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Will Peak Car Observed in the North Occur in the South? A Demographic Approach with Case Studies of Montreal, Lille, Juarez and Puebla

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ABSTRACT *In most developed countries, total car driving is stagnating since the early 2000s. This trend can be attributed primarily to people living in the largest urban areas: trips have become less frequent (with unbroken workdays) and less exclusively taken by car (as more young adults adopt multimodal behaviors). A review of the literature shows that demography is an important factor explaining peak car. It is examined through case studies from cities of different level of development. To represent developed economies we chose Lille in the North of France, and Montreal in Canada. For the emerging economies we chose two Mexican cities, Juarez, on the northern border of Mexico where the level of motorization is quite high, and Puebla more traditional, where car ownership is lower. A straightforward combination of fixed mobility by age group with the evolving number of inhabitants suggests that the demographic transition (i.e. a slower growth of the number of inhabitants with population ageing) shows a peak in the total amount of car travel. Then, considering travel behavior in terms of distance travelled per person per day, an age-cohort demographic projection model is implemented for each case-study in order to consider the extent to which, and in what time frame, the trends observed in developed cities could spread southward to the emerging economies.*

Keywords: Demographic approach, mobility, car-use, peak travel, developed vs. emerging cities.

This paper is a largely revised version of Madre et al. (2013), introductive paper presented at the round table on long term trends in travel demand organised by ITF/OECD [OECD/ITF, 2013], and Tapia-Villarreal et al. (2013) presented at the 13th WCTR, 2013 - Rio de Janeiro, Brazil.

1. Introduction

For several decades mobility and car use have followed a constant growth trend in developed economies. However, since the early 2000´s in most developed countries – in USA, Europe, Japan, … - urban mobility and car use have stagnated. Various data sources show that it can be attributed primarily to people living in the largest urban areas: trips have become less frequent (with unbroken workdays) and less exclusively taken by car (as more young adults adopt multimodal behaviors. In France, car use is also peaking in low density areas, but later and at a much higher level [Grimal et al., 2013; Hubert et al., 2016].

What will happen in emerging economies? Will we observe the same tendencies towards peak car and if so, in what timeframe? The difficulty of such a comparative-prospective analysis is a lack of consistent and continuously collected data. Considering these difficulties we will not pretend to explain all dimensionswith their retroaction , but focus on a demographic approach for which we have comparative data for the case studies under review: population projections by age-cohorts and gender and Origin-Destination surveys available for at least two points of observation allow the measurement of past evolutions. The case studies chosen are, representing developed economies, Lille (to which we added Montreal incorporating a more straightforward forecasting model implemented 25 years ago [Bussière & Fortin, 1990]), and for emerging economies, two cities of Mexico, Juarez, a border city with the USA, where the level of motorization is rather high and Puebla, less motorized.

A review of the literature shows that various socioeconomic factors are contributing to peak car, among which demography plays an important role (section 2). It will be examined by using data from census and O-D surveys, through case studies from cities of different level of development for which data will be described (section 3). Indeed, a straightforward combination of fixed mobility by age group with the evolving number of inhabitants in each age group suggests a peak in the total amount of car travel as shown for Montreal, and gives a first insight of what could happen in Puebla (section 4). Then, considering travel behavior in terms of distance travelled per person per day, Age-Cohort modeling shows that it has already reached a maximum in Lille, and that it could be so in Puebla and Juarez around 2030; the determinants of this phenomenon are identified in terms of population ageing and of changing behavior (section 5). Our results are discussed (section 6) before the conclusion (section 7).

Does this leveling off suggest that the saturation point is approaching? Is this a structural phenomenon (population ageing, high level of car ownership, durable change of mentalities) or a cyclical one linked to past rising and volatile fuel prices and to the recession? Not easy to answer and the clues are most probably multifactorial.

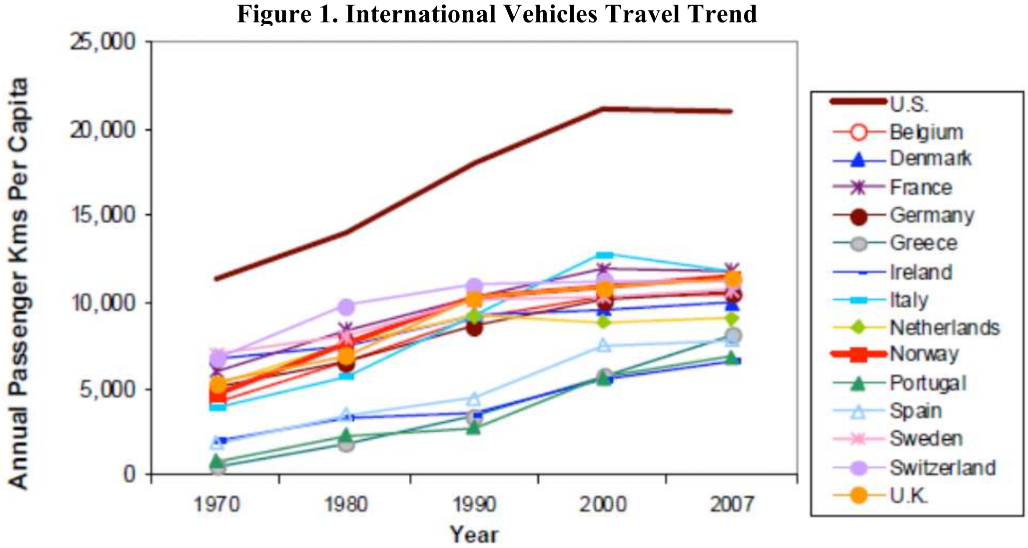
2. Background

After expanding rapidly in the 1960s and 1970s, growth in car driving per capita slowed in the early 2000s and seemed to approach saturation in a number of industrialized countries [Litman, 2009; Millard-Ball and Schipper, 2010; Newman and Kenworthy, 2011, Madre *et al.,* 2012] (Figure 1). The Australian Bureau of Infrastructure, Transport and Regional Economics, which has compiled a long series for 25 countries, explains this trend as a reflection of fuel prices and economic activity, as well as a time-related saturation effect for which a deeper understanding is needed [BITRE, 2012]. A comprehensive analysis of global transport demand trends over the next 40 years was presented by the JTRC/ITF in May 2011 in Leipzig [OECD/ITF, 2011] and regularly updated in "Outlooks" (see ITF website). 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 long term trends in travel demand organized by 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 licences 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 [Noble, 2005]. It has now been found that the licence-holding percentage among young people has started to decline in some 10 countries [Sivak and Schoettle, 2012], 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 diffusion of car ownership is too recent in Central Europe (Poland, Latvia), and to a lesser extent in the Mediterranean countries (Spain, Israel), for such a phenomenon to be observable yet. In France, the decline in the number of licence-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 [Avrillier *et al.,* 2010].

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 (Figure 2). Thus, young people are less likely to have a driving licence and to travel exclusively by car than in the previous generation [Kuhnimohf et al., 2012]. There are a number of possible explanations for this phenomenon: the fact that a growing proportion of young people pursue higher education, which defers their entry into the labour 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 1. International Vehicles Travel Trend

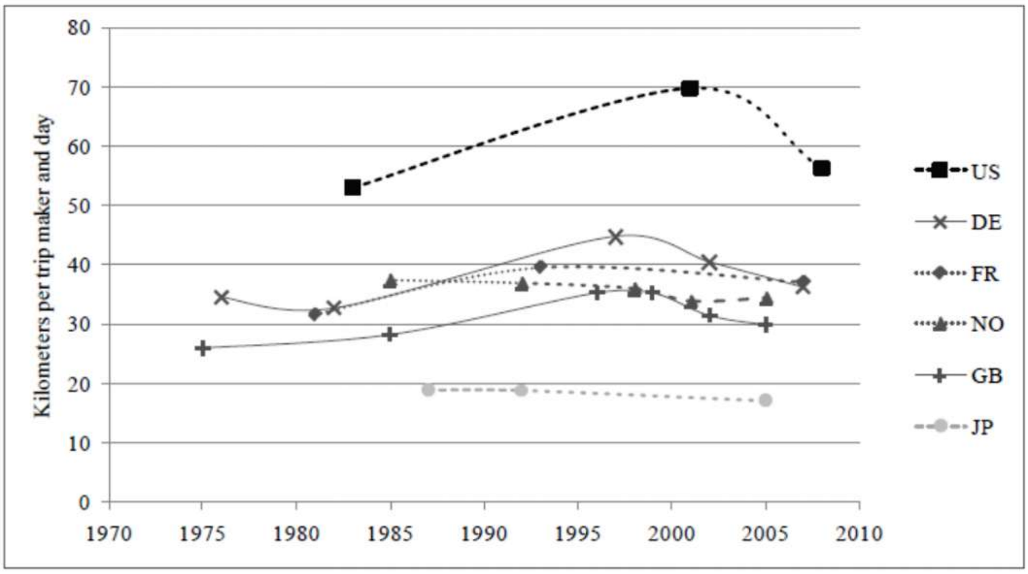


Per capita vehicle travel grew rapidly between 1970 and 1990, but has since leveled off in most OECD countries, and is much lower in European countries than in the U.S.

Source*:* Litman, Todd (2009).

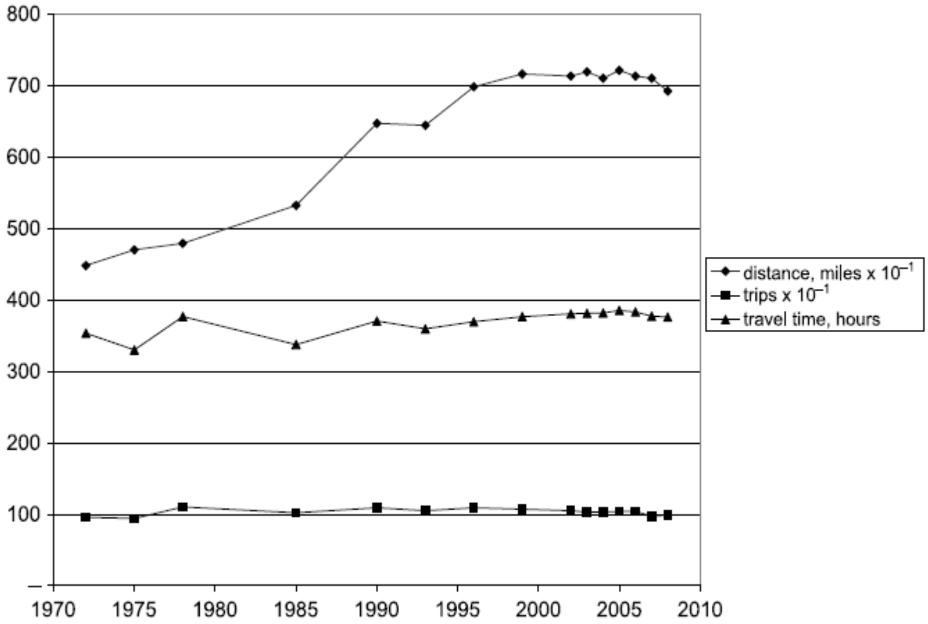
In Great-Britain [Metz, 2010] observes that over the past 30 years the average travel time has remained stable at about 1 hour per day (375 hours per person per year), as has the average number of trips (1 000 trips per person per year). Car ownership has more than doubled, as well as speeds, which in combination with rising income prompted a substantial increase in distances travelled, until a certain levelling off from the mid-1990s (Figure 3). Metz puts forward a number of explanations for the stagnation of traffic: fewer local trips due to longer absences from home [Madre and Armoogum, 1997], 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? [Millard-Ball and Schipper, 2010]. Is this decoupling happening first in the most densely populated regions and/or over a certain standard of living? [Goodwin, 2010-2011]? Some authors explain the reduction in travel in the developed countries in the medium terms, by a variety of socio-economic factors [Litman, 2011]. One could well ask whether this is a socio-demographic phenomenon (population ageing, re-densification of large city centers, fewer but more-intensive workdays, without returning home for lunch, etc.) or an economic one linked to rising and volatile fuel prices and the recession [Gardes et al*.,* 1996; Collet, 2012].

Figure 2. Vehicle-km trends (car driver and car passengers) per traveller, per day for young adults aged 20-29 (6 countries)



Source*:* Kuhnimohf et al. (2012).

Figure 3. Travel time (hours per person per year), distance (miles per person per year) in Great-Britain



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

3. Case Studies

We will present four case studies representing various levels of motorization: three in North America, Montreal, Canada, as an example of a developed city, and Juarez and Puebla in Mexico, representing two contrasted levels of motorization in an emergent economy.The fourth case study is Lille, in France, which can be compared to Juarez, two international cities with a population in a range of 1 to 2 million inhabitants. The four cities were chosen for their interest but also because of the availability of comparable Household Origin-Destination Surveys.

Metropolitan Area of Montreal (MAR) region had a population of 3.9 million in 2011, with a rather high annual rate of growth of 1.92% between 1986 and 2001, as well as between 1986-2011, and 15% of the population aged 65 and over in 2011. However, during the whole period 1986-2011, we assisted to urban sprawl, the annual population growth of the Central City being of only 0.34% vs. 3.95% for the rest of the MAR. For the period 2011-2031 projections of the Statistical Institute of Quebec (ISQ) give a slowdown of growth with an annual rate of 0.81%, and more pronounced ageing with 21% of 65 and over in 2031, and a continuation of urban sprawl [Ville de Montréal, nov 2014]. With very low fertility rates the main source of population growth for the City of Montreal is international migration, intra provincial migrations being negative [Ibid., Oct. 2011].

Juarez is a frontier city, 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 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.

Overall, by 1996 Juarez had a population of 1.1 million and an estimated population of 1.2 million in 2006. The transportation infrastructure projects implemented in the last decades in Juarez were only highway construction and no public transport projects, which made Juarez a car-dependent city over time. Two Origin-Destination surveys are available: 1996 and 2006.

Puebla is an urban area of 2 million inhabitants, located in the centre of Mexico and much less motorized, representative of a more traditional life-style. Two Origin-Destination surveys are available: 1994 and 2011. 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 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.

The Urban Community of Lille is located in northern France close to the Belgium border. It had a population of 1.1 million in 2010 with an annual growth of rate between 1999 and 2010 of +0.2%, and a population aged 65 and over of 12.7%. The demographic projections give a total number of inhabitants in 2030 equal to that of 2010, with a population aged 65 and over of 18.9% in 2030. Like most millionaire French cities it has good public transit with a metro and trams.

The percentage of private vehicle use in the modal choice seems to be almost the same in Lille and Juarez (Table 1) in spite of the disparities that two different economies might cause to urban mobility. The occupancy rate of private vehicle is higher in Juarez and Puebla (1.7 pas/veh in both Mexican cities than in Lille (1.35 pas/veh in 2006) and the number of daily trips per person is twice higher in Lille than in Juarez and Puebla. 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 (Pison, 2011). Nevertheless in Juarez both the occupancy rates (1.7 pas/veh) and the private car hare (50%) appear to be stabilized between 1996 and 2006 showing a strong automobile dependency for a Mexican city (e.g. only 27% in the Guadalajara Metropolitan Area in 2007) [Tapia-Villarreal, 2013]. This is due mostly to poor public transportation infrastructure, sprawled urban form and the availability of cheap used cars imported from the U.S. Public transport share decreased from 24% to 22% between 1996 and 2006 showing that in Juarez private auto users could be seen as captive users who are generally unable to change to other travelling alternative modes due to structural reasons. In 2011 in Puebla the occupancy rate was 1.7 pas/veh but the private car share was down to 13% from 20% in 1994 and public transit use rose from 48% to 56%, 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 economic cycle phenomena mentioned above.

Table 1. Indicators of mobility in Montreal, Lille, Juarez and Puebla

	Montreal			Lille c			Juarez c		Puebla c	
	1993	1998	2013	1987	1998	2006	1996	2006	1994	2011
Population (Million)	3.112c	3.210c	4.288	0.931	1.009	1.010	0.966	0.967	1.175	1.739
Households (Million)	1.230 c	1.295c	1.685c	0.374	0.428	0.457	0.276	0.267	0.282	0.424
% 65+	11.0%	12.0%	15.0%	11.9%	12.4%	12.7%	4.3%	4.6%	4.4%	6.0%
Trips/pers/day	2.49c	2.34c	2.32	3.86	4.39	4.14	1.99	2.02	1.74	1.71
Modal split by private vehicle (driver+pass)	0.64c	0.67c	0.69	0.535	0.585	0.546	0.499	0.490	0.196	0.120
Average distance/driver trip (km)	na	na	na	3.62	3.75	4.1	5.83	6.11	4.31	5.03
Modal split by Public Transport	0.17c	0.15c	0.16	0.06	0.06	0.09	0.24	0.22	0.48	0.56
Average distance/PT trip (km)	na	na	na	4.59	4.55	4.67	6.67	8.0	5.03	5.25

Source: O-D Household Surveys and calculations by IFSTTAR

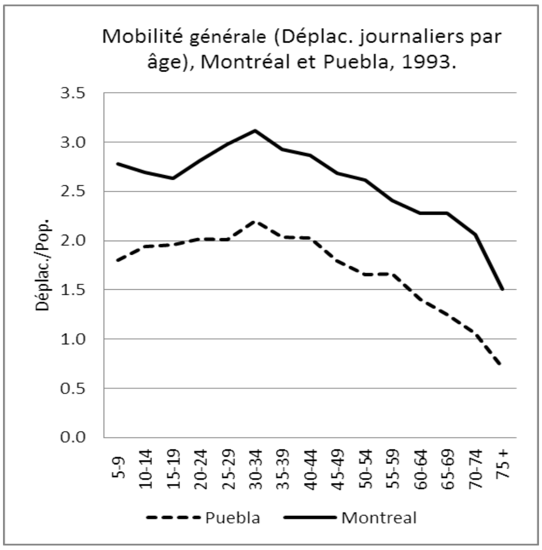
* c = constant survey area of metropolitan region when possible

e = estimate with available data; na = non available without access to original data

4. Population Growth and Ageing: A Straightforward Simulation. Montreal and Puebla

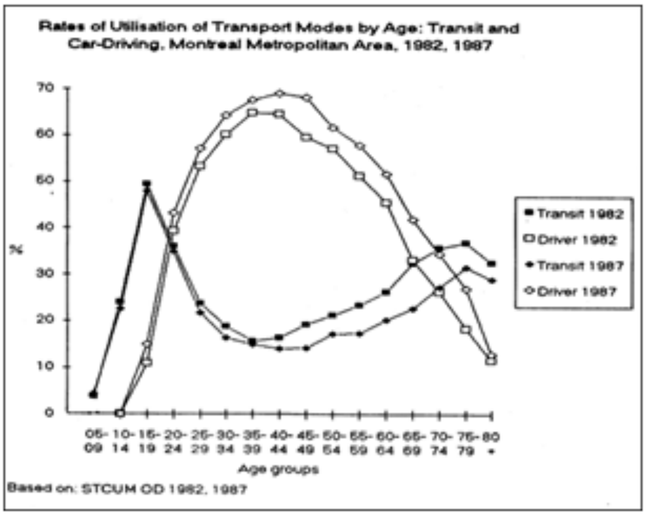
According to the trends shown in section 2 (Figure 1) with a ¨peak car travel¨ observed in most developed countries since the 2000s we may suspect that demographic factors play an important role in this trend, many baby-boomers reaching the age of retirement. When observing sociodemographic variables more closely we note that the linkage between age and mobility is well established. For instance, as can be observed in the figures 4 and 5, general mobility (i.e. the average number of trips per person per day) 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 (Figure 4). 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 quite similar. 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, 5 and 8). The combined result of these trends will inevitably yield high individual car use in active age groups, translating into car*kms such as can be noted in the United States for the period 1995-2001-2009, where a decrease in car*kms can be seen in respect of the youngest drivers, but an increase for the over-65 age groups (Figure 6).

Figure 4. Overall mobility by age, Montreal and Puebla (1993) (Trips per day by age) Trips/Pop.



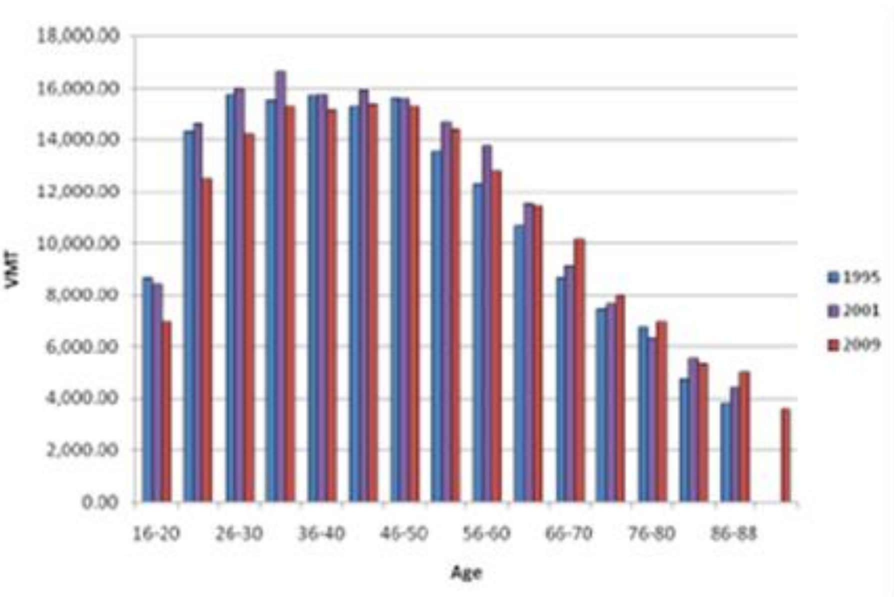
Source: Household Origin-Destination Surveys.

Figure 5. Modal choice by age Car – driver and Public transport (PT), Montreal (1982-1987)



Source: Household Origin-Destination Surveys.

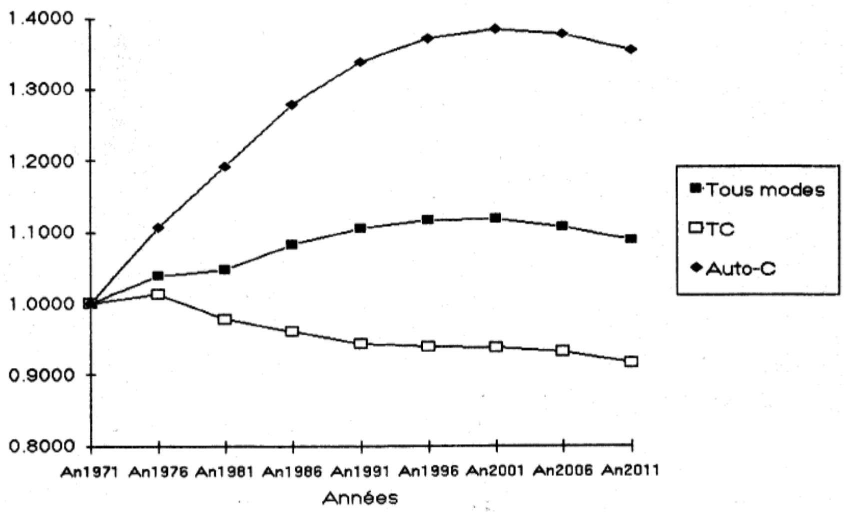
Figure 6. Annual vehicle-miles per driver by age USA, 1995, 2001, 2009



Source: OECD/ITF (2011), p. 29, pdf, www.

To illustrate long term demographic and mobility trends in the Montreal case we first adopted a straightforward extrapolation which considers mobility of 1982 for 5 years age groups as constant over time, multiplied by long term population (number of inhabitants) 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 through time (Figure 7) [Bussière & Fortin, 1990]. All factors, except population growth and ageing, are kept constant, namely mobility based on 1982 O-D Survey, and urban form. This simulation shows a peak travel around 2000.

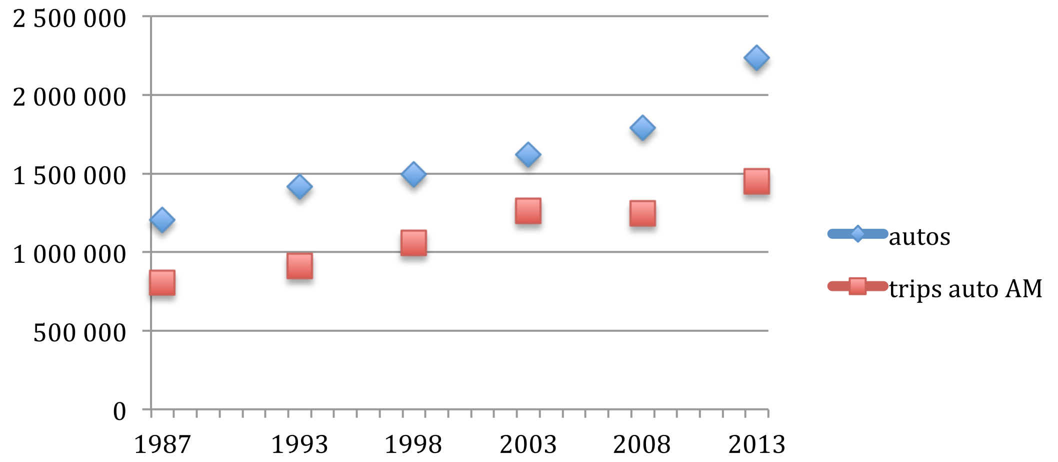
Figure 7. Transport demand trends measuring population impact (All modes, public transport, Car-Driver) Montreal 1971-2011 (1971 = 1) - At fixed 1982 behavior



Source: Bussière, Fortin 1990.

Is peak car observed in the Metropolitan Area of Montreal? According to O-D surveys (Figure 8) the auto (including motorcycles) vehicle fleet rose by 2.3% annually between 1987 and 2003 (compared to 1.92% for population growth between 1986-2002), and by 2.1% between 2003 and 2008 (compared to 0.96% of population growth between 2001-2011). However, at least for the morning peak period (6-9AM) between 1987 and 2003 car trips rose by 1.4% (0.79% annual) followed by a diminution of trips of 1 % (-0.2% annual) while the population was increasing. This diminution can be mainly attributed to the residents of the Central part of the Montreal Urban Area with -1.17% annual for the residents of the Island of Montreal vs. +1.17% in the suburbs [Verreault & Bergeron, 2010]. Between 2008 and 2013 population growth continues (estimates for 2011-2016 is +1.11% annual) mainly in the suburbs, with a growth of 2.18% annual of the auto fleet and an increase of 2.8% annual of all trips made by car. We also observe a slight diminution in the rate of occupation of cars which pases from 1.25 in 1998 to 1.20 in 2013. From these tendencies we could conclude that there was a very slight peak car which rapidly vanished due to demographic growth, mainly due to international immigration and low densities (urban sprawl) [AMT, O-D 2013].

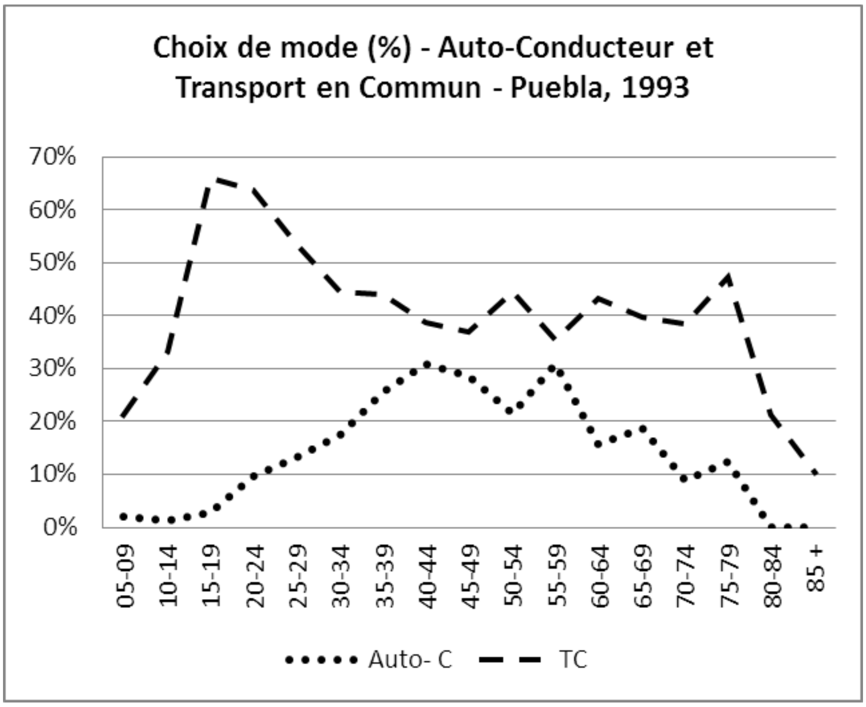
Figure 8. Number of Autos and Auto daily AM Trips in the Montreal Metropolitan Area, 1987-2013, constant territory of Area of O-D Survey



Source: With data of AMT, O-D Surveys of Montreal Metropolitan Area.

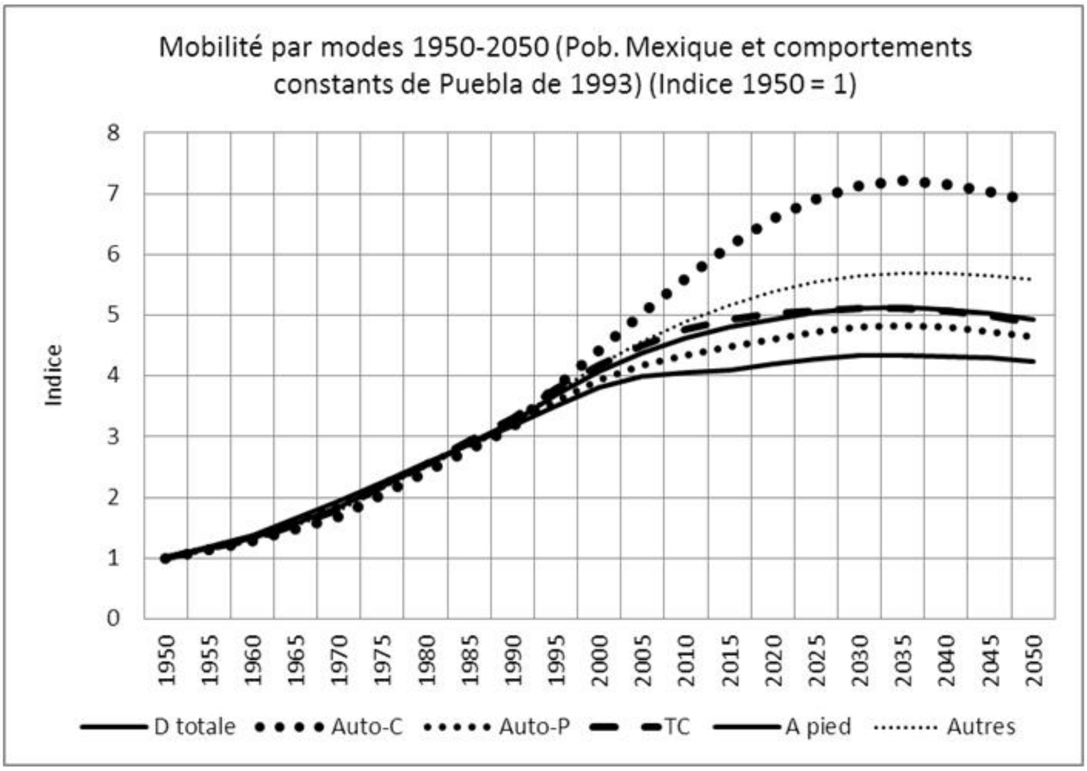
The same method was applied to Puebla over a 100-years period (1950-2050), based on constant behavior observed in the 1994 O-D Survey (Figures 9 and 10). In Puebla we should assist to two decades of heavy demographic pressure conducive to an increase in individual car driving and a slowdown in Public Transit. The inflection point is to come around 2035, after which there should be a slowdown in individual driving and still decreasing 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, the result would be explosive for at least another 20 years. A recent household origin destination 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; thus, the total number of cars 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 and increasing inequality. While in 1994 19.0% of households suffered from food poverty, the rate did not change in 2008, with 19.5% [CONEVAL, 2009]. 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 France, there has been an ageing of the cars on the road, the average age of which increased from 6.2 years in 1993 to 8.2 years in 2007 [Kolli, 2012], but for quite different reasons: the greater number of second cars, which are driven less and last for longer. In the next decades if poverty persists the answer to the demographic pressures towards more individual motorization may be further ageing of the vehicles.

Figure 9. Modal choice by age Car – driver (Auto-C) and Public transport (TC) Puebla (1993)



Source: Household Origin-Destination Surveys.

Figure 10. Transport demand trends in Puebla measuring the impact of population fixed behavior in 1994, 1950-2050 by mode defined as total daily trips (All Modes, Auto Dr., Auto Pas., Publ. Tr., Walking, Others)



Source: Bussière, oct. 1991.

5. Forecasting Mobility with the Age-Cohort Model

5.1. Description of the Model

For a detailled description of the model, see [Dejoux et al., *Transport Reviews*, 2009].

The projection of mobility (daily kilometers, 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/her date of birth);

α_a: measures the behavior of a generation of reference at the age a. This allows to calculate a «Standard Profile» over the life cycle;

γ_k: measures the gap between the cohort k and the generation of reference γ_{k^0} ;

As the gaps between cohorts for recent generations tend to disappear we took the last observed cohort (generation Y) as reference and maintained this gap for future generations [Madre & al., 1996]. The mobility for the population at the date t is estimated as follows:

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

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 [Krakutovski, 2004].

Assuming a constant gap between cohorts over time is a quite restrictive hypothesis, because it doesn`t allow to take into account of lagged phenomena (e.g. generation Y having their driving licence after 30 years old instead of passing it around 25). A more comprehensive approach is the Age-Period-Cohort model, but continuously collected data would be needed for the estimation of period effects; they can be related to income and fuel price [Berri et al., 2005]. For instance, the recent drop of fuel price (-10% between 2014 and 2015 in France) has stimulated a recovery of car traffic, which could also be the case in the US after the 2008 recession [Polzin, 2016].

5.2. Simulations

In an intent to forecast travel distance and isolate structural factors in the trends of an apparent saturation of urban mobility, we extrapolated distance travelled, applying the Age-Cohort projection model developed by INRETS (now IFSTTAR) with 2 variables: (1) veh*km travelled per capita per day to measure behaviour and (2) total veh*km travelled per day to measure impact.

The first indicator was simulated by 3 models: 1) Complete Age-Cohort Model, 2) Ageing Age-Cohort Model, 3) Behavior Age-Cohort Model, over the period 2000-2030 for Lille and 1995-2050 and 2000-2050 for Juarez and Puebla. The second indicator was simulated with the complete Age-Cohort model calibrated on a) older data before peak car and b) more recent data representing the lastest trend where a peak may have occured. Each scenario of the second indicator is made with constant population (pop.a) and growing population (pop. b) .

The three models were applied to: All Modes (including walking, Car Driver, Car Passenger and Public Transport. To simplify we will present only results for Car-Driver.

(1) Full Age-Cohort model: (Population growth, ageing, behavior changes through generations)
(2) Ageing AC model: (Everything constant, except ageing)
(3) Behavior AC model: (Everything constant, except behaviors)

Total veh*km travelled per day for simulation (2) Ageing, AC model has population constant. It is similar to the "straightforward model" used in section 4 for the number of trips except that the latter has varying population.

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 [Krakutovski, 2004] 1.

5.3. Results

5.3.1 Lille

The results 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 from a simulation over the period 2000-2030 . The demographic projection used was made by the National Institute of Statistics and Economic Studies using OMPHALE model (INSEE, 2005).

In terms of total distance travelled per day per capita (Figure 11) we get the following results. Measuring the sole impact of ageing of the population with fixed behavior shows a monotonous tendency of diminishing car driving. If we keep the age structure of 2000 to measure the sole impact of changing behavior, car driving increases until 2015, then decreases steadily after a more or less stable situation for 5 years. The complete Age Cohort model gives a stabilization of car driving, which reflects all the factors (including a strong cohort effect among the new generations of young adults), where population growth is important.

[1] In developed countries, it is possible to know a couple of decades in advance where new developments are going to be built, with a good approximation of the total population living in these new areas, while 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 do not take into account urban sprawl. We would probably expect greater travel distances if urban sprawl was included in the forecasts. A promising path of research could be taking into account different levels of urban sprawl and population densities.

In terms of total distance travelled per day by all auto drivers (Figure 12), the simulation calibrated with the 1998-2006 surveys, which takes into account the observed peak for these years, shows a slight increase in auto driving until 2010, followed by a constant diminution. However if we suppose that the peak observed is temporary and calibrate with the surveys of 1987 and 1998, we observe a continuous rise in auto-driver which reaches over 15% between 2000 and 2030 [Tapia-Villarreal et al., 2013]. Since population growth is slow scenarios with constant or variable population are similar.

Figure 11. Lille per capita daily vehicle-kms, simulation of Age-Cohort model for 2000-2030 (Indice 2000=100)

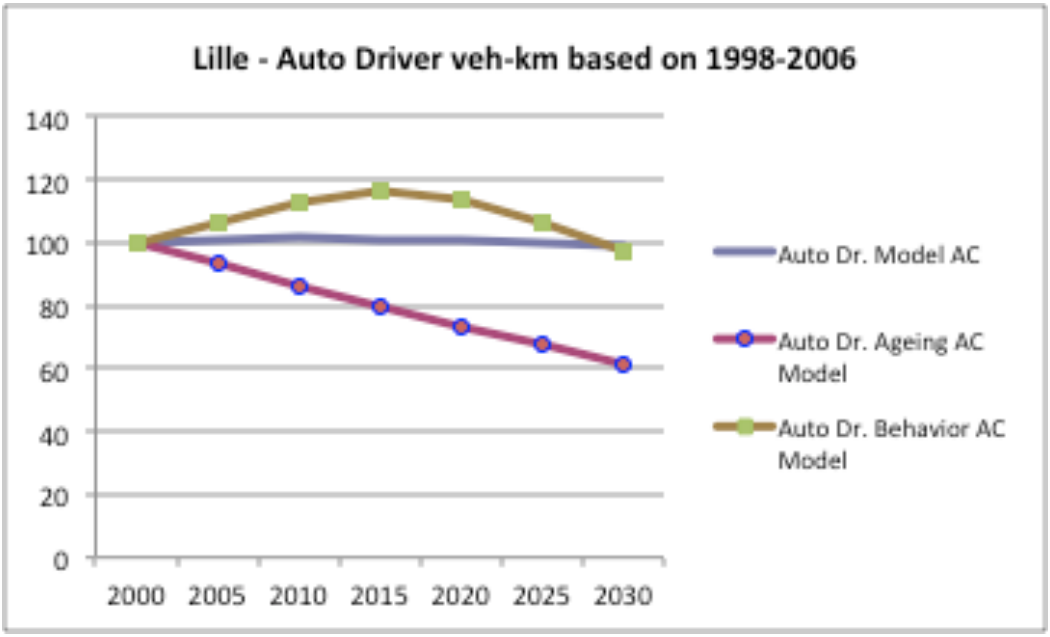
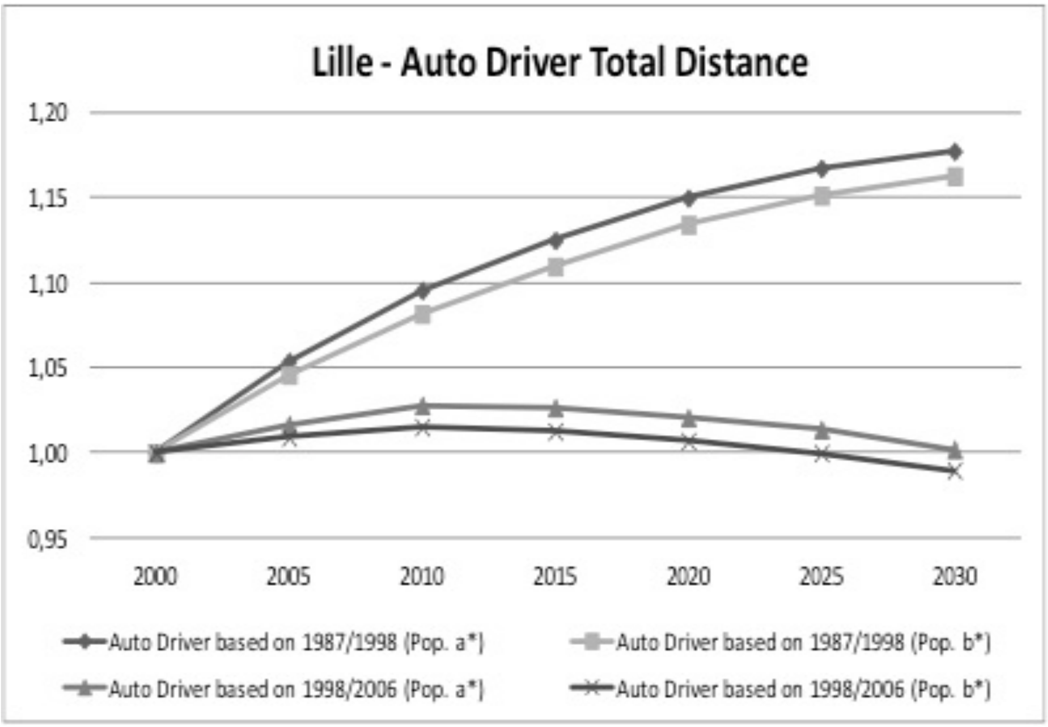


Figure 12. Lille, total daily auto-driver distance simulations with the Age-Cohort Model, 2000-2020 (Indice 2000=1)



* Pop. a=variable; Pop.b = constant

5.3.2 Juarez

For Juarez we chose a slow demographic growth scenario given the current context of violence [Morales et al., 2013] (projected average annual growth rates of 1.60% from 2006 to 2012 and 1.06% from 2015 to 2030).

In terms of total distance travelled per day per capita (Figure 13) we get similar results to Lille. Measuring the sole impact of ageing of the population with fixed behavior shows a monotonous tendency of diminishing car driving. The ageing factor is very different from the one observed in Puebla (see below). 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, then decreases steadily. The complete Age Cohort model gives a slight increase of car driving of less than 5% until 2030 and around 10% for the whole period.

In terms of total distance travelled per day by auto drivers (Figure 14), the simulation calibrated on 1996-2006 which reflects a tendency towards more individual motorization, shows a steady increase in auto driver for the whole period, with a plateau between 2020 and 2030. followed by a constant diminution. However if we calibrate the model with the 1996 survey, supposing no rising individual motorisation, we still have a tendency for more car driving but of only 5% over the whole period.

The inflection point for car driving appears in 2020, which could not be explained by population ageing, since only 5.4% of inhabitants will be aged 65 or over in 2015, but probably by a beginning of saturation for individual car ownership, with 72% of households having cars, as compared with 84% in France in 2008, and 36.4% of households having more than one car, as compared to 38% in France [Kolli, 2012] and in contrast to other major non-border Mexican cities, where this percentage of households with at least one motorized vehicle hardly exceeds 45%. As for Lille, since population growth is slow, scenarios with constant or variable population are similar.

The importance to model a highly motorized city such as Juarez lies in the necessity to observe and predict the trend for the use of the most pollutant mode, the private car. In Mexico City, for example, only 37% of households have a vehicle [INEGI, 1994]. Here, also, average vehicle age is increasing, rising from 11.7 years in 1996 to 13.8 in 2006, due 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. According to the latest data from the Urban Observatory of Security and Safety, the total number 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 0.6 vehicles per capita [Hernández, 2012].

Figure 13: Juarez, per capita daily vehicle-kms, simulation of Age-Cohort model for 1995-2050 (Indice 1995=100)

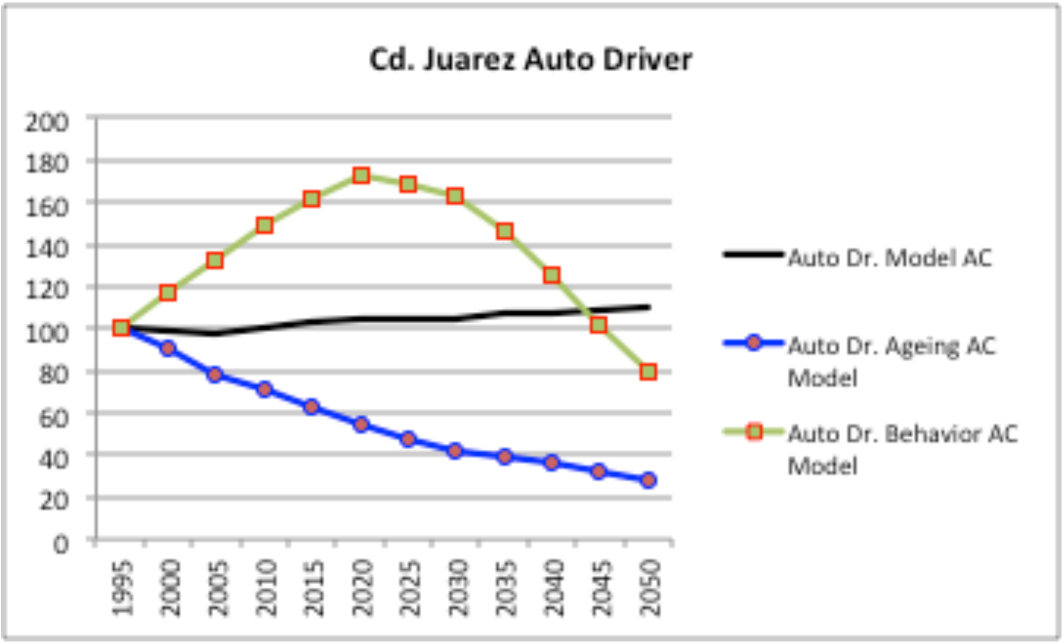
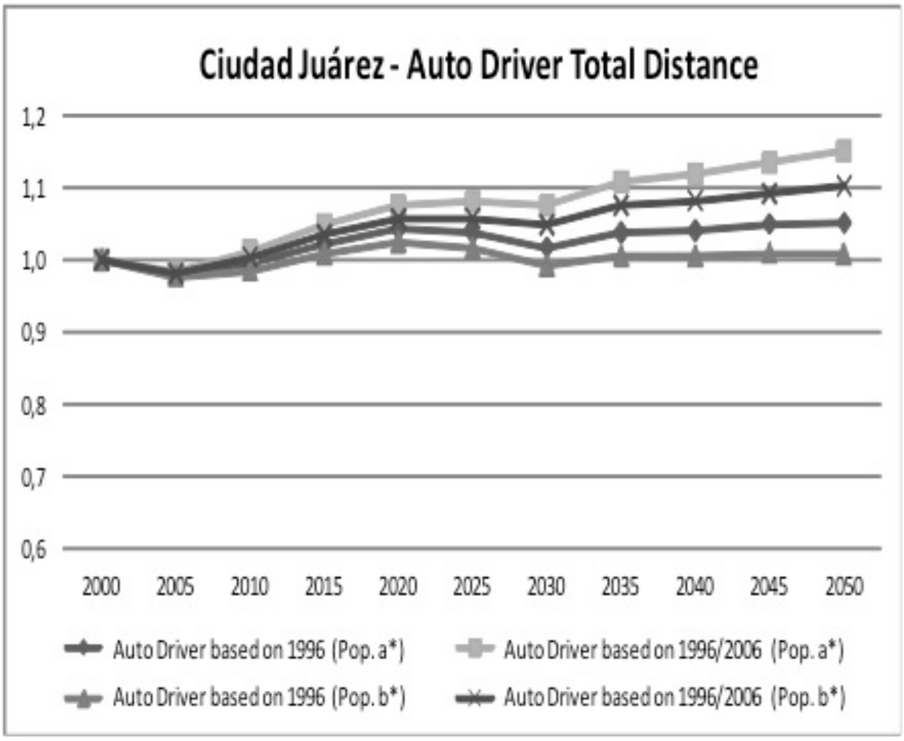


Figure 14. Juarez, total daily auto-driver distance simulations with the Age-Cohort Model, 2000-2050 (Indice 2000=1)



* Pop. a=variable; Pop.b = constant

5.3.3 Puebla

For Puebla we used the demographic growth scenario of CONAPO. The projected average annual growth rates of 1.60% from 2006 to 2012 and 1.06% from 2015 to 2030).

In terms of total distance travelled per day per capita (Figure 15) calibrated with the surveys of 1994 and 2011, we obtain more contrasted scenarios than in Lille and Juarez. Measuring the sole impact of ageing of the population with fixed behavior shows a strong monotonous tendency of diminishing car driving with a diminution of more than 60% in the whole period. The ageing factor has a negative effect for all the period of forecast, but the Behavior Model gives a very strong positive impact, reaching a peak in 2015, then decreasing steadily. The complete Age Cohort model gives a significant decrease of per capita car driving of around 20% for the whole period reflecting the tendency of less individual car use between the two surveys.

In terms of total distance travelled per day by all auto drivers (Figure 16), the simulation calibrated with the 1994 and 2011 surveys which reflects a tendency towards a stable individual motorization, shows an increase until 2025-2030 and then decreases slightly. However if we calibrate the model with the 1994 survey only, supposing a constant individual behavior (motorization and use) we obtain an increase of auto driving in the range of 60% until the peak around 2030, followed by a slight diminution until 2050. In 2050, the increase from 2000 would be over 50%. These results show that the demographic growth factor is absolutely determinant even with very conservative hypotheses of constant behavior. In the case of Puebla, since population growth is strong, scenarios with variable population give a much stronger rise in auto-driving than the constant population scenario.

Figure 15: Puebla, per capita daily vehicle-kms, simulation of Age-Cohort model for 2000-2050 (Indice 2000=100)

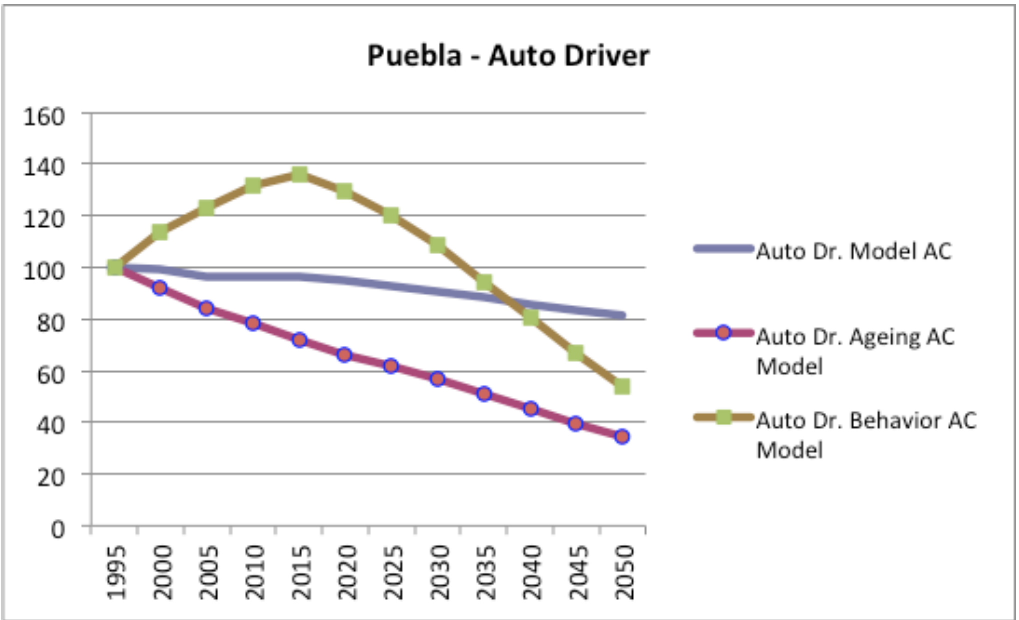
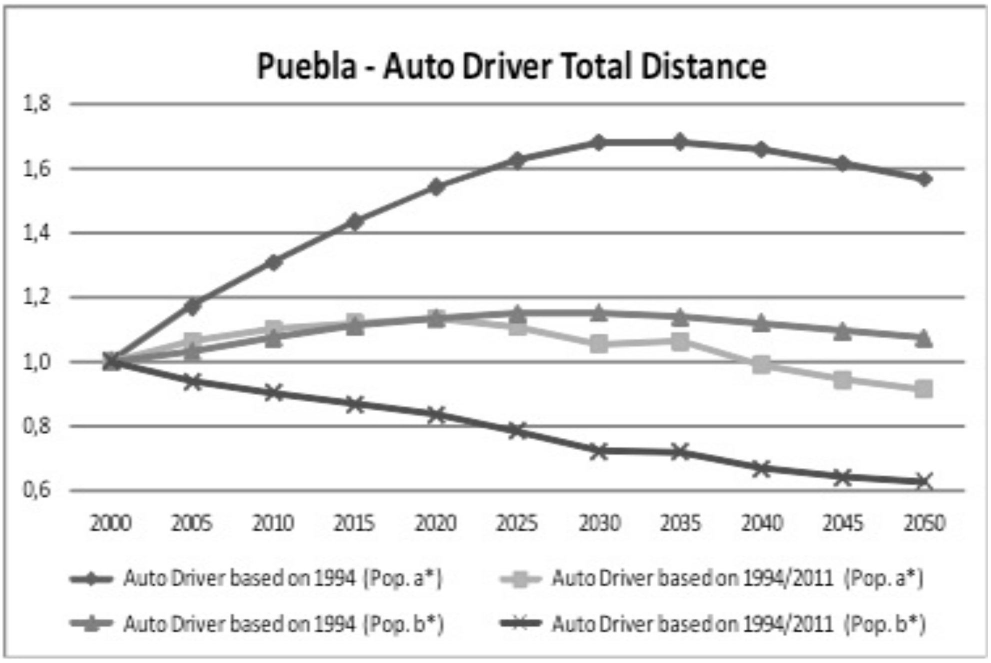


Figure 16. Puebla, total daily auto-driver distance simulations with the Age-Cohort Model, 2000-2050 (Indice 2000=1)



* Pop. a=variable; Pop.b = constant

5.3.4 CO2 Emissions

Even though a peak travel is observed in developed cities, a tendency which should occur in emergent cities but much later, the present level of CO2 emissions is much higher in developed cities as we can see from the French example (Table 2).

In the Paris Region Emissions have peaked between 1991-2011 (-0.04% yearly) and in Lille between 1998-2001 (-0.7%). In Juarez between 1996-2006 the emissions have more or less stabilized (+0.95%). In Puebla we observe between the two O-D Surveys a diminution of emissions (-0.70%) due to persistent poverty and most probably an under-estimation of auto trips due to the difficulty of surveying gated communities. Diminishing emissions linked to a lower level of car driving in Puebla will most probably not persist in the future considering the gap in car use between Puebla and the other case studies. Emissions are 5.7 times higher in the Paris Region than in Puebla. Those of Lille 1.9 times higher than in Juarez, which has 2.3 times more emissions than Puebla. This enormous gap in motorization between developed and emergent cities will slow the occurrence of a peak in emergent cities.

These results combined with world population projections (Table 3) give us an idea of the scale of the challenge to reduce emissions from the transportation of persons.

Table 2: CO2 emissions (gr) per capita from transportation of persons

	CO2 (gr) per capita			Anual variation	
Paris Region		**1991**	**2011**		**1991-2011**
		2,688	2,678		-0.04%
Lille	**1987**	**1998**	**2006**	**1987-1998**	**1998-2006**
	1,794	2,201	2,084	2.10%	-0.70%
Juarez		**1996**	**2006**		**1996-2006**
		1,007	1.103		0.95%
Puebla		**1994**	**2011**		**1994-2011**
		539	472		-0.70%

Source: Irving Tapia-Villareal, 2014.

Table 3: Population of the world and major areas, 2015, 2010, 2050 and 2100, according to the medium-variant projection

	2015	2030	2050	2100	
World	7,349	8,501	9,725	11,213	
Africa	1,186	1,679	2,478	4,387	
Asia	4,393	4,923	5,267	4,889	
Europe	738	734	707	646	
Latin America & Carribbean	634	721	784	721	
Northern America	358	396	433	500	
Oceania	39	47	57	71	
	Source: UN, 2015				
		Annual growth*		*Variation 2015-2050*	
	2015-2030	2030-2050	2050-2100	*Vol*	*%*
World	0.98%	0.67%	0.29%	*2,376*	*100.0%*
Africa	2.34%	1.97%	1.15%	*1,292*	*54.4%*
Asia	0.76%	0.34%	-0.15%	*874*	*36.8%*
Europe	-0.04%	-0.19%	-0.18%	*-31*	*-1.3%*
Latin America & Carribbean	0.86%	0.42%	-0.17%	*150*	*6.3%*
Northern America	0.67%	0.45%	0.29%	*75*	*3.2%*
Oceania	1.25%	0.97%	0.44%	*18*	*0.8%*
	* Our calculations				

If we look at the horizon 2050 which we considered in our scenarios for emerging economies, World population would increase by 2,376 million, 54.4% from Africa, 36.8% fron Asia, 6.3% from Latin America and the Carribean, and only 2.5% from the Rest of the world. This represents a massive potential demand for mobility, car and motorcycle driving. Latin American and the Carribean with only 6.3% accounts for 150 million persons.

6. Discussion

Is there a common pattern of development in terms of transportation trends in urban areas in France, Canada and Mexico? We tried to identify relative trend patterns observed from various simulations of the Age-Cohort model which were made !for All Modes, Auto-Driver, Auto-Passenger, Public Transit.

The travel trend pattern observed in Mexican cities is clearly distinct from the pattern of Lille. 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 overall mobility when taking into account latest surveys. The contribution of population growth on total distance forecasts is greater in Puebla than in Lille and Juarez due to a strong increase of population. Two modes of transportation seem to have similar relative trends with different calibration periods in the French and Mexican cities. The first one is "Public Transportation" with an increasing relative influence in 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 transport. On the other hand in the Mexican cities we expect ageing of the population later in comparison to Lille; and since there were no major public transportation projects implemented in between surveyed years (in Puebla in 1994 - after the OD Survey - a ring highway was constructed, which should have stimulated car use), we could link the increasing use of Public Transportation mostly to poverty [Madre et al., 2012].

The second mode that has similar trends patterns in both countries is "Auto Passenger" which has a decreasing relative influence when taking into account most recent surveys.

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, a shift probably amplified by the economic crisis started in 2008. Besides this shift from "Auto Passenger" to "Public Transport" due to generational or behavioral changes, in Juarez an additional hypothesis that needs to be tested is the shift from "Auto Passenger" towards "Auto Driver". A decrease in "Auto Passenger" mode in developing countries is not good news, the rate of occupancy of vehicles being an important factor of energy efficiency per passenger*km.

In France per capita car use had a decreasing trend after 90's [Kuhnimhohf et al., 2013]. Our results show more a stabilization trend for Lille but only if the peak observed in recent years persists. Per capita "Auto Driver" mode in Puebla experiences also a decreasing relative trend only when taking into account the most recent survey of 2011, which was conducted in the context of an economic downturn that could have amplified the downstream trend. However, the population effect gives for Puebla a strong increase for the total number of kilometers driven in all scenarios.

Opposed to the case of Puebla and Lille per capita “Auto Driver” mode in Juarez has a more important positive trend and total distance for all auto-drivers, still a more important rising trend. In Juarez peak car is not clear since the last survey shows a strong use of private vehicles, and ageing is not strong enough to slow down motorization trends in the following years.

In spite of the complexity of having different observations and models to compare, the analysis of relative trends 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 Lille. It is also clear that even if relative trends tend to be similar in Juarez and Puebla, there is sufficient evidence indicating that there is no general pattern in Mexican cities and that mobility behavior can vary considerably from one city to another.

In our case studies in Mexico, we can also perceive a saturation phenomenon that could take place around 2030, that is in roughly 15 years, in the most traditional cities and slightly earlier in more developed cities due to ageing, provided there is a slowdown in population growth, according to the demographic transition. However, the car fleet is old and does not tend to get any younger, because of lack of purchasing power, also due to policies that encourage ownership of old vehicles, such as the annual vehicle tax from which cars aged 10 years or older are exempted - a tax that was recently abolished at the national level (federal tax) and in certain states (Puebla and Tlaxcala in 2011) and the bi-annual pollution control tarifs are slighly higher on newer vehicles.

Given the finding that urban car mobility has reached a saturation point, or at the very least has been slowing in the developed countries, along with the probable appearance of a similar tendency in emerging economies, but only in about 15 years after intense pressure for individual car ownership, what can be concluded in policy terms?

In developed countries, where the growth of cities is slowing, there is an encouraging sign that it will be easier to shift the focus of urban transport planning: restrict car usage in the city, which many developed cities are doing, while promoting the use of public transport and soft modes; find ways to control urban extension by densifying suburbs; rethink the construction of toll roads at the periphery of metropolitan areas, which are perhaps no longer useful nor worthwhile economically; rethink our conception of quality-of-life in the city, with less emphasis on the fluidity of car travel; introduce various measures to manage demand in order to diminish the number of trips and car travel within cities. It would also be necessary to address the 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 emerging economies, despite the great disparities from one city to another, the example of Puebla and Juarez can give 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; cities will expand in a way that is disordered with urban sprawl; the great majority of transport policies will continue favouring the use of automobiles, along the lines of the US model from the 1970s, at least in Mexico and in most of Latin America; most public transport is fairly rudimentary and not very competitive in relation to travel by car, and the absence of redistributive taxation makes it difficult, except in very large cities, to modernize it and introduce operating subsidies to make it more competitive; the public's lack of awareness of environmental issues; security problems complicate the introduction of non-motorized modes, which cities in the north are promoting. What, therefore, would be the most appropriate policies?

First, existing facilities must be strengthened. Many Mexican and Latin American cities built on the European model still have high population densities comparable to that of European cities. Policies should be oriented to maintain the density of city centres and avoid constructing ring roads without complementary land use control measures to avoid population migration from the centre to the periphery; pursue modernizing public transport to make it more competitive relative to cars and to change its image from a mode of transport for poor people to a mode of transport for everyone; foster the introduction of pedestrian areas in city centres as well as in suburbs; foster continued use of bicycles in many cities where it has not yet disappeared; promote the expansion of bicycle use for utilitarian and recreational purposes; regulate the fleet of taxis and private cars, to make it younger, with cleaner vehicles; disseminate information and facilitate procedures to have access to carbon vouchers that could finance these measures.

7. Conclusion

To conclude briefly we can say that in developed economies car ownership has reached high levels and has shown signs of saturation in most developed cities. This tendency should persist if cyclical phenomena (i.e fuel price and economic growth) have not too much influence. However, the level of CO2 emissions from car use in developed economies is much higher than the one observed in emerging economies. The scenarios presented show a resistence to diminish car use, therefore emissions. We need changes in technology and a combination of measures to lower car use in cities.

The mexican case studies show that situations in emergent economies can be very diversified but that the main trend is towards an increase in car driving and that the population impact is absolutely determinant in these trends. The actual level of CO2 emissions is much lower than in developed economies due to less car ownership and use but the tendency will most probably be growth to catch up with developed economies with an ageing car fleet. The demographic transition (i.e. a decrease of population growth rates combined with population ageing) should induce a similar peak as that observed in developed economies but not before 15 or 20 years. In other emerging economies where population growth is still high and level of car ownership is low we could expect similar results. The mass effect of population growth in emerging economies at the horizon 2030 or 2050 will no doubt have a tremendous impact towards an increase of CO2 emissions from the urban transportation of persons.

Mainly for demographic reasons, 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 with two main time-lags: the first, within 15 years and later, purely demographic, is linked to lower demographic growth and population ageing, and the second representing the catching up process of car ownership and use which can last much longer. The challenges for sustainable transport are as great as ever.

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