0.001	2.45	3.93

‡ NC: Not completed; † C: Completed; • NA: Not available data in HTS; * NS: No statistically significant (p-value <0.05)

5.3. Lille

	1987				1998				2006			
	Number of obs		10003.00		Number of obs		10312		Number of obs		8934	
	Wald chi2(29)		908.86		Wald chi2(33)		875.96		Wald chi2(33)		539.63	
	Prob > chi2		<0.001		Prob > chi2		<0.001		Prob > chi2		<0.001	
	Pseudo R2		0.12		Pseudo R2		0.1333		Pseudo R2		0.089	
	Log pseudolikelihood		-374605		Log pseudolikelihood		-355490		Log pseudolikelihood		-337731	
Total_trips	Odds Ratio	P>z	[95% Conf. Interval]		Odds Ratio	P>z	[95% Conf. Interval]		Odds Ratio	P>z	[95% Conf. Interval]	
zone												
Center									1			
Inner suburbs	1.01	0.893	0.86	1.19	*NS				0.77	0.017	0.61	0.95
Outer suburbs	0.83	0.028	0.71	0.98					0.76	0.018	0.61	0.95
vehicles/hh	*NS				*NS				*NS			
dr_license												
No	1				1				1			
Supervised_dr	• NA				0.81	0.685	0.28	2.29	1.79	0.258	0.65	4.87
Yes	1.69	<0.001	1.46	1.96	1.69	<0.001	1.44	1.98	1.70	<0.001	1.42	2.03
transport_card												
No					1				1			
Yes. paid			•NA		1.69	0.001	1.23	2.33	1.49	0.003	1.14	1.95
Yes. free					1.70	<0.001	1.31	2.20	1.24	0.118	0.95	1.63
age_cat												
5-10 years	2.07	0.016	1.15	3.74	2.55	0.009	1.27	5.13	3.16	0.010	1.31	7.60
11-17 years	2.12	0.011	1.19	3.79	2.60	0.005	1.33	5.08	2.88	0.014	1.24	6.70
18-23 years	1.16	0.391	0.83	1.62	1.65	0.012	1.12	2.45	1.34	0.223	0.84	2.13
24-33 years	1.01	0.934	0.80	1.28	1.05	0.713	0.80	1.37	0.85	0.241	0.65	1.11
34-43 years	1				1				1			
44-53 years	0.73	0.015	0.57	0.94	0.69	0.004	0.54	0.89	0.82	0.172	0.61	1.09
54-63 years	0.76	0.029	0.59	0.97	0.48	<0.001	0.36	0.63	0.71	0.031	0.52	0.97
64-73 years	0.51	<0.001	0.37	0.70	0.32	<0.001	0.22	0.45	0.50	0.001	0.32	0.76
≥74 years	0.25	<0.001	0.18	0.35	0.16	<0.001	0.11	0.23	0.27	<0.001	0.18	0.42
gender	*NS				*NS				*NS			
family_role												
Head of HH	1				1				1			
Wife/husband	0.84	0.051	0.71	1	0.94	0.506	0.79	1.12	0.94	0.526	0.79	1.13
Son/Daughter	0.67	0.007	0.50	0.89	0.51	<0.001	0.38	0.68	0.67	0.037	0.46	0.98
Other relatives	0.59	0.008	0.40	0.87	0.59	0.011	0.39	0.89	0.46	0.001	0.29	0.73
activity												
Full time worker	1				1				1			
Part-time worker	1.15	0.451	0.80	1.64	1.36	0.075	0.97	1.92	1.53	0.027	1.05	2.22
Internship training	• NA				1.47	0.417	0.58	3.73	0.65	0.348	0.26	1.60
Student	1.30	0.688	0.36	4.62	1.24	0.370	0.78	1.96	1.35	0.501	0.57	3.19
School (until bac)	1.17	0.831	0.28	4.87	1.50	0.187	0.82	2.75	1.69	0.266	0.67	4.27
Unemployed	0.47	<0.001	0.36	0.63	0.58	<0.001	0.45	0.76	0.61	0.001	0.45	0.81
Retired	0.49	<0.001	0.38	0.65	0.77	0.091	0.57	1.04	0.66	0.024	0.47	0.95
Stay-at-home	0.38	<0.001	0.30	0.49	0.50	<0.001	0.39	0.64	0.64	0.015	0.45	0.92
Other	0.20	<0.001	0.13	0.29	0.39	<0.001	0.25	0.59	0.47	0.000	0.31	0.72
profession												
Unemployed/inactives	1								1			
Small-medium business	0.78	0.177	0.55	1.12					1.01	0.970	0.64	1.58
Freelance profession	1.08	0.656	0.76	1.55					1.45	0.058	0.99	2.13
Technicians	1.24	0.168	0.91	1.70	*NS				1.71	0.003	1.20	2.45
Employees	1.46	0.004	1.13	1.89					1.69	0.001	1.22	2.32
Working class	1.29	0.049	1	1.66					1.40	0.045	1.01	1.96
School (until bac)	0.98	0.974	0.24	3.96					1.72	0.141	0.84	3.52
Student	0.57	0.391	0.15	2.08					1.85	0.129	0.84	4.10
education												
0					1				1			
1					1.95	0.128	0.82	4.60	0.41	0.012	0.21	0.82
2					1.63	0.003	1.18	2.25	0.51	0.002	0.33	0.78
3					2.06	<0.001	1.48	2.86	0.75	0.166	0.50	1.13
4			×		2.31	<0.001	1.62	3.31	0.79	0.298	0.50	1.23
5					1.99	<0.001	1.37	2.87	2.10	0.161	0.74	5.92
6					1.69	0.043	1.02	2.82				
income_hh												
1					1							
2					1.19	0.252	0.88	1.61				
3					1.44	0.018	1.06	1.96				
4					1.51	0.010	1.10	2.06				
5					1.43	0.026	1.04	1.97	*NS			
6			•NA		1.52	0.015	1.09	2.14				
7					1.65	0.004	1.17	2.33				
8					1.92	0.001	1.32	2.79				
9					2.11	0.004	1.27	3.52				
10					2.48	0.082	0.89	6.88				
cons	10.80	<0.001	7.64	15.27	5.10	<0.001	3.61	7.22	6.12	<0.001	3.92	9.54

× : Not included due to collinearity; •NA: Not available data in HTS; NS: No statistically significant (p-value <0.05)

5.4. Paris Region

	1991				2001			
	Number of obs				Number of obs			
	25301.00				23505.00			
	Wald chi2(41)		1175.39		Wald chi2(43)		995.63	
	Prob > chi2		0.00		Prob > chi2		0.00	
	Pseudo R2		0.11	=	Pseudo R2		0.09	
	Log pseudolikelihood		-2167730.60		Log pseudolikelihood		-2246186.90	
Total_trip	Odds Ratio	P>z	[95% Conf. Interval]		Odds Ratio	P>z	[95% Conf. Interval]	
zone								
Center								
Inner suburbs	0.78	0.003	0.66	0.92	0.67	<0.001	0.55	0.81
Outer suburbs	0.81	0.011	0.69	0.95	0.67	<0.001	0.55	0.81
mot								
0								
1	1.24	0.008	1.06	1.46		*NS		
2	1.32	0.009	1.07	1.63				
≥3	1.41	0.040	1.02	1.96				
dr_license								
No	1.00				1.00			
Supervised_dr	*NA				2.15	0.154	0.75	6.17
Yes	1.32	<0.001	1.14	1.53	1.41	<0.001	1.23	1.62
transport_card								
No								
Regular paid card	2.04	<0.001	1.71	2.43	1.57	<0.001	1.31	1.87
Solidarity card	2.08	0.199	0.68	6.32	1.97	0.501	0.27	14.15
Student card	*NA				1.64	0.011	1.12	2.41
Other	1.43	0.007	1.10	1.84	1.87	<0.001	1.41	2.48
age_cat								
5-10 years	2.29	0.001	1.41	3.70	4.45	<0.001	2.56	7.74
11-17 years	2.83	<0.001	1.77	4.53	4.65	<0.001	2.78	7.79
18-23 years	1.07	0.675	0.77	1.49	1.01	0.953	0.71	1.44
24-33 years	1.01	0.897	0.82	1.26	0.93	0.509	0.74	1.16
34-43 years								
44-53 years	0.72	0.003	0.58	0.90	0.73	0.003	0.59	0.90
54-63 years	0.64	<0.001	0.51	0.80	0.56	<0.001	0.44	0.70
64-73 years	0.46	<0.001	0.35	0.61	0.49	<0.001	0.36	0.67
≥74 years	0.24	<0.001	0.18	0.32	0.24	<0.001	0.18	0.33
gender								
Male								
Female	1.29	0.001	1.11	1.49	1.17	0.026	1.02	1.34
family_role								
Reference person								
Wife/Husband	0.66	<0.001	0.55	0.80	0.94	0.437	0.79	1.11
Child	0.37	<0.001	0.28	0.49	0.38	<0.001	0.30	0.49
Other relative	0.29	<0.001	0.21	0.38	0.52	<0.001	0.36	0.74
Housemaid	0.09	0.001	0.02	0.38	1.00			
Other non relative	0.71	0.231	0.41	1.24	0.38	0.003	0.20	0.72
activity								
Active worker								
Student	0.86	0.521	0.55	1.35	1.13	0.640	0.68	1.86
Retired	0.72	0.005	0.57	0.91	0.74	0.014	0.58	0.94
Unemployed	0.66	0.002	0.51	0.86	0.62	<0.001	0.49	0.78
Other inactive	0.44	<0.001	0.37	0.53	0.53	<0.001	0.43	0.65
education								
No education					1.00			
Elementary school	1.32	0.011	1.07	1.63	1.00	0.978	0.76	1.31
Secondary school	1.28	0.031	1.02	1.60	1.28	0.072	0.98	1.69
Higher education	1.35	0.021	1.05	1.75	1.56	0.002	1.17	2.09
Still at school	1.94	0.001	1.29	2.92	1.40	0.167	0.87	2.25
income/hh								
0								
1	1.00							
2	1.05	0.637	0.86	1.29				
3	1.13	0.290	0.90	1.43				
4	1.27	0.082	0.97	1.65		×		
5	1.46	0.011	1.09	1.95				
6	1.11	0.537	0.80	1.55				
7	1.35	0.333	0.74	2.45				
8	0.68	0.001	0.54	0.85				
_cons	12.14	<0.001	7.22	20.42	17.40	<0.001	12.00	25.22

*NA: Not available data in HTS; *NS: No statistically significant (p-value <0.05); × : Not included due to collinearity

Annex. 6

Multiple linear regression for vehicle driver kilometers

6.1. Juarez

	1996				2006			
	Number of obs =	9151			Number of obs =	3009		
	F(41, 13927) =	113.01			F(41, 4244) =	28.26		
	Prob > F =	<0.001			Prob > F =	<0.001		
	R-squared =	0.2496			R-squared =	0.2144		
	Adj R-squared =	0.2474			Adj R-squared =	0.2069		
	Root MSE =	7.2613			Root MSE =	8.8792		
PVD_km	Coef.	P>t	[95% Conf.	Interval]	Coef.	P>t	[95% Conf.	Interval]
zone								
Center	0	(base)			0	(base)		
Inner suburbs	1.09	<0.001	0.64	1.63	1.24	0.019	0.20	2.28
Outer suburbs	2.18	<0.001	1.63	2.72	1.81	0.002	0.66	2.96
class_vehicle/hh								
0	0	(base)			0	(base)		
1	4.59	<0.001	4.13	5.04	3.03	<0.001	2.02	4.04
2	7.70	<0.001	7.18	8.23	6.63	<0.001	5.53	7.72
≥ 3	8.48	<0.001	7.77	9.20	6.45	<0.001	5.07	7.84
age								
18 – 23 years	-1.30	<0.001	-1.99	-.60	-2.08	0.004	-3.50	-0.66
24 – 33 years	-.33	0.006	-.934	-.15	-1.18	0.031	-2.25	-0.11
34 – 43 years	0	(base)			0	(base)		
44 – 53 years	-1.40	<0.001	-1.91	-.88	-2.665	<0.001	-3.90	-1.43
54 – 63 years	-2.16	<0.001	-2.99	-1.34	-2.665	0.001	-4.23	-1.09
64 – 73 years	-2.59	<0.001	-3.73	-1.44	-3.964	<0.001	-5.78	-2.14
≥ 74 years	-2.59	0.002	-4.21	-0.98	-2.918	0.023	-5.43	-0.41
gender								
Male	0	(base)						
Female	-1.19	<0.001	-1.66	-.73				
								*NS
family_role								
Head of HH	0	(base)			0	(base)		
Wife/husband	-2.12	<0.001	-2.70	-1.55	-1.26	0.030	-2.39	-0.12
Son/Daughter	-2.90	<0.001	-3.60	-2.19	-2.05	0.001	-3.31	-0.79
Other relatives	-3.42	<0.001	-4.33	-2.52	-3.04	<0.001	-4.47	-1.61
Housemaid	-5.31	<0.001	-8.36	-2.27	-7.35	0.163	-17.68	2.98
Guest	-3.89	<0.001	-6.33	-1.45	-5.98	0.257	-16.32	4.37
Other non-relatives	-3.13	0.008	-5.92	-.36	-4.82	0.004	-8.11	-1.53
activity								
Worker	0	(base)			0	(base)		
Unemployed	-1.43	0.001	-2.68	-.19	0.34	0.866	-3.61	4.29
Stay-at-home wife	-1.70	<0.001	-2.70	-.70	-0.74	0.699	-4.49	3.01
Full time student	-1.63	<0.001	-2.96	-.30	1.37	0.531	-2.91	5.64
Working student	0.70	0.156	-.53	1.92	6.67	<0.001	3.64	9.71
Retired	-1.20	0.089	-2.58	-.18	-0.32	0.837	-3.45	2.79
Other	-1.86	0.002	-3.29	-.43	-0.62	0.774	-4.87	3.63
profession								
Currently not working	0	(base)			0	(base)		
Industry	-0.23	0.664	-1.26	0.80	1.64	0.393	-2.12	5.40
Trade/commerce	0.20	0.711	-0.86	1.27	1.91	0.327	-1.90	5.71
Bank/finance	-0.01	0.990	-1.78	1.76	5.92	0.038	0.34	11.50
Other services	-0.12	0.838	-1.27	1.03	1.55	0.428	-2.28	5.38
Retired	1.53	0.012	0.34	2.72	7.73	<0.001	3.58	11.87
Freelance Profession	0.74	0.238	-0.49	1.98	3.81	0.071	-0.33	7.95
Other	-1.02	0.038	-1.97	-0.06	1.59	0.399	-2.11	5.29
income_per (min. wage)								
0	0	(base)			0	(base)		
1	-1.04	0.054	-2.10	0.02	-2.42	0.207	-6.18	1.34
2	-0.51	0.328	-1.53	0.51	-1.79	0.329	-5.39	1.81
3 – 4	0.79	0.139	-0.26	1.84	-0.37	0.841	-3.95	3.22
5 – 6	1.91	0.001	0.76	3.06	1.48	0.443	-2.31	5.28
7 – 8	2.49	<0.001	1.15	3.82	5.79	0.011	1.30	10.27
9 – 10	2.03	0.007	0.56	3.50	7.24	0.002	2.64	11.84
11 – 12	3.04	<0.001	1.40	4.67	4.49	0.082	-0.57	9.56
13 – 14	2.57	<0.001	1.27	3.87	5.77	0.011	1.30	10.24
cons	4.3443	<0.001	3.503497	5.185102	3.431284	0.023	.4747348	6.387832

*NS: No statistically significant (p-value <0.05)

6.2. Puebla

1994					2011				
		Number of obs	10368				Number of obs	13832	
		F(26, 10341)	76.84				F(22, 13809)	105.33	
		Prob > F	<0.001				Prob > F	<0.001	
		R-squared	0.1619				R-squared	0.1437	
		Adj R-squared	0.1598				Adj R-squared	0.1423	
		Root MSE	5.0535				Root MSE	3.7751	
PVD_km	Coef.	P>t	[95% Conf.	Interval]	PVD_km	Coef.	P>t	[95% Conf.	Interval]
zone					zone				
Center	0				Center	0			
Inner suburbs	0.37	0.001	0.15	0.59	Inner suburbs	0.13	0.114	-0.03	0.28
Outer suburbs	0.83	<0.001	0.56	1.10	Outer suburbs	0.48	<0.001	0.31	0.65
mot					mot				
0	0				0	0			
1	1.21	<0.001	0.98	1.44	1	1.16	<0.001	1.00	1.31
2	2.82	<0.001	2.41	3.22	2	2.20	<0.001	1.86	2.54
≥3	3.23	<0.001	2.67	3.78	≥3	2.67	<0.001	1.93	3.40
dr_license					dr_license				
No	0				No	0			
Yes	2.80	<0.001	2.56	3.08	Yes	2.32	<0.001	2.12	2.51
age_cat					age_cat				
18 – 23 years	-0.33	0.084	-0.69	0.04					
24 – 33 years	-0.56	<0.001	-0.86	-0.25					
34 – 43 years	0								
44 – 53 years	0.07	0.713	-0.29	0.42			*NS		
54 – 63 years	-0.40	0.057	-0.81	0.01					
64 – 73 years	-0.48	0.063	-0.99	0.03					
≥ 74 years	-0.56	0.078	-1.17	0.06					
gender					gender				
		*NS					*NS		
family_role					family_role				
Head of HH	0				Father	0			
Wife/husband	-0.74	<0.001	-1.02	-0.47	Mother	-0.47	<0.001	-0.69	-0.25
Son/Daughter	-1.12	<0.001	-1.44	-0.80	Son/Daughter	-0.63	<0.001	-0.83	-0.44
Other relatives	-0.68	0.002	-1.12	-0.25	Other relatives	-0.38	0.025	-0.71	-0.05
Housemaid	-1.63	0.071	-3.40	0.14	•NA				
Other relationship	-1.10	0.001	-1.77	-0.42	Other relationship	-0.54	0.014	-0.97	-0.11
Other non-relatives	-1.80	<0.001	-2.77	-0.82	Other non-relatives	-0.75	<0.001	-1.00	-0.49
activity					activity				
		*NS			Worker	0			
					Unemployed	-0.16	0.437	-0.55	0.24
					Stay-at-home	-0.18	0.063	-0.36	0.01
					Full time student	-0.55	<0.001	-0.79	-0.30
					Working student	-0.18	0.665	-0.97	0.62
					Retired	-0.63	<0.001	-0.98	-0.28
					Other	0.38	0.256	-0.27	1.03
education					education				
None	0				None	0			
Elementary incomplete	-0.14	0.610	-0.66	0.39	Kinder garden	0.54	0.472	-0.93	2.01
Elementary complete	-0.18	0.457	-0.65	0.29	Elementary school	-0.04	0.824	-0.38	0.30
Technical 3 years	0.21	0.503	-0.41	0.84	•NA				
Middle school	0.24	0.342	-0.26	0.74	Middle school	0.10	0.585	-0.25	0.44
Technical 5 years	0.53	0.119	-0.14	1.19	•NA				
High school	0.84	0.002	0.32	1.35	High school	0.27	0.128	-0.08	0.62
Teacher training system	-0.28	0.495	-1.07	0.52	•NA				
Higher education	1.34	<0.001	0.80	1.88	Higher education	0.73	<0.001	0.36	1.10
Income_hh					Income_hh				
		•NA					*NS		
_cons	0.09	<0.001	-0.43	0.62	_cons	0.11	0.566	-0.26	0.48

*NS: No statistically significant (p-value <0.05) ; •NA: Not available data in HTS

6.3. Lille

	1987				1998				2006			
	Number of obs		7804.00		Number of obs		8124		Number of obs		7436	
	F(30. 7773)		90.10		F(44. 8079)		63.49		F(40. 7395)		61.69	
	Prob > F		<0.001		Prob > F		<0.001		Prob > F		<0.001	
	Adj R-squared		0.2552		Adj R-squared		0.2542		Adj R-squared		0.2482	
	Root MSE		9.6704		Root MSE		11.346		Root MSE		10.919	
PVD_km	Coef.	P>t	[95% Conf. Interval]		Coef.	P>t	[95% Conf. Interval]		Coef.	P>t	[95% Conf. Interval]	
zone												
Center	0				0				0			
Inner suburbs	1.53	<0.001	0.92	2.15	1.59	<0.001	0.87	2.31	1.97	<0.001	1.23	2.70
Outer suburbs	3.10	<0.001	2.46	3.74	3.64	<0.001	2.89	4.40	4.02	<0.001	3.24	4.81
vehicles/hh												
0	0				0.00				0.00			
1	2.36	<0.001	1.70	3.02	3.10	<0.001	2.22	3.98	2.62	<0.001	1.76	3.47
2	5.96	<0.001	5.12	6.80	7.52	<0.001	6.47	8.58	5.48	<0.001	4.45	6.51
≥3	7.45	<0.001	6.11	8.79	9.39	<0.001	7.96	10.81	7.24	<0.001	5.81	8.68
dr_license												
No	0				0.00				0.00			
Supervised_dr	• NA				-2.22	0.418	-7.61	3.16	-1.86	0.198	-4.70	0.97
Yes	4.80	0.00	4.19	5.415	4.33	<0.001	3.58	5.08	4.56	<0.001	3.79	5.32
transport_card												
No					0	0.00						
Yes. paid			•NA		-2.47	<0.001	-3.53	-1.41	-2.72	<0.001	-3.57	-1.87
Yes. free					-0.98	0.071	-2.05	0.08	-0.68	0.227	-1.79	0.42
age_cat												
18-23 years	-0.30	0.576	-1.35	0.75	-1.43	0.032	-2.73	-0.12	-0.05	0.937	-1.37	1.27
24-33 years	0.08	0.823	-0.60	0.75	-0.69	0.096	-1.51	0.12	-0.11	0.799	-0.92	0.71
34-43 years	0				0.00				0.00			
44-53 years	-1.45	<0.001	-2.23	-0.68	-2.75	<0.001	-3.58	-1.93	-1.21	0.005	-2.05	-0.36
54-63 years	-1.97	<0.001	-2.80	-1.13	-2.91	<0.001	-3.98	-1.85	-2.07	<0.001	-3.09	-1.05
64-73 years	-2.53	<0.001	-3.75	-1.31	-2.84	<0.001	-4.34	-1.34	-2.61	0.001	-4.22	-1.00
≥74 years	-1.99	0.003	-3.31	-0.68	-3.50	<0.001	-5.11	-1.89	-3.03	<0.001	-4.72	-1.35
gender												
			*NS				*NS				*NS	
family_role												
Head of HH	0.00				0.00				0.00			
Wife/husband	-2.96	<0.001	-3.54	-2.37	-3.54	<0.001	-4.20	-2.89	-2.36	<0.001	-3.00	-1.73
Son/Daughter	-2.02	<0.001	-2.99	-1.05	-2.69	<0.001	-3.81	-1.57	-1.96	0.002	-3.19	-0.72
Other relatives	-3.30	<0.001	-4.92	-1.67	-2.14	0.017	-3.90	-0.39	-2.34	0.011	-4.15	-0.53
activity												
Full time worker	0.00				0.00				0.00			
Part-time worker	-1.03	0.034	-1.98	-0.08	-1.50	0.003	-2.48	-0.52	-1.27	0.009	-2.22	-0.32
Internship training	• NA				-0.62	0.663	-3.39	2.15	-3.63	0.008	-6.30	-0.96
Student	-0.70	0.829	-7.06	5.66	-1.61	0.438	-5.67	2.45	-2.80	0.032	-5.37	-0.24
School (up to high-school)	-11.60	0.019	-21.30	-1.89	-3.46	0.137	-8.01	1.10	-3.90	0.015	-7.02	-0.77
Unemployed	-3.01	<0.001	-4.00	-2.02	-3.19	<0.001	-4.24	-2.15	-3.55	<0.001	-4.61	-2.48
Retired	-2.16	<0.001	-3.20	-1.13	-3.49	<0.001	-4.79	-2.20	-3.45	<0.001	-4.77	-2.13
Stay-at-home	-1.77	<0.001	-2.68	-0.85	-3.14	<0.001	-4.37	-1.91	-3.30	<0.001	-4.56	-2.04
Other	-3.63	<0.001	-5.27	-1.99	-5.22	<0.001	-7.08	-3.36	-4.11	<0.001	-5.80	-2.42
profession												
Unemployed/inactives	0				0.00				0.00			
Small-medium business	-1.60	0.019	-2.94	-0.26	2.38	0.007	0.64	4.11	0.63	0.512	-1.24	2.50
Freelance profession	2.25	0.001	0.97	3.53	1.65	0.035	0.12	3.17	2.05	0.010	0.50	3.61
Technicians	1.60	0.006	0.46	2.74	1.49	0.035	0.11	2.88	1.76	0.018	0.31	3.22
Employees	0.32	0.543	-0.71	1.34	-0.20	0.761	-1.48	1.09	-0.07	0.921	-1.40	1.26
Working class	-0.66	0.203	-1.68	0.36	-0.43	0.520	-1.73	0.88	-0.19	0.789	-1.55	1.18
School (up to high school)	6.42	0.194	-3.27	16.12	-1.88	0.426	-6.50	2.74	-0.39	0.726	-2.58	1.80
Student	-2.10	0.527	-8.60	4.40	-0.50	0.816	-4.68	3.69	0.52	0.638	-1.66	2.70
education												
			x				*NS				*NS	
Income_hh												
1					0.00				0			
2					1.18	0.077	-0.13	2.48	-0.25	0.573	-1.14	0.63
3					0.37	0.588	-0.97	1.71	1.12	0.031	0.10	2.14
4					0.66	0.339	-0.69	2.01	-0.13	0.832	-1.32	1.07
5					0.68	0.340	-0.72	2.08	0.99	0.153	-0.37	2.35
6					0.86	0.249	-0.60	2.33	1.98	0.034	0.14	3.81
7					0.75	0.313	-0.71	2.21				
8					1.94	0.014	0.40	3.48				
9					2.03	0.034	0.16	3.90				
10					2.97	0.059	-0.11	6.04				
_cons	6.68	<0.001	5.31	8.05	2.92	0.002	1.07	4.78	2.00	0.023	0.28	3.73

*NS: No statistically significant (p-value <0.05) ; •NA: Not available data in HTS; x: Not included due to collinearity

6.4. Paris Region

	1991				2001			
	Number of obs				Number of obs			
	20690				19289			
	F(36. 20653)				F(39. 19249)			
	176.4				153.25			
	Prob > F				0			
	0				0			
	R-squared				R-squared			
	0.2352				0.2369			
	Adj R-squared				Adj R-squared			
	0.2338				0.2354			
	Root MSE				Root MSE			
	15.713				16.221			
PVD_km	Coef.	P>t	[95% Conf.	Interval]	Coef.	P>t	[95% Conf.	Interval]
zone								
Center	0				0			
Inner suburbs	1.07	0.001	0.47	1.68	1.31	<0.001	0.64	1.98
Outer suburbs	4.78	<0.001	4.15	5.41	5.54	<0.001	4.84	6.23
mot								
0	0				0			
1	3.32	<0.001	2.64	4.00	3.31	<0.001	2.60	4.02
2	8.66	<0.001	7.80	9.51	8.43	<0.001	7.53	9.32
≥3	11.52	<0.001	10.24	12.80	12.93	<0.001	11.67	14.19
dr_license								
No	0				0			
Supervised_dr	•NA				-2.72	0.195	-6.84	1.39
Yes	2.59	<0.001	1.97	3.20	2.89	<0.001	2.21	3.57
transport_card								
No	0				0			
Regular paid card	-8.05	<0.001	-8.59	-7.50	-9.03	<0.001	-9.64	-8.42
Solidarity card	-8.94	<0.001	-11.98	-5.89	-6.19	0.065	-12.76	0.37
Student card	•NA				-5.40	<0.001	-6.97	-3.84
Other	-2.66	<0.001	-3.83	-1.48	-2.58	<0.001	-3.78	-1.38
age_cat								
18-23 years	-1.62	0.004	-2.72	-0.52	-1.61	0.018	-2.95	-0.27
24-33 years	0.29	0.384	-0.37	0.95	-0.43	0.263	-1.18	0.32
34-43 years	0				0			
44-53 years	-1.73	<0.001	-2.45	-1.02	-1.51	<0.001	-2.25	-0.77
54-63 years	-2.94	<0.001	-3.80	-2.09	-2.33	<0.001	-3.19	-1.46
64-73 years	-2.52	<0.001	-3.77	-1.27	-3.26	<0.001	-4.62	-1.89
≥74 years	-2.98	<0.001	-4.35	-1.60	-3.79	<0.001	-5.27	-2.31
gender								
Male	0				0			
Female	-2.34	<0.001	-2.96	-1.73	-1.34	<0.001	-1.99	-0.69
family_role								
Reference person	0				0			
Wife/Husband	-5.63	<0.001	-6.35	-4.90	-5.64	<0.001	-6.40	-4.88
Child	-5.27	<0.001	-6.33	-4.22	-5.69	<0.001	-6.82	-4.55
Other relative	-4.34	<0.001	-6.04	-2.65	-3.27	0.002	-5.32	-1.23
Housemaid	-11.48	0.008	-19.92	-3.04	-3.02	0.754	-21.87	15.84
Other non relative	-3.37	0.002	-5.52	-1.23	-5.34	0.001	-8.39	-2.30
activity								
Active worker	0				0			
Student	-2.79	0.004	-4.66	-0.92	-2.83	0.007	-4.89	-0.76
Retired	-5.02	<0.001	-6.08	-3.96	-5.38	<0.001	-6.53	-4.22
Unemployed	-4.38	<0.001	-5.45	-3.31	-4.80	<0.001	-5.87	-3.72
Other inactive	-4.80	<0.001	-5.63	-3.97	-5.09	<0.001	-6.06	-4.11
education								
No education	0				0			
Elementary school	-0.67	0.235	-1.78	0.44	-0.29	0.704	-1.76	1.19
Secondary school	1.27	0.025	0.16	2.39	1.42	0.052	-0.01	2.86
Higher education	1.82	0.003	0.63	3.01	2.57	0.001	1.09	4.06
Still at school	2.14	0.050	0.00	4.29	1.12	0.361	-1.28	3.51
Income/hh								
0	0				0			
1	0				1.87	0.356	-2.10	5.84
2	-0.18	0.703	-1.12	0.76	2.21	0.266	-1.68	6.10
3	-0.18	0.718	-1.19	0.82	2.19	0.269	-1.70	6.08
4	1.31	0.021	0.20	2.42	2.87	0.152	-1.06	6.80
5	1.00	0.092	-0.16	2.17	3.24	0.104	-0.67	7.16
6	1.59	0.020	0.25	2.93	3.32	0.100	-0.63	7.27
7	0.03	0.981	-2.16	2.22	4.68	0.029	0.48	8.88
8	-0.30	0.591	-1.37	0.78	2.85	0.151	-1.05	6.75
_cons	7.70	<0.001	6.21	9.18	4.46	0.036	0.29	8.63

•NA: Not available data in HTS

Annex 7.

Multiple linear regression for vehicle passenger
kilometers

7.1. Juarez

	1996					2006				
	Number of obs	=		13969		Number of obs	=		4286	
	F(41, 13927)	=		15.2		F(41, 4244)	=		6.45	
	Prob > F	=		<0.001		Prob > F	=		<0.001	
	R-squared	=		0.0428		R-squared	=		0.0587	
	Adj R-squared	=		0.04		Adj R-squared	=		0.0496	
	Root MSE	=		5.6732		Root MSE	=		6.5489	
PVP_km	Coef.	P>t	[95% Conf. Interval]		Coef.	P>t	[95% Conf. Interval]			
zone										
Center	0		(base)		0		(base)			
Inner suburbs	0.48	<0.001	0.24	0.72	0.42	0.143	-0.14	0.98		
Outer suburbs	0.90	<0.001	0.61	1.18	0.72	0.022	0.10	1.33		
class_vehicle/hh										
0	0		(base)		0		(base)			
1	1.02	<0.001	0.78	1.26	1.64	<0.001	1.11	2.16		
2	1.84	<0.001	1.57	2.12	2.38	<0.001	1.82	2.94		
≥ 3	1.97	<0.001	1.60	2.35	2.03	<0.001	1.28	2.78		
age										
5 – 10 years	1.25	<0.001	0.66	1.85						
11 – 17 years	1.19	<0.001	0.64	1.74						
18 – 23 years	0.70	0.002	0.26	1.14						
24 – 33 years	0.69	<0.001	0.39	1.00						
34 – 43 years	0		(base)				*NS			
44 – 53 years	-0.06	0.785	-0.46	0.35						
54 – 63 years	0.51	0.063	-0.03	1.05						
64 – 73 years	0.55	0.145	-0.19	1.29						
≥ 74 years	0.48	0.368	-0.56	1.52						
gender										
Male	0		(base)		0		(base)			
Female	0.37	0.001	0.15	0.59	0.54	0.026	0.06	1.01		
family_role										
Head of HH	0		(base)							
Wife/husband	0.52	0.004	0.17	0.88						
Son/Daughter	0.00	0.989	-0.43	0.42						
Other relatives	-0.18	0.516	-0.71	0.35			*NS			
Housemaid	-1.74	0.044	-3.44	-0.05						
Guest	0.07	0.921	-1.31	1.45						
Other non-relatives	0.02	0.975	-1.49	1.54						
activity										
Worker	0		(base)		0		(base)			
Unemployed	0.50	0.194	-0.25	1.25	-0.86	0.442	-3.05	1.33		
Stay-at-home	0.11	0.728	-0.49	0.71	-1.13	0.286	-3.21	0.95		
Full time student	1.38	<0.001	0.71	2.05	0.76	0.482	-1.36	2.88		
Working student	0.06	0.877	-0.65	0.76	1.95	0.034	0.15	3.76		
Retired	0.35	0.431	-0.52	1.21	1.09	0.363	-1.26	3.45		
Other	0.52	0.194	-0.26	1.30	-1.00	0.371	-3.20	1.19		
profession										
Currently not working					0		(base)			
Industry					0.26	0.809	-1.85	2.37		
Trade/commerce					0.71	0.521	-1.45	2.86		
Bank/finance			*NS		-0.98	0.566	-4.31	2.36		
Other services					0.79	0.472	-1.37	2.96		
Retired					3.49	0.004	1.10	5.88		
Freelance Professional					0.21	0.866	-2.18	2.59		
Other					0.97	0.358	-1.10	3.04		
income_per (min. wage)										
0	0		(base)		0		(base)			
1	0.70	0.029	0.07	1.32	0.11	0.921	-1.98	2.19		
2	0.81	0.009	0.21	1.41	-1.34	0.189	-3.35	0.66		
3 – 4	0.84	0.009	0.21	1.46	-0.85	0.404	-2.85	1.15		
5 – 6	0.60	0.091	-0.10	1.30	-2.37	0.031	-4.52	-0.22		
7 – 8	0.59	0.163	-0.24	1.41	-1.78	0.181	-4.39	0.83		
9 – 10	0.14	0.761	-0.77	1.05	-2.57	0.062	-5.26	0.13		
11 – 12	0.39	0.461	-0.64	1.41	-1.26	0.411	-4.25	1.74		
13 – 14	-0.06	0.873	-0.85	0.72	-1.34	0.311	-3.94	1.25		
_cons	-1.14	0.001	-1.80	-0.48	-0.66	0.553	-2.84	1.52		

* NS: No statistically significant (p-value <0.05)

7.2. Puebla

1994					2011				
Number of obs		14721			Number of obs		16651		
F(30. 14690)		14.85			F(21. 18327)		15.55		
Prob > F		<0.001			Prob > F		<0.001		
R-squared		0.0294			R-squared		0,028		
Adj R-squared		0.0275			Adj R-squared		0.0189		
Root MSE		2.8127			Root MSE		2,8147		
PVP_km	Coef.	P>t	[95% Conf.	Interval]	PVP_km	Coef.	P>t	[95% Conf.	Interval]
zone					zone				
Center	0				Center	0			
Inner suburbs	0.07	0.188	-0.03	0.17	Inner suburbs	0.09	0.052	-0.02	0.18
Outer suburbs	0.22	<0.001	0.10	0.34	Outer suburbs	0.23	<0.001	0.13	0.32
mot					mot				
0	0				0	0			
1	0.62	<0.001	0.51	0.73	1	0.48	<0.001	0.40	0.57
2	1.05	<0.001	0.87	1.24	2	0.63	<0.001	0.43	0.83
≥3	0.99	<0.001	0.74	1.25	≥3	0.27	0.265	-0.21	0.75
dr_license					dr_license				
No	0				No	0			
Yes	0.35	<0.001	0.21	0.49	Yes	-0.14	0.021	-0.25	-0.02
age_cat					age_cat				
5 - 10 years	0.32	0.006	0.09	0.54					
11 - 17 years	0.32	0.003	0.11	0.53					
18 – 23 years	0.01	0.942	-0.19	0.20					
24 – 33 years	-0.10	0.250	-0.26	0.07					
34 – 43 years	0								
44 – 53 years	-0.03	0.786	-0.22	0.17					
54 – 63 years	0.00	0.975	-0.22	0.23					
64 – 73 years	0.02	0.880	-0.25	0.30					
≥ 74 years	0.19	0.263	-0.14	0.53					
gender					gender				
Male					Male	0			
Female	0.19	<0.001	0.09	0.28	Female	0.13	0.003	0.04	0.21
family_role					family_role				
Head of HH									
Wife/husband									
Son/Daughter		*NS					*NS		
Other relatives									
Housemaid									
Other relationship									
Other non-relatives									
activity					activity				
					Worker	0			
					Unemployed	-0.25	0.046	-0.49	0.00
					Stay-at-home	-0.16	0.003	-0.27	-0.05
					Full time student	0.04	0.416	-0.05	0.13
					Working student	0.07	0.780	-0.41	0.54
					Retired	-0.12	0.308	-0.34	0.11
					Other	0.03	0.884	-0.34	0.39
education					education				
None					None	0			
Elementary NC ‡					Kinder garden	-0.21	0.127	-0.47	0.06
Elementary C †					Elementary school	-0.08	0.412	-0.28	0.11
Technical 3 years		×			•NA				
Middle school					Middle school	-0.09	0.375	-0.29	0.11
Technical 5 years					•NA				
High school					High school	-0.20	0.047	-0.41	0.00
Teacher training system					•NA				
Higher education					Higher education	0.00	0.991	-0.21	0.21
income_hh					income_hh				
					1	0			
					2	0.06	0.214	-0.03	0.15
					3	0.33	<0.001	0.22	0.44
					4	0.36	<0.001	0.19	0.53
					5	0.66	<0.001	0.35	0.96
_cons	-0.17	0.051	-0.34	0.00	_cons	0.01	0.923	-0.21	0.23

‡ NC: Not completed; † C: Completed.

*NS: No statistically significant (p-value <0.05) ; •NA: Not available data in HTS; ×: Not included due to collinearity

7.3. Lille

	1987				1998				2006			
	Number of obs		10107		Number of obs		10300		Number of obs		8990	
	F(33. 9968)		24.45		F(39. 10260)		18.79		F(25. 8964)		20.92	
	Prob > F		0		Prob > F		<0.001		Prob > F		<0.001	
	R-squared		0.0572		R-squared		0.0666		R-squared		0.0551	
	Adj R-squared		0.0548		Adj R-squared		0.0731		Adj R-squared		0.0625	
	Root MSE		4.8832		Root MSE		5.3728		Root MSE		5.0901	
PVP_km	Coef.	P>t	[95% Conf.	Interval]	Coef.	P>t	[95% Conf.	Interval]	Coef.	P>t	[95% Conf.	Interval]
zone												
Center	0				0				0			
Inner suburbs	0.27	0.059	-0.01	0.54	0.52	0.001	0.21	0.83	0.35	0.029	0.04	0.67
Outer suburbs	1.14	<0.001	0.85	1.43	1.16	<0.001	0.84	1.48	0.92	<0.001	0.59	1.26
vehicles/hh												
0	0.00				0				0			
1	1.09	<0.001	0.80	1.39	1.13	<0.001	0.76	1.50	0.97	<0.001	0.61	1.32
2	1.39	<0.001	1.03	1.74	1.21	<0.001	0.78	1.65	1.18	<0.001	0.76	1.60
≥3	1.11	<0.001	0.51	1.72	1.40	<0.001	0.80	2.00	1.66	<0.001	1.07	2.25
dr_license												
No	0.00				0				0			
Supervised_dr	• NA				0.02 0.980				-1.31 1.34			
Yes	-0.96	<0.001	-1.25	-0.66	-1.32	<0.001	-1.67	-0.98	-1.78	<0.001	-2.11	-1.45
transport_card												
No	0.00				0.00							
Yes. paid	• NA				0.51 0.024				0.07 0.95			
Yes. free					0.42 0.049				0.00 0.84			
age_cat												
5-10 years	1.60	<0.001	0.75	2.44	3.08	<0.001	2.14	4.01	1.15	0.001	0.46	1.83
11-17 years	1.02	0.015	0.19	1.84	2.99	<0.001	2.09	3.89	0.64	0.060	-0.03	1.30
18-23 years	1.06	<0.001	0.54	1.57	1.67	<0.001	1.07	2.28	1.14	<0.001	0.63	1.65
24-33 years	0.54	0.002	0.21	0.88	0.89	<0.001	0.50	1.27	0.48	0.012	0.10	0.86
34-43 years	0.00				0				0			
44-53 years	0.11	0.565	-0.28	0.50	-0.17	0.389	-0.56	0.22	0.23	0.246	-0.16	0.63
54-63 years	0.27	0.202	-0.15	0.69	0.26	0.239	-0.17	0.70	0.27	0.211	-0.15	0.69
64-73 years	0.67	0.031	0.06	1.28	-0.12	0.615	-0.59	0.35	0.47	0.057	-0.01	0.96
≥74 years	0.12	0.721	-0.53	0.77	-0.50	0.065	-1.04	0.03	0.02	0.955	-0.51	0.54
gender												
Male	0.00				0				0			
Female	0.41	0.001	0.16	0.66	0.43	0.001	0.17	0.69	0.46	<0.001	0.20	0.71
family_role												
Head of HH	0.00				0				0			
Wife/husband	1.33	<0.001	0.99	1.66	0.91	<0.001	0.57	1.25	0.46	0.006	0.13	0.78
Son/Daughter	-0.34	0.161	-0.81	0.14	-0.05	0.841	-0.56	0.45	-0.08	0.761	-0.61	0.44
Other relatives	0.42	0.292	-0.36	1.20	0.45	0.260	-0.34	1.24	-0.62	0.128	-1.42	0.18
activity												
Full time worker	0.00											
Part-time worker	-0.43	0.074	-0.90	0.04								
Student	0.70	0.025	0.09	1.30								
School (up to high-school)	0.24	0.513	-0.49	0.97	*NS				*NS			
Unemployed	-0.01	0.958	-0.50	0.47								
Retired	-0.45	0.091	-0.97	0.07								
Stay-at-home	-1.07	<0.001	-1.47	-0.68								
Other	-0.91	0.029	-1.73	-0.09								
profession												
Unemployed/inactives	0				0				0			
Small-medium business					0.68 0.072				-0.06 1.42			
Freelance profession	×				0.03 0.934				-0.60 0.65			
Technicians					-0.11 0.700				-0.66 0.44			
Employees					0.26 0.313				-0.24 0.76			
Working class					0.48 0.070				-0.04 1.00			
School (up to high school)					-1.22 0.005				-2.07 -0.37			
Student					0.14 0.708				-0.59 0.87			
education	×				*NS				*NS			
income_hh												
1	0				0				0			
2					0.05 0.847				-0.50 0.61			
3					0.49 0.091				-0.08 1.05			
4					0.57 0.049				0.00 1.14			
5					0.59 0.047				0.01 1.18			
6	• NA				0.32 0.307				-0.29 0.93			
7					0.58 0.062				-0.03 1.19			
8					1.34 <0.001				0.70 1.98			
9					0.70 0.072				-0.06 1.47			
10					0.70 0.273				-0.56 1.97			
_cons	-1.02	0.003	-1.68	-0.35	-0.59	0.114	-1.33	0.14	0.23	0.377	-0.28	0.74

7.4. Paris Region

	1991					2001				
	Number of obs					Number of obs				
	25395.00					23508.00				
	F(30. 25364)					F(29. 23478)				
	19.91					24.08				
	Prob > F					Prob > F				
	0.00					0.00				
	R-squared					R-squared				
	0.02					0.03				
	Adj R-squared					Adj R-squared				
	0.02					0.03				
	Root MSE					Root MSE				
	6.82					6.85				
PVP_km	Coef.	P>t	[95% Conf.	Interval]		Coef.	P>t	[95% Conf.	Interval]	
zone										
Center	0.00					0.00				
Inner suburbs	0.19	0.127	-0.05	0.43		0.08	0.549	-0.18	0.34	
Outer suburbs	0.99	<0.001	0.74	1.24		1.11	<0.001	0.85	1.38	
mot										
0	0.00					0.00				
1	0.71	<0.001	0.44	0.97		0.68	<0.001	0.42	0.94	
2	0.83	<0.001	0.51	1.16		1.12	<0.001	0.81	1.43	
≥3	0.88	0.001	0.38	1.38		1.35	<0.001	0.89	1.81	
dr_license										
No	0.00					0.00				
Supervised_dr						1.69	0.014	0.34	3.05	
Yes	-0.78	<0.001	-1.03	-0.53		-0.60	<0.001	-0.88	-0.32	
transport_card										
No	0.00									
Regular paid card	-0.38	0.001	-0.59	-0.16						*NS
Solidarity card	0.04	0.943	-1.19	1.28						
Other	0.26	0.216	-0.15	0.68						
age_cat										
5-10 years	0.52	0.067	-0.04	1.08		1.86	<0.001	1.13	2.59	
11-17 years	-0.10	0.715	-0.63	0.43		1.43	<0.001	0.73	2.13	
18-23 years	0.97	<0.001	0.54	1.40		1.32	<0.001	0.77	1.87	
24-33 years	0.71	<0.001	0.43	0.99		0.94	<0.001	0.63	1.25	
34-43 years	0.00					0.00				
44-53 years	-0.08	0.630	-0.38	0.23		0.17	0.282	-0.14	0.48	
54-63 years	0.28	0.105	-0.06	0.61		0.72	<0.001	0.35	1.08	
64-73 years	0.74	<0.001	0.36	1.13		0.54	0.065	-0.03	1.11	
≥74 years	-0.01	0.959	-0.47	0.44		0.36	0.250	-0.25	0.97	
gender										
Male	0.00					0.00				
Female	0.42	<0.001	0.20	0.64		0.33	0.005	0.10	0.55	
family_role										
Reference person	0.00					0.00				
Wife/Husband	1.03	<0.001	0.75	1.30		1.21	<0.001	0.93	1.50	
Child	0.20	0.368	-0.23	0.62		0.37	0.113	-0.09	0.82	
Other relative	0.04	0.912	-0.65	0.73		0.26	0.520	-0.54	1.06	
Housemaid	-0.55	0.767	-4.20	3.09		-1.36	0.736	-9.28	6.56	
Other non relative	0.26	0.557	-0.62	1.15		1.80	0.003	0.62	2.99	
activity										
Active worker						0.00				
Student						-0.44	0.183	-1.09	0.21	
Retired		*NS				0.72	0.003	0.24	1.20	
Unemployed						-0.28	0.216	-0.72	0.16	
Other inactive						0.10	0.624	-0.30	0.50	
education										
No education						0.00				
Elementary school						0.47	0.131	-0.14	1.08	
Secondary school		*NS				0.75	0.013	0.16	1.34	
Higher education						0.56	0.072	-0.05	1.16	
Still at school						0.43	0.257	-0.31	1.17	
income/hh										
1	0.00									
2	0.10	0.611	-0.28	0.47						
3	0.15	0.446	-0.24	0.55						
4	0.46	0.039	0.02	0.89						
5	0.67	0.004	0.22	1.11						*NS
6	0.56	0.032	0.05	1.07						
7	0.48	0.257	-0.35	1.30						
8	0.29	0.184	-0.14	0.72						
cons										
	-0.11	0.635	-0.58	0.35		-1.11	0.001	-1.77	-0.45	

*NS: No statistically significant (p-value <0.05)

Annex 8.

Multiple linear regression for public transport
kilometers

8.1. Juarez

	1996				2006			
	Number of obs	=	13969		Number of obs	=	4286	
	F(41, 13927)	=	46.11		F(41, 4244)	=	8.78	
	Prob > F	=	<0.001		Prob > F	=	<0.001	
	R-squared	=	0.1195		R-squared	=	0.0782	
	Adj R-squared	=	0.1169		Adj R-squared	=	0.0693	
	Root MSE	=	7.0003		Root MSE	=	6.753	
PT_km	Coef.	P>t	[95% Conf. Interval]		Coef.	P>t	[95% Conf. Interval]	
zone								
Center	0				0			
Inner suburbs	0.27	0.076	-0.03	0.56	0.68	0.021	0.10	1.26
Outer suburbs	0.89	<0.001	0.54	1.25	1.08	0.001	0.45	1.71
class_vehicle/hh								
0	0	(base)			0	(base)		
1	-3.06	<0.001	-3.35	-2.76	-2.08	<0.001	-2.62	-1.54
2	-4.15	<0.001	-4.48	-3.81	-3.28	<0.001	-3.86	-2.70
≥ 3	-4.64	<0.001	-5.11	-4.18	-3.73	<0.001	-4.50	-2.96
Age								
5 – 10 years	-2.03	<0.001	-2.76	-1.30	-2.73	<0.001	-4.00	-1.47
11 – 17 years	-0.06	0.866	-0.74	0.63	-0.42	0.473	-1.58	0.73
18 – 23 years	0.78	0.005	0.24	1.32	1.13	0.013	0.24	2.02
24 – 33 years	0.28	0.139	-0.09	0.66	-0.04	0.899	-0.74	0.65
34 – 43 years	0	(base)			0	(base)		
44 – 53 years	0.62	0.014	0.12	1.12	0.30	0.470	-0.51	1.10
54 – 63 years	0.38	0.260	-0.28	1.04	-0.16	0.753	-1.17	0.85
64 – 73 years	-0.41	0.384	-1.32	0.51	-1.23	0.041	-2.40	-0.05
≥ 74 years	-1.12	0.087	-2.40	0.16	-1.68	0.039	-3.28	-0.09
gender								
Male			*NS				*NS	
Female								
family_role								
Head of HH	0	(base)						
Wife/husband	0.22	0.332	-0.22	0.65				
Son/Daughter	0.46	0.083	-0.06	0.99				
Other relatives	0.82	0.014	0.17	1.48			*NS	
Housemaid	-1.67	0.117	-3.76	0.42				
Guest	0.58	0.503	-1.12	2.28				
Other non-relatives	-1.35	0.156	-3.22	0.52				
Activity								
Worker	0	(base)			0	(base)		
Unemployed	-1.11	0.019	-2.03	-0.18	-3.11	0.007	-5.36	-0.85
Stay-at-home housewife	-0.92	0.015	-1.66	-0.18	-2.55	0.020	-4.69	-0.40
Full time student	-0.43	0.301	-1.26	0.39	-0.41	0.713	-2.60	1.78
Working student	-0.33	0.452	-1.20	0.53	3.59	<0.001	1.73	5.45
Retired	-1.09	0.045	-2.16	-0.02	0.77	0.531	-1.65	3.20
Other	-1.09	0.026	-2.06	-0.13	-2.50	0.031	-4.76	-0.23
profession								
Currently not working	0	(base)			0	(base)		
Industry	2.20	<0.001	1.48	2.91	1.02	0.359	-1.16	3.20
Trade/commerce	-0.12	0.748	-0.88	0.63	2.56	0.024	0.34	4.79
Bank/finance	-0.22	0.733	-1.51	1.06	4.74	0.007	1.31	8.18
Other services	0.56	0.183	-0.26	1.38	1.16	0.306	-1.07	3.40
Retired	0.17	0.693	-0.69	1.04	2.52	0.045	0.06	4.99
Freelance Professional	0.26	0.573	-0.64	1.16	1.49	0.237	-0.97	3.95
Other	0.65	0.043	0.02	1.27	2.07	0.057	-0.06	4.21
income_per (min. wage)								
0	0	(base)			0	(base)		
1	0.80	0.042	0.03	1.57	-3.14	0.004	-5.29	-0.99
2	1.39	<0.001	0.64	2.13	-2.66	0.012	-4.72	-0.59
3 – 4	0.37	0.349	-0.40	1.14	-2.67	0.011	-4.73	-0.61
5 – 6	-0.51	0.205	-1.37	0.36	-4.41	<0.001	-6.62	-2.19
7 – 8	-1.83	<0.001	-2.84	-0.81	-3.94	0.004	-6.63	-1.26
9 – 10	-1.43	0.013	-2.55	-0.30	-4.31	0.002	-7.08	-1.53
11 – 12	-2.11	0.001	-3.38	-0.85	-5.11	0.001	-8.20	-2.02
13 – 14	-1.81	<0.001	-2.78	-0.84	-4.89	<0.001	-7.57	-2.21
_cons	5.13	<0.001	4.32	5.94	6.11	<0.001	3.86	8.36

*NS: No statistically significant (p-value <0.05)

8.2. Puebla

1994					2011				
Number of obs		14719			Number of obs		18324		
F(35. 14683)		60.05			F(30. 18293)		76.32		
Prob > F		<0.001			Prob > F		<0.001		
R-squared		0.1252			R-squared		0.1112		
Adj R-squared		0.1231			Adj R-squared		0.1098		
Root MSE		7.1311			Root MSE		7.3933		
PT_km	Coef.	P>t	[95% Conf.	Interval]	PT_km	Coef.	P>t	[95% Conf.	Interval]
zone					zone				
Center	0				Center	0			
Inner suburbs	1.90	<0.001	1.64	2.17	Inner suburbs	1.53	<0.001	1.26	1.80
Outer suburbs	2.55	<0.001	2.24	2.86	Outer suburbs	2.72	<0.001	2.43	3.01
mot					mot				
0	0				0	0			
1	-0.98	<0.001	-1.25	-0.71	1	-1.55	<0.001	-1.80	-1.29
2	-1.57	<0.001	-2.04	-1.09	2	-2.14	<0.001	-2.73	-1.54
≥3	-2.41	<0.001	-3.06	-1.76	≥3	-4.39	<0.001	-5.75	-3.03
dr_license					dr_license				
No	0				No	0			
Yes	-2.19	<0.001	-2.55	-1.83	Yes	-1.81	<0.001	-2.18	-1.45
age_cat					age_cat				
5 - 10 years	-5.26	<0.001	-6.00	-4.52	5 - 10 years	-5.73	<0.001	-6.44	-5.01
11 - 17 years	-3.76	<0.001	-4.40	-3.12	11 - 17 years	-4.06	<0.001	-4.67	-3.44
18 - 23 years	-0.72	0.007	-1.25	-0.20	18 - 23 years	0.25	0.311	-0.23	0.73
24 - 33 years	0.01	0.952	-0.41	0.44	24 - 33 years	0.51	0.010	0.12	0.90
34 - 43 years	0				34 - 43 years	0			
44 - 53 years	-0.51	0.045	-0.99	-0.01	44 - 53 years	0.17	0.418	-0.24	0.57
54 - 63 years	-0.87	0.003	-1.45	-0.29	54 - 63 years	0.34	0.167	-0.14	0.81
64 - 73 years	-1.20	0.001	-1.94	-0.47	64 - 73 years	-0.27	0.389	-0.89	0.35
≥ 74 years	-2.12	<0.001	-3.04	-1.21	≥ 74 years	-0.70	0.094	-1.53	0.12
gender					gender				
*NS					*NS				
family_role					family_role				
Head of HH	0				Father	0			
Wife/husband	0.02	0.943	-0.46	0.49	Mother	-0.41	0.061	-0.84	0.02
Son/Daughter	0.65	0.004	0.21	1.09	Son/Daughter	0.19	0.370	-0.22	0.60
Other relatives	0.23	0.42	-0.33	0.8	Other relatives	-1.49	<0.001	-2.15	-0.84
Housemaid	-0.45	0.675	-2.56	1.66	•NA				
Other relationship	0.34	0.422	-0.50	1.18	Other relationship	-0.51	0.238	-1.36	0.34
Other non-relatives	-1.23	0.069	-2.55	0.09	Other non-relatives	-0.09	0.726	-0.56	0.39
activity					activity				
Worker	0				Worker	0			
Unemployed	-2.46	<0.001	-3.34	-1.59	Unemployed	-1.84	<0.001	-2.61	-1.08
Stay-at-home	0.98	<0.001	0.52	1.43	Maid	-2.36	<0.001	-2.72	-2.01
Student	1.64	0.566	-3.97	7.25	Full time student	0.82	0.001	0.35	1.30
Military service	-1.98	<0.001	-2.84	-1.21	Working student	1.24	0.101	-0.24	2.72
Retired	-3.63	<0.001	-4.05	-3.21	Retired	-1.98	<0.001	-2.73	-1.23
Other	-3.33	<0.001	-4.35	-2.31	Other	-2.14	<0.001	-3.26	-1.01
education					education				
None	0				None	0			
Elementary NC ‡	0.02	0.952	-0.52	0.55	Kinder garden	-0.01	0.989	-0.89	0.88
Elementary C †	0.89	0.001	0.35	1.44	Elementary school	0.56	0.081	-0.07	1.20
Technical 3 years	2.51	<0.001	1.72	3.31	•NA				
Middle school	2.30	<0.001	1.73	2.88	Middle school	0.98	0.003	0.33	1.64
Technical 5 years	2.84	<0.001	1.98	3.69	•NA				
High school	2.79	<0.001	2.16	3.43	High school	1.98	<0.001	1.30	2.65
Teacher training system	2.59	<0.001	1.53	3.66	•NA				
Higher education	1.78	<0.001	1.11	2.45	Higher education	2.21	<0.001	1.51	2.91
Income/hh					Income/hh				
•NA					*NS				
_cons	4.38	<0.001	3.73	5.03	_cons	4.63	<0.001	3.88	5.39

‡ NC: Not completed; † C: Completed.

*NS: No statistically significant (p-value <0.05 ; •NA: Not available data in HTS)

8.3. Lille

	1987				1998				2006			
	Number of obs 10003.00				Number of obs 10300				Number of obs 8984			
	F(30. 9972) 25.97				F(33. 10266) 84.32				F(29. 8954) 69.01			
	Prob > F <0.001				Prob > F <0.001				Prob > F <0.001			
	R-squared 0.0725				R-squared 0.2132				R-squared 0.1827			
	Adj R-squared 0.0697				Adj R-squared 0.2107				Adj R-squared 0.1800			
	Root MSE 3.6036				Root MSE 3.8669				Root MSE 4.9355			
PT_km	Coef.	P>t	[95% Conf.	Interval]	Coef.	P>t	[95% Conf.	Interval]	Coef.	P>t	[95% Conf.	Interval]
zone												
Center					0				0			
Inner suburbs	*NS				0.08 0.496 -0.14 0.30				-0.06 0.690 -0.37 0.24			
Outer suburbs					0.52 <0.001 0.29 0.75				0.33 0.046 0.01 0.65			
vehicles/hh												
0	0				0				0			
1	-0.71	<0.001	-0.92	-0.49	-0.18	0.140	-0.42	0.06	-0.39	0.026	-0.73	-0.05
2	-1.19	<0.001	-1.45	-0.93	-0.38	0.005	-0.65	-0.11	-0.76	<0.001	-1.15	-0.38
≥3	-1.50	<0.001	-1.95	-1.04	-0.64	0.001	-1.03	-0.26	-1.36	<0.001	-1.91	-0.80
dr_license												
No	0				0				0			
Supervised_dr	• NA				1.98 <0.001 1.03 2.93				2.82 <0.001 1.79 3.85			
Yes	-0.54	<0.001	-0.76	-0.315	-0.82	<0.001	-1.06	-0.58	-0.74	<0.001	-1.07	-0.41
transport_card												
No	• NA				0				0			
Yes. paid					4.96 <0.001 4.64 5.27				4.72 <0.001 4.37 5.07			
Yes. free					3.62 <0.001 3.32 3.93				3.30 <0.001 2.89 3.71			
age_cat												
5-10 years	-3.00	<0.001	-3.65	-2.35	-2.66	<0.001	-3.33	-1.98	-3.69	<0.001	-4.67	-2.70
11-17 years	-1.56	<0.001	-2.19	-0.93	-1.73	<0.001	-2.37	-1.08	-2.48	<0.001	-3.42	-1.54
18-23 years	0.76	<0.001	0.37	1.15	0.18	0.389	-0.23	0.59	0.15	0.614	-0.43	0.73
24-33 years	-0.07	0.564	-0.32	0.18	0.02	0.866	-0.25	0.30	0.07	0.690	-0.29	0.44
34-43 years	0				0				0			
44-53 years	0.15	0.313	-0.14	0.44	0.06	0.682	-0.22	0.34	0.04	0.824	-0.34	0.43
54-63 years	0.11	0.479	-0.20	0.42	-0.18	0.334	-0.54	0.18	-0.34	0.147	-0.80	0.12
64-73 years	-0.10	0.664	-0.56	0.35	-0.99	<0.001	-1.49	-0.48	-0.74	0.047	-1.46	-0.01
≥74 years	-0.10	0.684	-0.59	0.39	-1.44	<0.001	-1.99	-0.90	-1.27	0.001	-2.03	-0.51
gender												
Male	*NS				*NS				0			
Female									-0.54 <0.001 -0.79 -0.29			
family_role												
Head of HH	0				0				0			
Wife/husband	-0.21	0.059	-0.42	0.01	*NS				0.26 0.106 -0.06 0.58			
Son/Daughter	0.63	<0.001	0.28	0.99					1.01 <0.001 0.49 1.53			
Other relatives	0.21	0.471	-0.36	0.79					0.15 0.707 -0.63 0.92			
activity												
Full time worker	0				0				0			
Part-time worker	0.50	0.005	0.15	0.85	0.03	0.835	-0.29	0.36	0.07	0.763	-0.37	0.50
Internship training	• NA				0.42 0.373 -0.50 1.34				1.00 0.057 -0.03 2.03			
Student	0.00	0.998	-2.11	2.11	2.36	<0.001	1.11	3.61	2.06	<0.001	1.47	2.65
School (up to high-school)	1.45	0.217	-0.85	3.74	-0.43	0.531	-1.76	0.91	1.26	0.004	0.41	2.11
Unemployed	-0.40	0.032	-0.77	-0.04	-0.09	0.626	-0.43	0.26	-0.49	0.037	-0.95	-0.03
Retired	-0.70	<0.001	-1.08	-0.31	-0.23	0.302	-0.67	0.21	-0.62	0.041	-1.22	-0.03
Stay-at-home	-0.60	0.001	-0.95	-0.26	-0.58	0.005	-0.98	-0.18	-1.01	<0.001	-1.52	-0.51
Other	-1.20	<0.001	-1.81	-0.58	-0.28	0.385	-0.90	0.35	-0.85	0.028	-1.60	-0.09
profession												
Unemployed/inactives	0				0							
Small-medium business	-0.07	0.771	-0.57	0.42	0.13	0.653	-0.45	0.72				
Freelance profession	0.35	0.145	-0.12	0.83	0.24	0.350	-0.26	0.75				
Technicians	0.32	0.144	-0.11	0.74	0.17	0.473	-0.29	0.64	*NS			
Employees	0.60	0.002	0.22	0.98	-0.02	0.938	-0.45	0.42				
Working class	0.04	0.840	-0.34	0.42	-0.28	0.205	-0.72	0.15				
School (up to high school)	0.01	0.991	-2.30	2.33	1.89	0.006	0.55	3.23				
Student	2.20	0.046	0.04	4.36	-0.58	0.377	-1.88	0.71				
education	×				*NS				*NS			
income_hh	• NA				*NS				*NS			
_cons	1.26	<0.001	0.79	1.73	1.34	<0.001	0.80	1.88	2.33	<0.001	1.84	2.82

*NS: No statistically significant (p-value <0.05) ; •NA: Not available data in HTS; ×: Not included due to collinearity

8.4. Paris Region

	1991				2001			
	Number of obs				Number of obs			
	25350.00				23607.00			
	F(33. 25316)		326.50		F(21. 23585)		489.98	
	Prob > F		0.00		Prob > F		0.00	
	R-squared		0.30		R-squared		0.30	
	Adj R-squared		0.30		Adj R-squared		0.30	
	Root MSE		11.95		Root MSE		11.54	
PT_km	Coef.	P>t	[95% Conf.	Interval]	Coef.	P>t	[95% Conf.	Interval]
zone								
Center	0.00				0.00			
Inner suburbs	1.93	<0.001	1.50	2.35	2.06	<0.001	1.64	2.47
Outer suburbs	5.82	<0.001	5.39	6.26	4.96	<0.001	4.54	5.37
mot								
0	0.00							
1	-0.33	0.163	-0.79	0.13				*NS
2	-0.91	0.002	-1.49	-0.34				
≥3	-1.45	0.001	-2.33	-0.57				
dr_license								
No	0.00				0.00			
Supervised_dr	•NA				-1.32	0.258	-3.60	0.97
Yes	0.67	0.003	0.23	1.11	0.71	0.001	0.28	1.14
transport_card								
No	0.00				0.00			
Regular paid card	17.20	<0.001	16.81	17.59	17.97	<0.001	17.57	18.38
Solidarity card	13.63	<0.001	11.46	15.79	8.67	<0.001	4.54	12.79
Student card	•NA				12.25	<0.001	11.45	13.04
Other	6.42	<0.001	5.69	7.15	6.33	<0.001	5.60	7.07
age_cat								
5-10 years	-3.22	<0.001	-4.39	-2.05	-3.07	<0.001	-4.24	-1.90
11-17 years	-3.51	<0.001	-4.63	-2.39	-3.81	<0.001	-4.89	-2.73
18-23 years	-0.16	0.706	-0.97	0.66	-0.37	0.388	-1.20	0.47
24-33 years	-0.27	0.291	-0.76	0.23	-0.14	0.587	-0.66	0.37
34-43 years	0.00				0.00			
44-53 years	-0.27	0.318	-0.81	0.26	0.02	0.926	-0.49	0.54
54-63 years	-0.12	0.705	-0.77	0.52	-0.01	0.964	-0.62	0.59
64-73 years	-0.86	0.074	-1.80	0.08	0.10	0.842	-0.86	1.05
≥74 years	-1.17	0.026	-2.20	-0.14	-0.13	0.806	-1.15	0.89
gender								
Male					0.00			
Female	-0.44	0.006	-0.74	-0.12	-0.37	0.018	-0.68	-0.06
family_role								
Reference person								
Wife/Husband								
Child								*NS
Other relative								*NS
Housemaid								
Other non relative								
activity								
Active worker	0.00				0.00			
Student	0.34	0.423	-0.48	1.16	1.91	<0.001	1.00	2.83
Retired	-0.61	0.137	-1.41	0.19	-1.49	<0.001	-2.30	-0.68
Unemployed	-1.06	0.010	-1.87	-0.26	-0.11	0.771	-0.85	0.63
Other inactive	-0.94	0.003	-1.57	-0.32	-1.34	<0.001	-2.01	-0.68
education								
			×				×	
income/hh								
1	0.00							
2	0.67	0.047	0.01	1.34				
3	1.07	0.003	0.37	1.77				
4	1.30	0.001	0.53	2.06				*NS
5	1.52	<0.001	0.73	2.31				
6	1.95	<0.001	1.05	2.85				
7	2.13	0.004	0.68	3.58				
8	0.90	0.019	0.15	1.66				
cons								
	-1.59	<0.001	-2.42	-0.77	-1.54	<0.001	-2.21	-0.86

*NS: No statistically significant (p-value <0.05) ; •NA: Not available data in HTS ; × : Not included due to collinearity

Annex 9.

Multiple linear regression for all modes kilometers

9.1. Juarez

	1996				2006			
	Number of obs	=	13969		Number of obs	=	4286	
	F(41, 13927)	=	42.83		F(41, 4244)	=	18.88	
	Prob > F	=	<0.001		Prob > F	=	<0.001	
	R-squared	=	0.112		R-squared	=	0.1543	
	Adj R-squared	=	0.1094		Adj R-squared	=	0.1461	
	Root MSE	=	10.033		Root MSE	=	12.243	
Total_km	Coef.	P>t	[95% Conf. Interval]	Coef.	P>t	[95% Conf. Interval]		
zone								
Center	0	(base)		0	(base)			
Inner suburbs	1.56	<0.001	1.13 1.98	2.95	<0.001	1.90 4.00		
Outer suburbs	3.67	<0.001	3.16 4.18	4.18	<0.001	3.04 5.32		
class_vehicle/hh								
0	0	(base)		0	(base)			
1	0.63	0.004	0.20 1.05	0.77	0.121	-0.20 1.75		
2	1.92	<0.001	1.44 2.40	2.35	<0.001	1.30 3.40		
≥ 3	2.10	<0.001	1.43 2.76	1.50	0.035	0.10 2.89		
age								
5 – 10 years	-3.45	<0.001	-4.50 -2.40	-4.98	<0.001	-7.27 -2.70		
11 – 17 years	-1.85	<0.001	-2.83 -0.87	-2.75	0.01	-4.84 -0.66		
18 – 23 years	-0.04	0.928	-0.81 0.74	0.43	0.597	-1.18 2.05		
24 – 33 years	0.37	0.174	-0.16 0.91	-0.35	0.584	-1.61 0.91		
34 – 43 years	0	(base)		0	(base)			
44 – 53 years	-0.74	0.04	-1.45 -0.03	-3.22	<0.001	-4.67 -1.77		
54 – 63 years	-1.47	0.002	-2.42 -0.52	-4.08	<0.001	-5.91 -2.24		
64 – 73 years	-2.68	<0.001	-3.99 -1.37	-5.65	<0.001	-7.78 -3.52		
≥ 74 years	-4.07	<0.001	-5.91 -2.23	-5.74	<0.001	-8.63 -2.85		
gender			*NS			*NS		
family_role								
Head of HH	0	(base)		0	(base)			
Wife/husband	-1.22	<0.001	-1.84 -0.59	-0.07	0.923	-1.47 1.33		
Son/Daughter	-2.07	<0.001	-2.82 -1.32	-2.26	0.001	-3.65 -0.87		
Other relatives	-2.15	<0.001	-3.08 -1.21	-2.72	<0.001	-4.25 -1.19		
Housemaid	-7.69	<0.001	-10.69 -4.69	-13.71	0.026	-25.80 -1.62		
Guest	-2.90	0.02	-5.34 -0.47	-5.74	0.301	-16.64 5.15		
Other non-relatives	-3.73	0.006	-6.41 -1.05	-3.83	0.034	-7.39 -0.28		
activity								
Worker	0	(base)		0	(base)			
Unemployed	-2.31	0.001	-3.64 -0.99	-3.40	0.104	-7.49 0.70		
Stay-at-home housewife	-2.73	<0.001	-3.80 -1.67	-3.28	0.098	-7.17 0.61		
Full time student	-0.57	0.339	-1.75 0.60	0.72	0.724	-3.25 4.69		
Working student	0.27	0.667	-0.97 1.51	9.81	<0.001	6.43 13.18		
Retired	-2.03	0.009	-3.57 -0.50	1.39	0.537	-3.01 5.79		
Other	-2.46	<0.001	-3.84 -1.08	-3.23	0.122	-7.34 0.87		
profession								
Currently not working	0	(base)		0	(base)			
Industry	1.62	0.002	0.60 2.64	7.97	<0.001	4.02 11.92		
Trade/commerce	-0.03	0.958	-1.11 1.05	4.47	0.03	0.43 8.50		
Bank/finance	-0.25	0.793	-2.09 1.60	9.33	0.003	3.10 15.56		
Other services	0.53	0.382	-0.65 1.71	3.38	0.102	-0.67 7.42		
Retired	2.06	0.001	0.82 3.29	14.34	<0.001	9.86 18.81		
Freelance Professional	0.88	0.181	-0.41 2.17	6.33	0.005	1.87 10.79		
Other	-0.12	0.788	-1.02 0.77	4.41	0.026	0.53 8.28		
income_per (min. wage)								
0	0	(base)		0	(base)			
1	-0.05	0.934	-1.15 1.06	-3.29	0.098	-7.19 0.61		
2	1.11	0.042	0.04 2.18	-3.48	0.068	-7.23 0.26		
3 – 4	1.71	0.003	0.60 2.82	-2.45	0.198	-6.18 1.28		
5 – 6	1.88	0.003	0.64 3.11	-4.79	0.019	-8.81 -0.77		
7 – 8	1.22	0.099	-0.23 2.68	0.74	0.766	-4.14 5.61		
9 – 10	1.19	0.147	-0.42 2.81	0.46	0.858	-4.57 5.49		
11 – 12	1.66	0.073	-0.16 3.47	-1.90	0.506	-7.50 3.70		
13 – 14	1.10	0.122	-0.29 2.48	-0.84	0.733	-5.70 4.01		
Cons	9.21	<0.001	8.05 10.37	8.42	<0.001	4.38 12.46		

*NS: No statistically significant (p-value <0.05)

9.2. Puebla

1994					2011					
	Number of obs		14719			Number of obs		16651		
	F(35. 14683)		68.35			F(27. 18296)		70.93		
	Prob > F		<0.001			Prob > F		<0.001		
	R-squared		0.1401			R-squared		0.1141		
	Adj R-squared		0.1381			Adj R-squared		0.1152		
	Root MSE		8.6322			Root MSE		8.3257		
Total_km	Coef.	P>t	[95% Conf.	Interval]	Total_km	Coef.	P>t	[95% Conf.	Interval]	
zone					zone					
Center	0				Center	0				
Inner suburbs	2.16	<0.001	1.85	2.48	Inner suburbs	1.85	<0.001	1.54	2.17	
Outer suburbs	4.89	<0.001	4.51	5.27	Outer suburbs	3.71	<0.001	3.36	4.05	
mot					mot					
0	0									
1	0.38	0.022	0.05	0.71						
2	1.50	<0.001	0.93	2.08						
≥3	1.05	0.009	0.26	1.84						
dr_license					dr_license					
No	0				No	0				
Yes	0.89	<0.001	0.46	1.33	Yes	0.43	0.041	0.02	0.84	
age_cat					age_cat					
5 - 10 years	-4.48	<0.001	-5.37	-3.59	5 - 10 years	-5.28	<0.001	-6.11	-4.44	
11 - 17 years	-2.89	<0.001	-3.67	-2.12	11 - 17 years	-3.60	<0.001	-4.33	-2.88	
18 - 23 years	-0.75	0.020	-1.39	-0.12	18 - 23 years	0.26	0.367	-0.30	0.82	
24 - 33 years	-0.57	0.029	-1.09	-0.06	24 - 33 years	0.50	0.032	0.04	0.95	
34 - 43 years	0				34 - 43 years	0.00				
44 - 53 years	-0.43	0.163	-1.02	0.17	44 - 53 years	-0.03	0.900	-0.51	0.45	
54 - 63 years	-1.35	<0.001	-2.05	-0.64	54 - 63 years	-0.07	0.804	-0.63	0.49	
64 - 73 years	-1.66	<0.001	-2.55	-0.77	64 - 73 years	-0.51	0.169	-1.25	0.22	
≥ 74 years	-2.41	<0.001	-3.52	-1.31	≥ 74 years	-1.33	0.008	-2.31	-0.34	
gender					gender					
			*NS					*NS		
family_role					family_role					
Head of HH	0				Father	0				
Wife/husband	-0.45	0.126	-1.02	0.13	Mother	-0.94	<0.001	-1.44	-0.43	
Son/Daughter	-0.54	0.047	-1.07	-0.01	Son/Daughter	-0.86	0.001	-1.35	-0.38	
Other relatives	-0.93	0.008	-1.61	-0.24	Other relatives	-2.19	<0.001	-2.96	-1.42	
Housemaid	-3.47	0.008	-6.02	-0.91	•NA					
Other relationship	-0.49	0.341	-1.51	0.52	Other relationship	-0.77	0.136	-1.79	0.24	
Other non-relatives	-3.44	<0.001	-5.04	-1.83	Other non-relatives	-1.14	<0.001	-1.70	-0.58	
activity					activity					
Worker	0				Worker	0				
Unemployed	-3.57	<0.001	-4.62	-2.51	Unemployed	-2.40	<0.001	-3.29	-1.50	
Stay-at-home	-4.04	<0.001	-4.54	-3.53	Unemployed	-2.88	<0.001	-3.30	-2.46	
Student	0.73	0.010	0.18	1.28	Maid	-2.88	<0.001	-3.30	-2.46	
Military service	-1.06	0.760	-7.85	5.73	Full time student	0.41	0.145	-0.14	0.97	
Retired	-2.81	<0.001	-3.73	-1.89	Working student	1.38	0.121	-0.36	3.12	
Other	-3.86	<0.001	-5.09	-2.63	Retired	-2.91	<0.001	-3.81	-2.01	
					Other	-2.23	0.001	-3.56	-0.89	
education					education					
None	0				None	0.00				
Elementary NC ‡	0	0.997	-0.65	0.64	Kinder garden	-0.08	0.876	-1.10	0.94	
Elementary C †	0.81	0.016	0.15	1.48	Elementary school	0.49	0.188	-0.24	1.22	
Technical 3 years	2.86	<0.001	1.90	3.83	•NA					
Middle school	2.45	<0.001	1.76	3.14	Middle school	0.93	0.017	0.17	1.69	
Technical 5 years	3.57	<0.001	2.53	4.60	•NA					
High school	3.57	<0.001	2.80	4.34	High school	1.80	<0.001	1.02	2.59	
Teacher training system	3.06	<0.001	1.77	4.35	•NA					
Higher education	3.22	<0.001	2.42	4.03	Higher education	2.86	<0.001	2.04	3.68	
income_hh					income_hh					
			•NA		1	0				
					2	0.35	0.046	0.01	0.69	
					3	0.66	0.001	0.26	1.06	
					4	0.59	0.064	-0.03	1.21	
					5	0.54	0.325	-0.54	1.63	
_cons	5.37	<0.001	4.58	6.15	_cons	5.68	<0.001	4.83	6.53	

‡ NC: Not completed; † C: Completed; *NS: No statistically significant (p-value <0.05) ; •NA: Not available data in HTS

9.3. Lille

	1987				1998				2006			
	Number of obs		10003.00		Number of obs		10300.00		Number of obs		7790	
	F(32. 9970)		83.87		F(47. 10252)		61.09		F(43. 7746)		48.89	
	Prob > F		<0.001		Prob > F		<0.001		Prob > F		<0.001	
	R-squared		0.2121		R-squared		0.2188		R-squared		0.2135	
	Adj R-squared		0.2096		Adj R-squared		0.2173		Adj R-squared		0.2091	
Total_km	Coef.	P>t	[95% Conf.	Interval]	Coef.	P>t	[95% Conf.	Interval]	Coef.	P>t	[95% Conf.	Interval]
zone												
Center	0				0				0			
Inner suburbs	1.61	<0.001	1.05	2.16	2.06	<0.001	1.41	2.72	2.07	<0.001	1.31	2.83
Outer suburbs	3.98	<0.001	3.41	4.56	4.80	<0.001	4.19	5.52	5.09	<0.001	4.29	5.89
vehicles/hh												
0	0				0				0			
1	1.53	<0.001	0.94	2.11	2.05	<0.001	1.27	2.83	2.07	<0.001	1.19	2.95
2	3.27	<0.001	2.56	3.98	4.61	<0.001	3.72	5.56	3.63	<0.001	2.61	4.66
≥3	4.28	<0.001	3.05	5.50	6.09	<0.001	4.82	7.36	4.98	<0.001	3.56	6.41
dr_license												
No	0				0				0			
Supervised_dr	• NA				1.70	0.235	-1.10	4.52	2.42	0.054	-0.44	4.85
Yes	3.33	<0.001	2.73	3.92	2.92	<0.001	2.19	3.65	2.14	<0.001	1.63	3.32
transport_card												
No			• NA		0				0			
Yes. paid					2.85	<0.001	1.91	3.79	1.76	<0.001	1.01	2.72
Yes. free					2.41	<0.001	1.52	3.31	1.67	0.001	0.64	2.69
age_cat												
5-10 years	-2.61	0.003	-4.36	-0.86	-2.96	0.005	-5.01	-0.91	-6.21	<0.001	-8.63	-3.78
11-17 years	-0.55	0.525	-2.26	1.15	-0.73	0.465	-2.70	1.23	-4.20	<0.001	-6.53	-1.87
18-23 years	1.52	0.004	0.47	2.56	-0.24	0.714	-1.05	1.54	1.35	0.064	-0.08	2.79
24-33 years	0.45	0.190	-0.22	1.13	-0.14	0.732	-0.67	0.96	0.83	0.068	-0.06	1.72
34-43 years	0				0				0			
44-53 years	-1.20	0.002	-1.98	-0.43	-2.52	<0.001	-3.35	-1.69	-0.66	0.162	-1.60	0.26
54-63 years	-1.83	<0.001	-2.67	-0.99	-3.39	<0.001	-4.46	-2.32	-1.84	0.001	-2.98	-0.71
64-73 years	-2.66	<0.001	-3.88	-1.43	-4.91	<0.001	-6.41	-3.40	-2.46	0.009	-4.32	-0.61
≥74 years	-3.44	<0.001	-4.75	-2.12	-7.07	<0.001	-8.69	-5.46	-4.39	<0.001	-6.40	-2.37
gender												
Male			*NS		0				0			
Female					-0.72	0.011	-1.27	-0.16	-1.11	<0.001	-1.72	-0.49
family_role												
Head of HH	0				0				0			
Wife/husband	-1.61	<0.001	-2.19	-1.03	-1.58	<0.001	-2.32	-0.84	-1.05	0.010	-1.84	-0.25
Son/Daughter	-1.10	0.023	-2.05	-0.15	-1.34	0.015	-2.43	-0.25	0.18	0.784	-1.12	1.48
Other relatives	-2.41	0.002	-3.95	-0.86	-0.47	0.577	-2.15	1.19	-1.53	0.140	-3.56	0.50
activity												
Full time worker	0				0				0			
Part-time worker	-0.67	0.166	-1.62	0.28	-1.54	0.002	-2.53	-0.55	-1.10	0.032	-2.18	-0.09
Internship training	• NA				0.51	0.709	-2.19	3.23	-2.33	0.111	-5.19	0.05
Student	-1.07	0.712	-6.75	4.61	1.85	0.325	-1.83	5.55	-1.28	0.298	-3.71	1.13
School (up to high-school)	-4.21	0.182	-10.39	1.97	-3.20	0.111	-7.13	0.73	-2.61	0.023	-5.00	-0.37
Unemployed	-3.76	<0.001	-4.75	-2.78	-3.58	<0.001	-4.62	-2.54	-4.01	0.000	-5.21	-2.81
Retired	-3.84	<0.001	-4.88	-2.80	-3.62	<0.001	-4.92	-2.33	-4.18	0.000	-5.70	-2.67
Stay-at-home	-3.56	<0.001	-4.48	-2.64	-3.67	<0.001	-4.90	-2.43	-4.08	0.000	-5.54	-2.62
Other	-6.59	<0.001	-8.23	-4.94	-5.37	<0.001	-7.21	-3.52	-4.91	0.000	-6.91	-2.92
profession												
Unemployed/inactives	0				0							
Small-medium business	-1.35	0.049	-2.69	-0.01	3.61	<0.001	1.88	5.34				
Freelance profession	2.27	0.001	0.99	3.54	2.26	0.004	0.74	3.78				
Technicians	1.67	0.004	0.53	2.82	1.26	0.079	-0.14	2.66			*NS	
Employees	1.03	0.048	0.01	2.06	0.16	0.800	-1.12	1.45				
Working class	-0.16	0.764	-1.17	0.86	-0.07	0.916	-1.37	1.23				
School (up to high school)	1.79	0.574	-4.44	8.01	-1.41	0.484	-5.37	2.54				
Student	0.69	0.816	-5.13	6.51	-2.43	0.210	-6.25	1.37				
education												
No education					0				0			
Still at school					1.99	0.128	-0.57	4.56	-0.41	0.730	-2.75	1.92
Elementary school					0.13	0.875	-1.52	1.80	-0.61	0.573	-2.74	1.51
Middle/Secondary school			x		1.17	0.162	-0.47	2.83	0.23	0.817	-1.73	2.19
Professional training					-0.54	0.666	-3.01	1.92	-0.17	0.923	-3.65	3.30
High-school					2.62	0.003	0.90	4.34	•NA			
Higher education					2.32	0.012	0.51	4.14	2.21	0.034	0.17	4.25
income_hh	1				0				0			
2					1.12	0.065	-0.06	2.30	0.55	0.238	-0.36	1.47
3					0.86	0.160	-0.34	2.08	2.40	<0.001	1.37	3.43
4					1.71	0.006	0.48	2.93	1.32	0.030	0.13	2.52
5					1.21	0.061	-0.05	2.46	2.69	<0.001	1.38	4.05
6			•NA		1.24	0.065	-0.07	2.55	3.38	<0.001	1.62	5.14
7					1.19	0.073	-0.11	2.49				
8					2.77	<0.001	1.39	4.14				
9					2.01	0.016	0.36	3.64				
10					3.32	0.015	0.63	6.00				
_cons	9.88	<0.001	8.56	11.20	7.01	<0.001	5.20	8.82	8.19	<0.001	6.17	10.21

9.4. Paris Region

	1991				2001			
			Number of obs				Number of obs	
	F(41. 23466)		25301.00		F(41. 23466)		23508.00	
	Prob > F		0.00		Prob > F		0.00	
	R-squared		0.25		R-squared		0.23	
	Adj R-squared		0.25		Adj R-squared		0.23	
Total_km	Coef.	P>t	[95% Conf.	Interval]	Coef.	P>t	[95% Conf.	Interval]
zone								
Center	0.00				0.00			
Inner suburbs	3.16	<0.001	2.50	3.82	3.46	<0.001	2.74	4.18
Outer suburbs	10.84	<0.001	10.16	11.52	10.97	<0.001	10.23	11.71
mot								
0	0.00				0.00			
1	3.33	<0.001	2.61	4.05	3.03	<0.001	2.29	3.77
2	6.92	<0.001	6.03	7.82	6.48	<0.001	5.56	7.39
≥3	9.20	<0.001	7.83	10.57	10.92	<0.001	9.60	12.23
dr_license								
No	0.00				0.00			
Supervised_dr	•NA				-0.76	0.688	-4.49	2.97
Yes	3.09	<0.001	2.39	3.80	3.66	<0.001	2.89	4.43
transport_card								
No	0.00				0.00			
Regular paid card	7.95	<0.001	7.35	8.56	7.10	<0.001	6.42	7.78
Solidarity card	4.44	0.010	1.04	7.83	3.86	0.273	-3.04	10.75
Student card	•NA				7.08	<0.001	5.77	8.38
Other	2.74	<0.001	1.61	3.88	2.91	<0.001	1.71	4.11
age_cat								
5-10 years	-11.30	<0.001	-13.13	-9.46	-8.45	<0.001	-10.53	-6.36
11-17 years	-9.81	<0.001	-11.57	-8.05	-8.45	<0.001	-10.40	-6.51
18-23 years	-1.09	0.094	-2.36	0.19	-1.57	0.044	-3.10	-0.05
24-33 years	0.39	0.326	-0.39	1.16	-0.14	0.754	-1.00	0.72
34-43 years	0.00				0.00			
44-53 years	-2.64	<0.001	-3.48	-1.80	-1.65	<0.001	-2.51	-0.80
54-63 years	-3.37	<0.001	-4.37	-2.37	-2.76	<0.001	-3.76	-1.76
64-73 years	-3.28	<0.001	-4.75	-1.82	-4.00	<0.001	-5.57	-2.43
≥74 years	-5.22	<0.001	-6.82	-3.61	-5.34	<0.001	-7.03	-3.64
gender								
Male	0.00				0.00			
Female	-2.51	<0.001	-3.11	-1.91	-2.29	<0.001	-2.92	-1.66
family_role								
Reference person	0.00				0.00			
Wife/Husband	-5.77	<0.001	-6.56	-4.99	-4.44	<0.001	-5.25	-3.63
Child	-4.04	<0.001	-5.23	-2.84	-4.44	<0.001	-5.70	-3.17
Other relative	-2.08	0.033	-3.98	-0.17	-3.03	0.007	-5.24	-0.83
Housemaid	-12.39	0.014	-22.31	-2.48	-1.38	0.901	-23.13	20.38
Other non relative	-3.45	0.005	-5.87	-1.02	-4.70	0.005	-7.95	-1.45
activity								
Active worker	0.00				0.00			
Student	-2.27	0.011	-4.03	-0.52	-3.00	0.002	-4.87	-1.13
Retired	-6.68	<0.001	-7.92	-5.43	-6.79	<0.001	-8.13	-5.46
Unemployed	-6.23	<0.001	-7.48	-4.98	-6.44	<0.001	-7.67	-5.21
Other inactive	-6.34	<0.001	-7.32	-5.37	-6.89	<0.001	-8.01	-5.78
education								
No education	0.00				0.00			
Elementary school	-0.48	0.467	-1.77	0.81	0.13	0.876	-1.54	1.80
Secondary school	1.39	0.036	0.09	2.69	2.47	0.003	0.84	4.09
Higher education	1.97	0.005	0.60	3.34	3.26	<0.001	1.58	4.94
Still at school	0.98	0.319	-0.95	2.92	1.98	0.057	-0.06	4.02
income/hh								
0					0.00			
1	0.00				1.55	0.481	-2.76	5.86
2	0.70	0.183	-0.33	1.74	1.52	0.482	-2.71	5.74
3	1.14	0.042	0.04	2.24	1.84	0.392	-2.38	6.06
4	2.33	<0.001	1.12	3.53	2.80	0.199	-1.47	7.06
5	2.35	<0.001	1.09	3.61	3.06	0.158	-1.19	7.31
6	3.10	<0.001	1.67	4.53	2.87	0.189	-1.41	7.16
7	1.73	0.136	-0.54	4.00	4.99	0.031	0.46	9.53
8	0.79	0.189	-0.39	1.97	2.54	0.240	-1.69	6.77
cons	9.50	<0.001	7.81	11.20	6.71	0.004	2.16	11.26

Annex 10. Per capita mobility projections (relative numbers)

Figure 1. Age-Cohort model forecasts, Juarez 2000-2050. Average distance travelled per day per person in veh-km by mode (base index=1 in 2000)

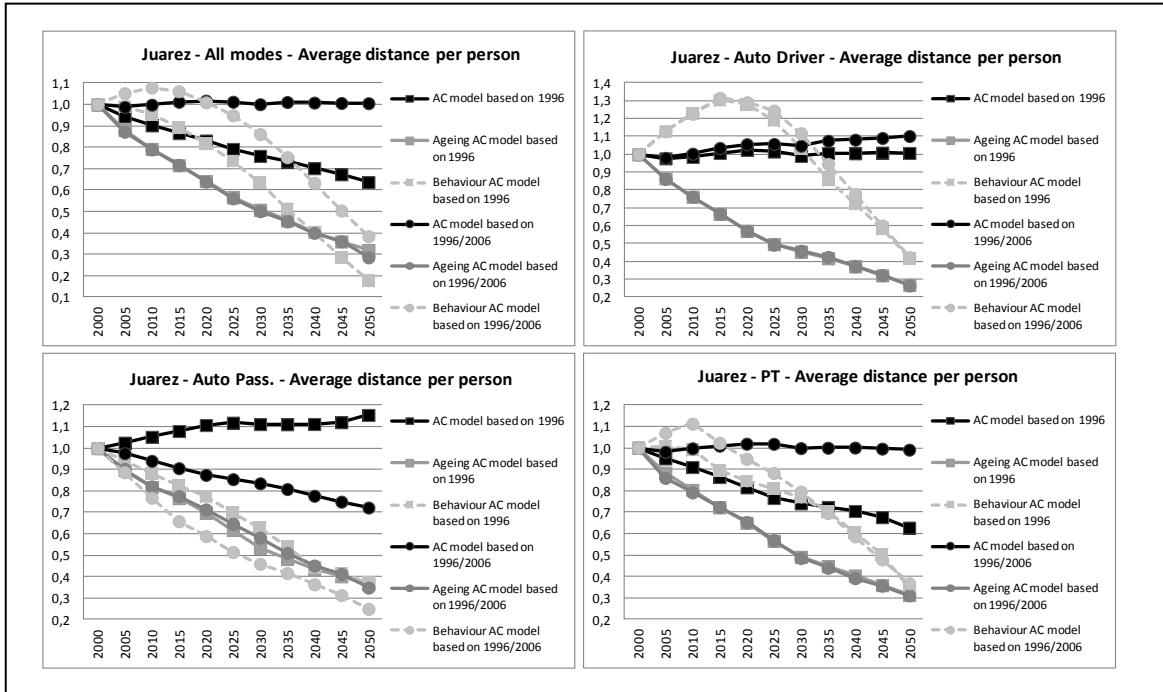


Figure 2. Age-Cohort model forecasts, Juarez 2000-2050. Average number of trips per day per person by mode (base index=1 in 2000)

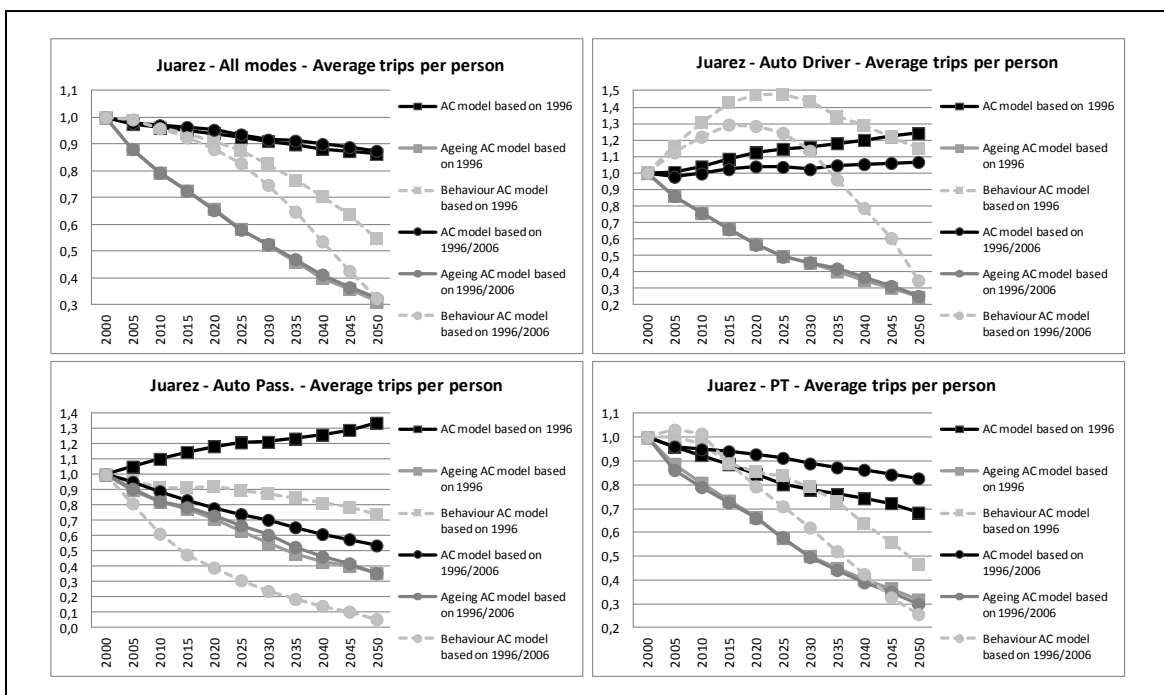


Figure 3. Age-Cohort model forecasts, Puebla 2000-2050. Average distance travelled per day per person in veh-km by mode (base index=1 in 2000)

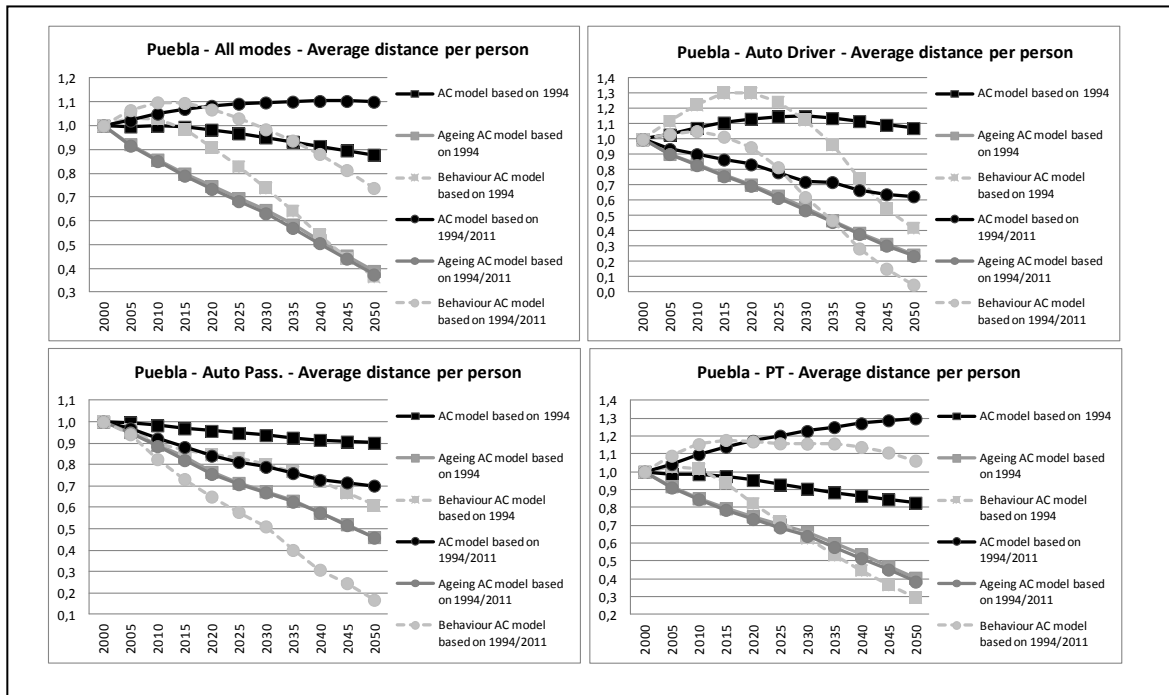


Figure 4. Age-Cohort model forecasts, Puebla 2000-2050. Average number of trips per day per person by mode (base index=1 in 2000)

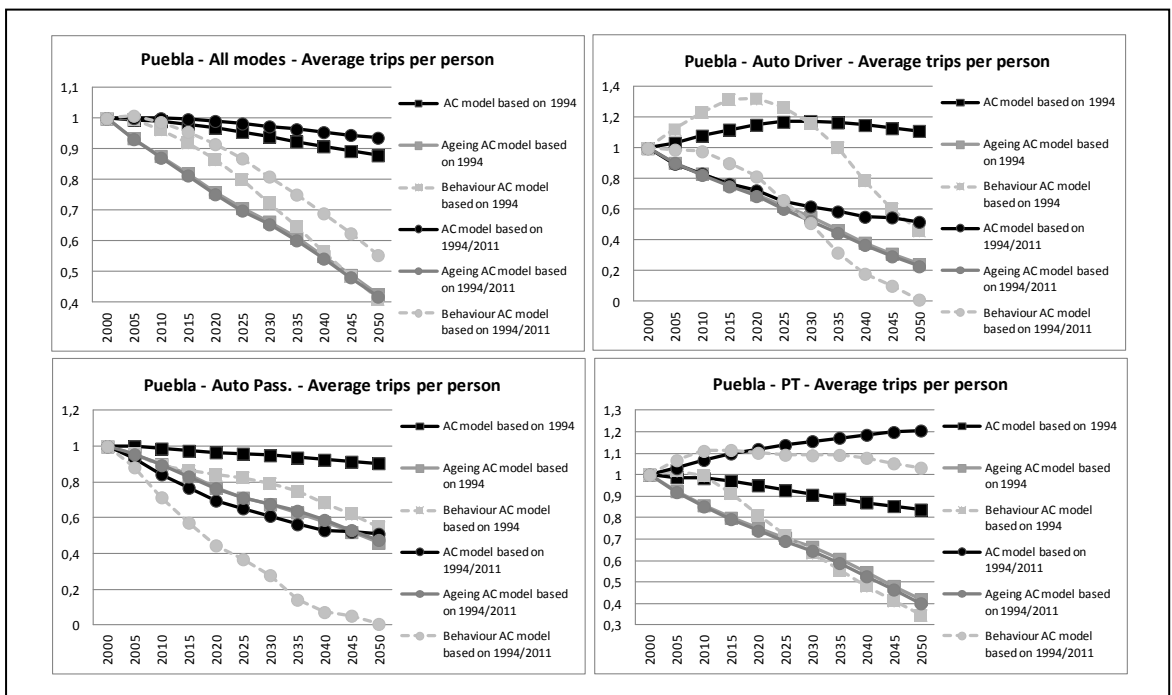


Figure 5. Age-Cohort model forecasts, Lille 2000-2030. Average distance travelled per day per person in veh-km by mode (base index=1 in 2000)

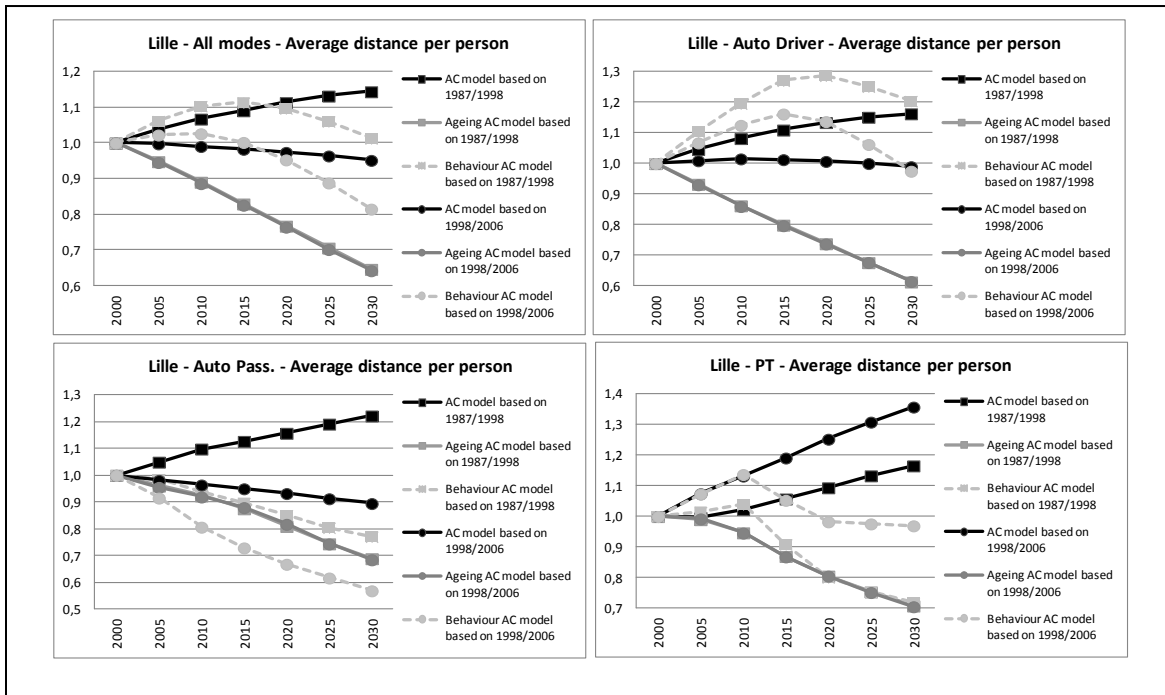
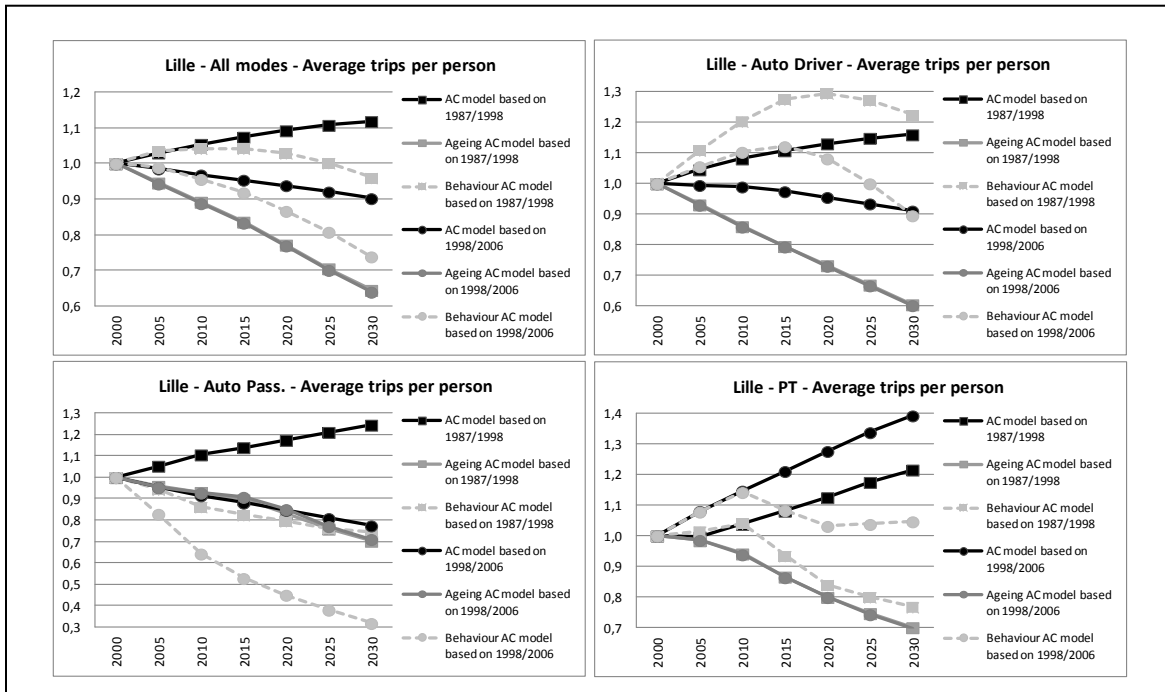


Figure 6. Age-Cohort model forecasts, Lille 2000-2030. Average number of trips per day per person by mode (base index=1 in 2000)



Annex 11. Global travel demand forecasts

Figure 1. Age-Cohort model forecasts, Juarez 2000-2050. Total distance travelled per day in veh-km by mode (base index=1 in 2000)

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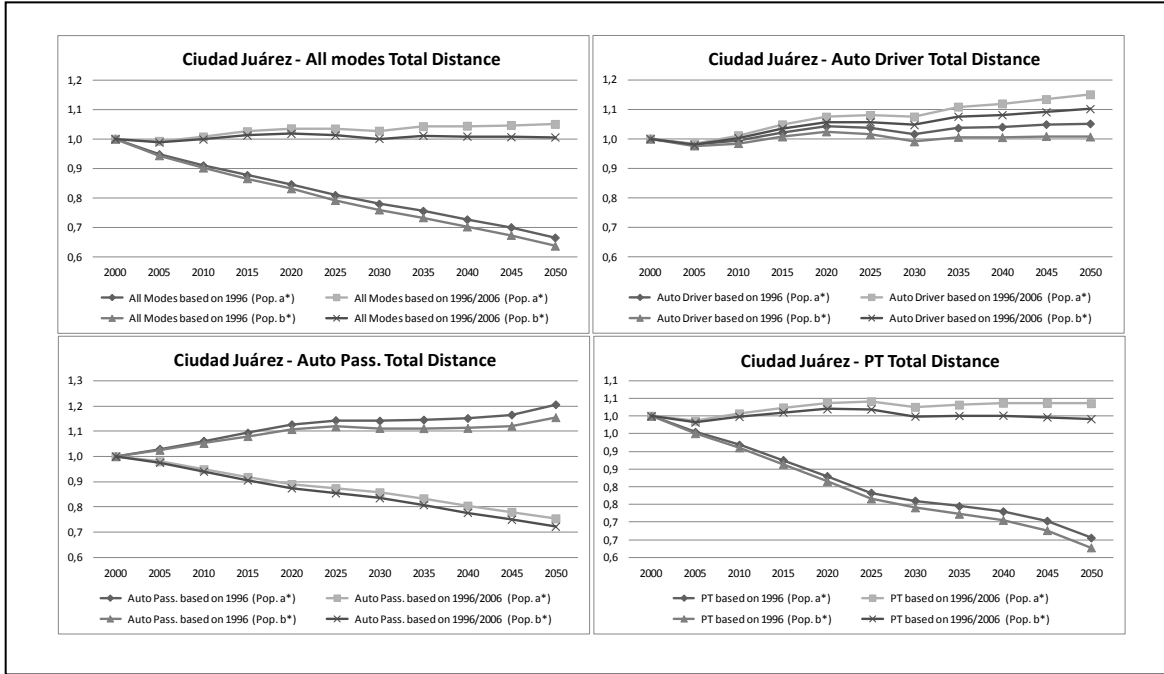
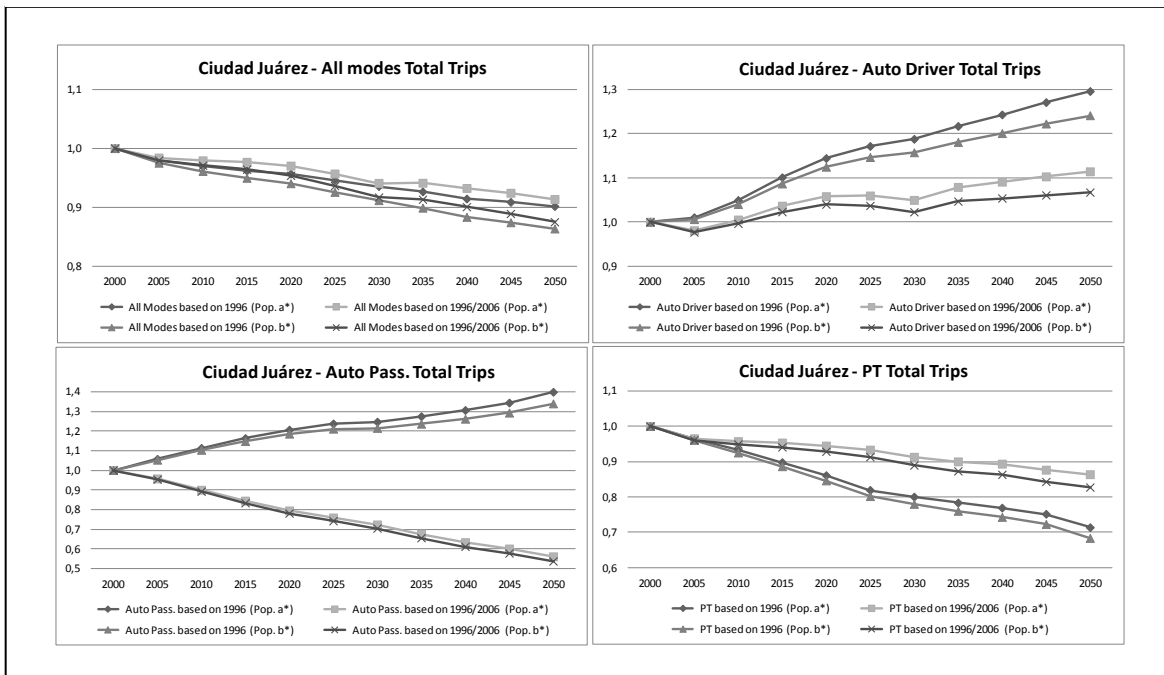


Figure 2. Age-Cohort model forecasts, Juarez 2000-2050. Total number of trips per day by mode (base index=1 in 2000)



¹³³ *Pop. a = Increasing population and age pyramid changes, Pop. b= Total population fixed at year 2000 but changing age pyramid

Figure 3. Age-Cohort model forecasts, Puebla 2000-2050. Total distance travelled per day in veh-km by mode (base index=1 in 2000)

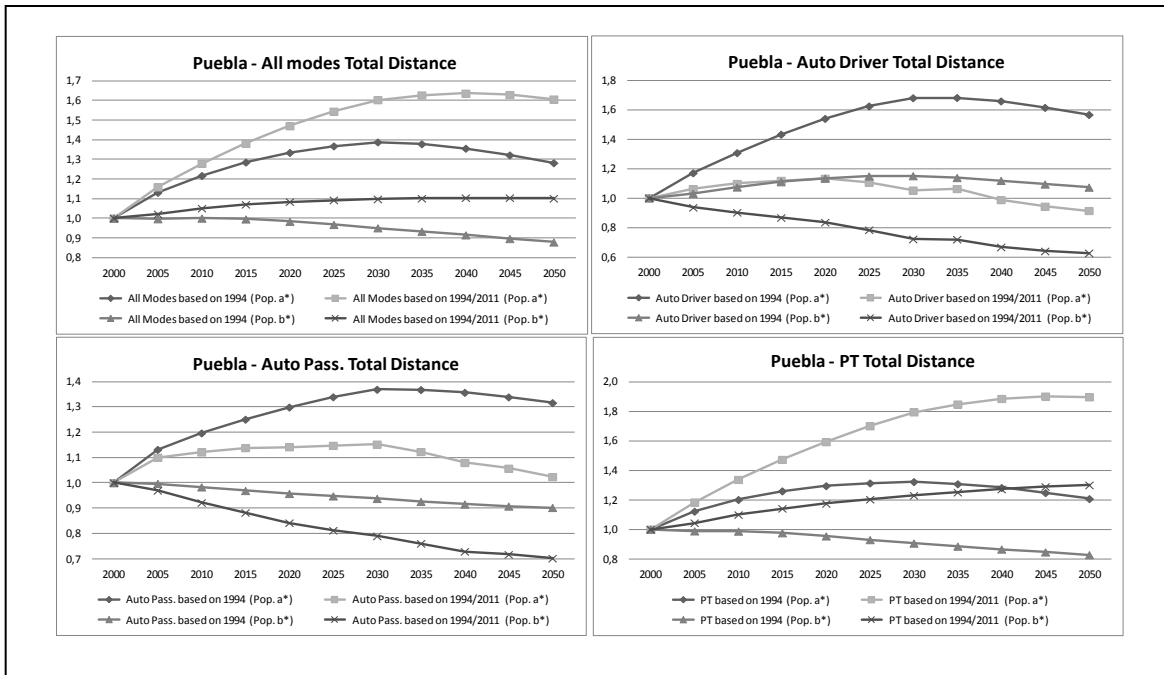


Figure 4. Age-Cohort model forecasts, Puebla 2000-2050. Total number of trips per day by mode (base index=1 in 2000)

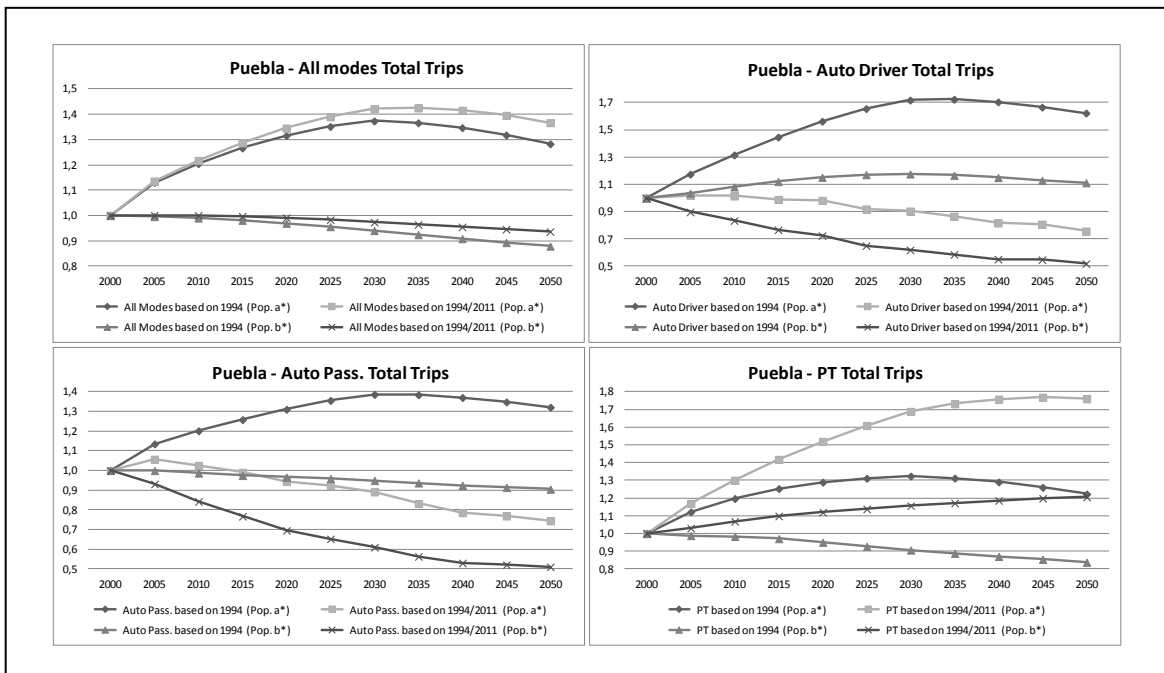


Figure 5. Age-Cohort model forecasts, Lille 2000-2030. Total distance travelled per day in veh-km by mode (base index=1 in 2000)

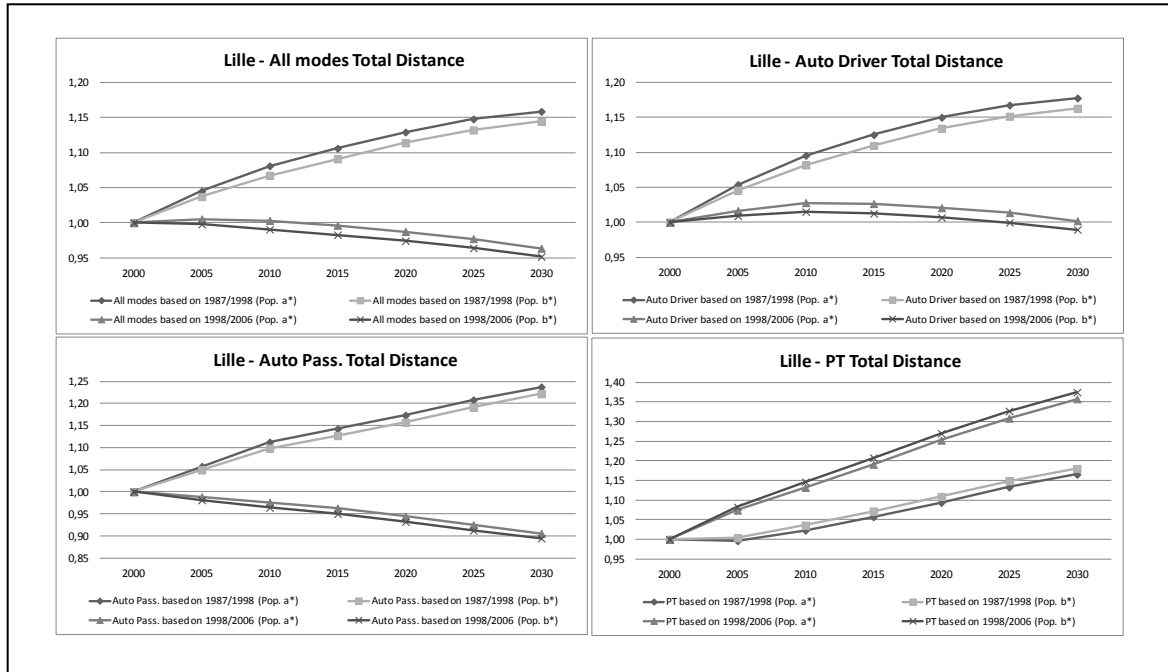
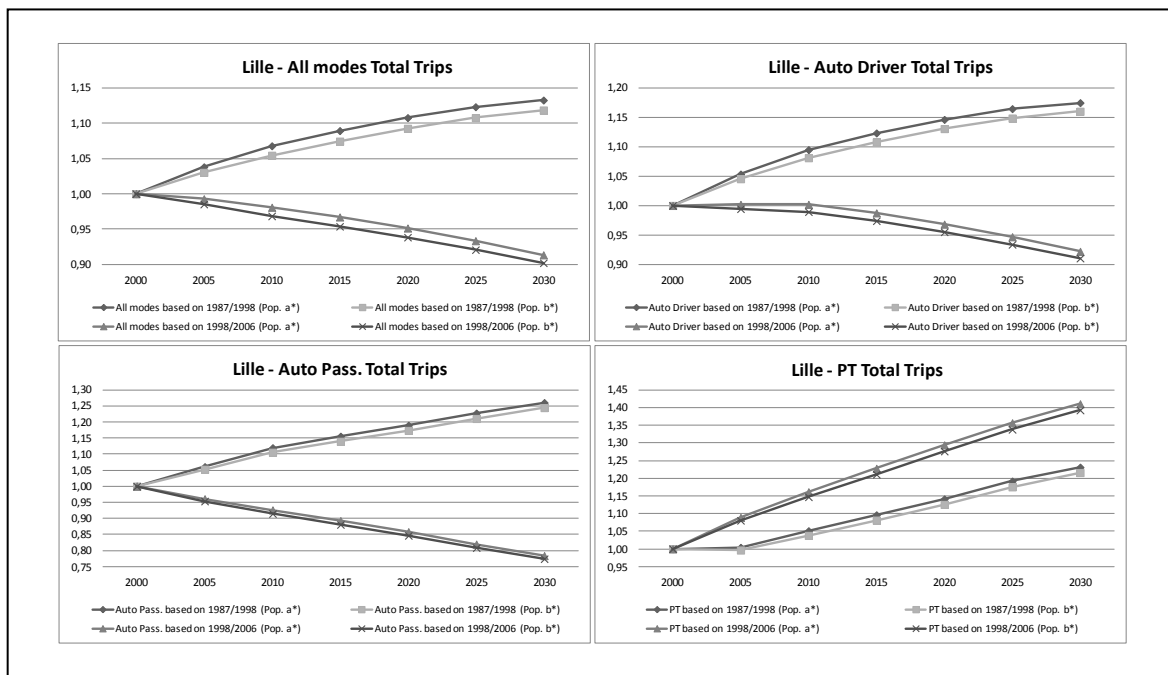


Figure 6. Age-Cohort model forecasts, Lille 2000-2030. Total number of trips per day by mode (base index=1 in 2000)



Annex 12. Age-cohort models trends by main transportation mode

		Puebla			Juarez			Lille		
		Peak 90s survey	Peak 90s & 00s surveys	Influence last survey	Peak 90s survey	Peak 90s & 00s surveys	Influence last survey	Peak 90s survey	Peak 90s & 00s survey	Influence last survey
All modes	Total Dist. (a)	2030	2040	+	2000	2035-2050	+	2030	2000-2010	-
	Total Dist. (b)	2000-2015	2030-2050	+	2000	2000-2050	+	2030	2000-2005	-
	Dist/pers.	2000-2015	2040-2050	+	2000	2000-2050	+	2030	2000-2005	-
	Total Trips (a)	2030	2035	+	2000	2000	+*	2030	2000	-
	Total Trips (b)	2000-2010	2000-2020	+	2000	2000	+*	2030	2000	-
	Trips/pers.	2000-2010	2000-2015	+	2000	2000-2005	+*	2030	2000	-
Auto Driver	Total Dist. (a)	2030-2035	2020	-	2040-2050	2050	+	2030	2010-2015	-
	Total Dist. (b)	2030	2000	-	2020	2050	+	2030	2010-2015	-
	Dist/pers.	2030	2000	-	2020	2045-2050	+	2030	2000-2030	-
	Total Trips (a)	2030-2035	2000-2010	-	2050	2050	-	2030	2000-2010	-
	Total Trips (b)	2030	2000	-	2050	2050	-	2030	2000-2005	-
	Trips/pers	2030	2000	-	2050	2040-2050	-	2030	2000-2010	-
Auto Passenger	Total Dist. (a)	2030-2035	2030	-	2050	2000	-	2030	2000	-
	Total Dist. (b)	2000-2005	2000	-	2050	2000	-	2030	2000	-
	Dist/pers.	2000-2005	2000	-	2050	2000	-	2030	2000	-
	Total Trips (a)	2030-2035	2005	-	2050	2000	-	2030	2000	-
	Total Trips (b)	2000-2010	2000	-	2050	2000	-	2030	2000	-
	Trips/pers.	2000-2005	2000	-	2050	2000	-	2030	2000	-
Public Transport	Total Dist. (a)	2025-2030	2045-2050	+	2000	2040-2050	+	2030	2030	+
	Total Dist. (b)	2000-2010	2050	+	2000	2025	+	2030	2030	+
	Dist/pers.	2000-2015	2045-2050	+	2000	2000-2050	+	2030	2030	+
	Total Trips (a)	2030	2045-2050	+	2000	2000	+	2030	2030	+
	Total Trips (b)	2000-2010	2050	+	2000	2000	+	2030	2030	+
	Trips/pers.	2000-2010	2045-2050	+	2000	2000	+	2030	2030	+

+ Increasing change when taking into account latest survey

- Decreasing change when taking into account latest survey

+* Slightly increasing when taking into account latest survey

(a) Increasing population and age pyramid changes

(b) Total population fixed at year 2000 but changing age pyramid

Note: Having an increasing (+) and decreasing (-) influence means that the last survey had a positive (+) or negative (-) relative impact by mode and model in relation to the first survey and regardless of the base index coefficient for each year (1 in 2000). For instance negative influence could go from 1.4 to 1.1 (base index 1 in 2000), while positive influence could go from 0.7 to 0.9.

Abstract

In the context of the Kyoto Protocol, France has set Greenhouse Gas (GHG) emission reduction targets of 75% below 1990 levels by 2050. More recently, Mexico has set the objective to achieve a 50% reduction by 2050 with respect to the base year 2000. Since the transport sector in urban areas with approximately 1 million inhabitants accounts for most CO₂ emissions and will continue to increase its share, we wanted to determine to what extent the experiences observed in cities from developed countries (peak travel, dissemination of new vehicle technologies) may be repeated in urban areas from developing nations. For this purpose, we focus on case studies in France (Paris and Lille) and Mexico (Juarez and Puebla). The first objective of this thesis was to identify the determinants of mobility on each urban region. The second objective was to apply the age-cohort model for the development of long-term travel demand forecasts in order to take into account changes in the population structure (ageing) and in travel behaviour. The last objective was to develop GHG emissions assessments from observed travel demand. The decline in mobility and the dissemination of new vehicle technologies in France led to a reduction in GHG emissions. However, these changes are not sufficient to achieve the GHG reduction targets. The case studies in Mexico show the inability to reverse the trend towards the increase of GHG emissions; therefore the reduction targets will be hardly achieved. The case of Mexico give us an overview of trends in emerging countries, which are very far from achieving sustainable development and will face a major challenge in the coming decades.

Keywords: Travel demand forecast ; Age-cohort model ; Global Warming ; Developing nations.

Résumé

Dans le cadre du protocole de Kyoto, la France s'est engagée à diviser par quatre ses émissions de gaz à effet de serre (GES) de 1990 à l'horizon 2050. Le Mexique a pour objectif d'atteindre une réduction de 50% en 2050 par rapport à l'année 2000. En vue du poids croissant du secteur des transport dans les villes d'environ 1 million d'habitants dans le total des émissions de CO₂, nous souhaitons vérifier dans quelles mesures les expériences observées dans le Nord (plafonnement de la mobilité, diffusion de nouvelles technologies sur les véhicules) peuvent se répéter dans le Sud. Nous nous sommes pour cela appuyé sur des études de cas en France (Paris et Lille) et au Mexique (Juarez et Puebla). Le premier objectif de cette thèse a été d'identifier les déterminants de la mobilité urbaine. Le deuxième objectif a été d'appliquer le modèle âge-cohorte pour la prévision de la demande de transport, afin de prendre en compte l'évolution de la structure de la population (vieillesse) et les changements de comportement. Finalement, nous avons développé des diagnostics des émissions de GES. En France, nous avons observé des tendances vers une réduction des émissions de GES due à la baisse de la mobilité et aux nouvelles technologies, mais qui est encore loin d'être suffisante pour atteindre les objectifs fixés. Les études de cas du Mexique montrent l'incapacité à inverser la tendance à l'augmentation des émissions de GES ; par conséquent les objectifs de réduction seront difficilement atteints. Le cas du Mexique peut nous donner un aperçu des tendances dans les pays émergents, qui sont très loin d'atteindre un développement durable et resteront face à un grand défi dans le futur.

Mots-clés : Projection de mobilité urbaine ; Modèle Âge-Cohorte ; Réchauffement climatique ; Pays du Sud.