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TOPIC 15
TRAVEL CHOICE AND
DEMAND MODELLING

DEMOGRAPHIC DYNAMICS OF MOBILITY IN URBAN AREAS: A CASE STUDY OF PARIS AND GRENOBLE

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Abstract

This paper presents a socio-demographic method of forecasting urban travel demand applied to two case studies: the Paris Metropolitan Region (11 million) and the Grenoble Metropolitan Region (0.5 million) over the period 1990-2010. The Age-Cohort model presented incorporates an analysis of household behaviour in terms of motorisation to generate future travel demand.

INTRODUCTION

This paper presents a socio-demographic method of forecasting urban travel demand based on two case studies: the Paris Metropolitan Region and the Grenoble Metropolitan Region. The model incorporates both an analysis of household behavior in terms of motorization defined here as car ownership of the household and an analysis of the behavior of individuals in terms of mobility and modal choice. The profound structural changes which have accompanied the rapid growth of individual mobility in developed countries underline the necessity of studying transportation demand not only in a context of equilibrium, but also in a context of historical evolution (Goodwin et al. 1987). Only a longitudinal analysis of behavior, centered on the time series analysis of the behavior of individuals or cohorts, permits us to identify the factors of this evolution. At the national level, we find various examples of the use of demographic techniques to realize long-term projections of total car fleet and car use: in the Netherlands (Van den Broecke and Van Leusden 1987), in Sweden (Jansson 1989), in France (Madre and Gallez 1992; Gallez 1994). This method has also been applied at the regional level (Madre and Pirotte 1991 and Peltan 1992). At the local urban level, the influence of structural factors on the long-term evolution of travel demand can be seen in at least three ways: the growth of the total population, its aging, and its spatial distribution in the form of urban sprawl. Bussière (1990, 1992b) has presented a prospective analysis of travel demand in the Montreal Metropolitan Region showing the important influence of purely demographic trends. In the present article, we present the projections of motorization of households in the Ile-de-France or Paris Metropolitan Region (Madre, Armoogum et al. 1994) and in the Grenoble Metropolitan Region (Madre, Girard et al. 1994). In each region we will distinguish three concentric zones to take into account the phenomenon of urban sprawl: the central city, the inner suburbs, and the outer suburbs. The population of the two sites (Paris, 11 million and Grenoble, 0.5 million) and their sub-areas as well as their population densities are important factors which distinguish them. We may add other variants to this, namely, the history of the diffusion of automobile use, which was different in Paris from the provincial cities. Since the expansion of automobile use is a major factor in the evolution of mobility behavior patterns, we will first present results on motorization levels. We will then treat the question of mobility (globally and by mode), both in terms of number of trips and distance travelled (in kms). After a general presentation of the Age-Cohort Model, we will indicate the specificity of its application to different phases of the projections and show how it describes the process or dynamics of motorization during the last fifteen years in the two regions of study. We will then analyze the projections of the model for the horizon year 2010 and discuss the issues at stake in terms of transportation policy.

WHAT IS AN AGE-COHORT MODEL?

Why a demographic approach to motorization?

The origin of this approach is two-fold. First, it forms a critique of the traditional econometric models used for the long-term projection of motorization. If, in a cross-section analysis, household income remains one of the main variables explaining the rate of motorization of households, it cannot be considered, at the current stage of diffusion of private car use, as the only factor explaining the rise in the rate of car ownership. Second, the choice of a new approach corresponds also to the need to locate the analysis of motorization in a precise temporal setting, by explicitly taking into account the history of the diffusion of the use of the automobile. In this way it incorporates the phenomenon of saturation which starts to appear, without having to establish an a priori level of saturation. Thus the model should take into account the history of the implementation of automobile use, namely the differences in its diffusion in Paris compared to provincial regions. A recent paper (Madre, Bussière et al. 1994) showed even more important differences in diffusion patterns between French cities (Paris and Grenoble) and a North American city (Montreal). Most life cycle profiles of individual travel demand show changes through time, under the combined influence of the replacement of generations and factors linked to the general economic environment, such as the evolution of the standard of living, of consumer tastes, and of travel supply patterns. Only a longitudinal analysis, or a time series analysis of successive generations, allows us to measure the relative importance and persistence of this evolution.

Decomposition of time into three variables: age, generation and period

The longitudinal approach highlights the complex impact of age which, in a dated temporal context, consists of three interlinked dimensions: (1) the moment in the life cycle where age becomes important for car ownership decisions and travel behavior; (2) the generation (or age cohort), which identifies the behavior of individuals born during the same period, and therefore sharing a common life experience; and (3) the period, which indicates the impact of the global socio-economic context. The evaluation of the effect of life cycle status gives us a characteristic curve that indicates the evolution of mobility related to age and corresponds to a stabilized pattern of behavior (designated as the *Standard Life Cycle Profile*). The introduction of the generation effects (generally measured in terms of lag time) which we have designated as *Generation Gaps* constitute a first amendment to the vision of equilibrium, and permits us to place this profile in a historical perspective. For instance, in the case of the acquisition of durable goods, this approach is quite relevant, since it shows us the importance of effects of diffusion linked, for example, to the evolution of the life styles, institutional constraints, needs of the consumers, or characteristics of supply. We will show that we can extend its application to the analysis of relatively stable behavior patterns such as the daily mobility in large urban areas. Finally the taking into account of *Period Effects* permits us to measure short-term or medium-term factors of disequilibrium which simultaneously affect all the individuals or households. They can be neglected in the case of short-term disequilibriums, but they will be taken into account in the cases where they appear to be structural changes not explained by the generation gaps (as in modal choice, for example). The long-term projection model is thus comprised of two parts: (1) a projection of the age structure of the population, which allows us to take into account purely demographic phenomena, in relation, for example, to urban sprawl and to aging which is foreseeable in most industrialized societies; and (2) fundamental to the model, the estimation of a Standard Life Cycle Profile and its evolution through time, calculated by a simple analysis of variance with three dimensions: age, generation, and period.

Construction of the Age-Cohort model

Since the hypothesis of stability of the period effects tends to be very fragile in projection, we can generally neglect it and specify an Age-Cohort Model. In the case of car ownership, the behavior of households, which is a major factor affecting mobility, a longitudinal analysis applied to French data at the national level (Madre and Gallez 1992) shows the importance of gaps between successive generations, as well as the remarkable stability of the curves throughout the life cycle. Once the respective influences of age and generation have been isolated, it appears that the effect of the global economic context (petroleum crisis and post-crisis, economic growth, recession,...) can be considered as residual. We found similar results for individual motorization, mobility and modal choice. We have therefore specified a model of an "Age-Cohort" type, which can be treated as a model of analysis of variance with two factors, the modal value of an age group (age 37 for 35-39), and the modal value of a generation cohort (1948 for cohort 1946-50), corresponds to an explanatory variable:

$$M(a,g,t) = A(a) + B(g)$$

where:

M(a,g,t): measures a characteristic or behavior (proportion of households owning a car, number of kilometers travelled daily by person,...) observed at the date "t" (year of the surveys), when the age of the person of reference (generally the individual, and in some cases the head of the household) who belongs to the generation "g"(defined by his date of birth) is equal to "a";

A(a): measures the behavior of the generation of reference at the age "a". This permits us to define a standard profile during the life cycle (part (a) of figures 1 to 8);

B(g): measures the gap in years between the cohort g and the generation of reference g° (for the study of car ownership as shown in Figures 1 and 2, the generation of the household heads born between 1946 and 1950 for which we fix B(g°) = 0);

The unit of measurement which was used is five years, both for the definition of the generations and for the description of the standard life cycle profiles, this unit being standard in demographic analysis. The life cycle is represented by the age groups: 5-9 years, 10-14 years,.... 80-84 years and "85- +"; for the analysis of households the first age group of the head of household is "15-19 years". In the case of small samples we may aggregate the latter age groups. The observed generations correspond to the dates of birth: "before 1915", 1916-1920,..., 1981-1985, to which we have to add, for the projections, four cohorts (1986-1990,..., 2001-2005) for which we have no observations.

FURTHER METHODOLOGICAL CHOICES

The main idea in our approach is to outline the variables of age (with its components of life cycle, generation and period mentioned above), of gender, and of spatial distribution to explain the dynamics of motorization, mobility, and modal choice. The trips are largely conditioned by the supply of travel modes, especially the availability of a car (Bonnafous 1993). The rate of motorization thus appears as a key variable of mobility behavior. Therefore, we will start by studying motorization: first, at the level of the household, namely to project the number of automobiles, then at the level of the individual to be able to study mobility patterns. This latter analysis which develops measures in terms of number of trips as well as in terms of distances travelled will be done globally and by travel modes. The analysis will be based on the Global Surveys of 1976-77, 1983-84 and 1991-92, which give, for the Parisian region, consistent data through time on motorization and mobility. We will project, to the horizon year 2010, motorization, mobility and choice of mode, transposing at the local level the methodology developed at the national level (Gallez 1994). For the projections, the Paris metropolitan region was divided in three zones: the City of Paris (central city), the "petite couronne" (inner suburbs), and the "grande couronne" (outer suburbs). The measure of distances travelled was facilitated by the grid pattern of 300 meters used to locate the origin and destination of the trips. For Grenoble, household surveys were conducted in 1978-79, 1984 and 1992. Smaller samples and larger zones (to calculate distances) make data less accurate. The main problem however is that households located in the outer suburbs have not been surveyed in Grenoble.

Car ownership of households and automobile fleet

We consider that the household remains the unit of decision for motorization even though multi-vehicle acquisition tends to individualize the choices. The generations are defined by the date of birth of the head of household. Motorization is characterized by lack of ownership on the one hand, and by multiple vehicles on the other hand, the proportion of single vehicle ownership being calculated by the difference. The car fleet is estimated by taking the product of the number of households and the proportion of single ownership and multiple ownership. We can also estimate the fleet by multiplying the number of adults by the average number of cars per adult. A longitudinal analysis of motorization behavior based on French national data (Madre and Gallez 1992) shows the importance of generation lags in behavior and the remarkable stability of the curves in relation to the life cycle. Once the age and generation effects have been taken into account, the period effect (economic or political context) appeared to be residual and thus justified the age-cohort approach.

Individual motorization

To measure the availability of the automobile, we used as a proxy, a factor relating to a household without a car, with one car, or with two or more cars. This criterion proved quite discriminatory relative to the level of mobility (increasing with motorization) and to modal choice (highly linked to car accessibility). We adjusted the model for three categories, adult men, adult women and the young (less than 25 years), to take into account the fact that children in a household are not those who make the decision regarding vehicle ownership in the household (although they might influence it).

Global mobility

The analysis of mobility (global and by mode) is measured in two ways: in terms of the frequency of trips (average number of trips by person for a typical week day) and in terms of distance (number of kilometers travelled by person per week day). For global mobility we used the Age-Cohort Model, the period effect being negligible.

Modal choice

Five types of travel modes were considered: (1) car driver, which permits us to estimate vehicle-kilometers when we measure mobility in distance travelled; (2) car passenger, which permits to calculate a rate of occupation per vehicle by comparison with the mobility of the drivers; (3) urban transit; (4) walking; (5) other modes (two wheels, school bus, employer shuttle, taxi, etc...).

The generation effects already present in the individual motorisation and in the global mobility models were statistically insignificant in the analysis of modal choice. However, important period effects exist partly due to supply factors: increase in highway infrastructures and transit supply, decline in the incidence of walking and the use of two-wheel transport. The modal split was calculated by adjusting linear regressions separately for each category created by the application of the following variables: zone of residence, motorization, gender, and three age groups: 6-24; 25-54, and 55 and over. In cases where the samples were too small we had to fine-tune the adjustments by hand.

RESULTS FOR THE OBSERVED PERIOD

To simplify the presentation, we will present only the figures for the Paris metropolitan region. However, we will also comment on results published elsewhere for the Grenoble region (Madre, Girard et al. 1994 and Madre, Bussière et al. 1994).

Motorization and the automobile fleet

The rapid growth of motorization after the Second World War shows important gaps between successive generations, which confirms the necessity of a longitudinal analysis. The different phases of motorization appear in the different curves of the average number of vehicles per household (Gallez and Madre 1992). During the period of economic growth (the sixties), households of all generations started to motorize. Since then, the diffusion of automobile use has been generalized, and the pattern of motorization of households during its life cycle seems to have stabilized. Figures 1a and 2a show the Standard Life Cycle Profiles of the generation 1946-1950. From these profiles we can observe that, for the young households, access to the first automobile is rapid. Households reach a minimum rate of non-motorization (or a maximum rate of motorization) around the age of 35. This motorization happens slightly earlier outside the central city (Figure 1a). The access to a second car is more gradual; the maximum rate of multi-motorization is reached when the head of household is in the 50-54 year old bracket, this period in the life cycle corresponding to the acquisition of a car by grown-up children in the household (Figure 2a). After this maximum value, the rates of the non-motorized rise progressively through to the end of the life cycle; this movement being accompanied by a diminution of the rate of multi-motorization due to the changes in the household (departure of the children, widowhood, ...). However, if, in order to take these modifications into account, we examined the number of cars owned by adult, which gives a better measure of behavior towards the end of the life cycle, we would find that the number of cars by adult also diminishes around the age of 60: In the inner suburbs of Paris, its rate of decrease between the age groups of 60-64 and 75-79 is 34%. In Grenoble the decline is less significant. At all ages and in both regions, motorization increases as we get farther from the central city. In the middle of the life cycle and for each zone (central city, inner suburbs, outer suburbs), the level of motorization follows a pattern inversely proportional to the size of the regions: it is higher in Grenoble than in Paris.

Generation gaps

To the life cycle effect we must add the differences between generations or generation gaps which are illustrated here for the age group 35-39 years, as calculated by the model for the different generations (Figure 1b for the non-motorized and in Figure 2b for the multi-motorized). For the City of Paris (central city), the rates of non-motorization reach a low for the generations born in 1926-30 until the generation of 1951-55, followed by a rise in the proportion of non-motorized. In the inner and outer suburbs the low is reached somewhat later, around the early fifties. However, we do not observe these trends for the multi-motorized household. In Grenoble, we found that the most motorized generation seems to be born in the sixties, but we are not absolutely certain about the apparent change of trend since. During the last survey, the indication is that the next generation was still incomplete. Even though the differences are not very significant in the maximum range, it appears that the most motorized generation, mainly in Paris, becomes younger as we get farther from the centre. However, the differences are much more pronounced in the outer suburbs than in the inner suburbs in both regions, since the curves intersect for the generations born in the twenties in Paris (Figure 2b) and in the thirties in Grenoble. This illustrates the heterogeneity of the population living in the outer suburbs which may be due to the recent arrival of households with a higher level of mobility, who are still working in the central city (Andan and Faivre d'Arcier 1992). Finally we can say that both the generation lags or gaps and the turnaround of tendencies observed for the rate of motorization indicate in a dynamic way the phenomenon of saturation. We will now show how this model can be adapted to analyse mobility.

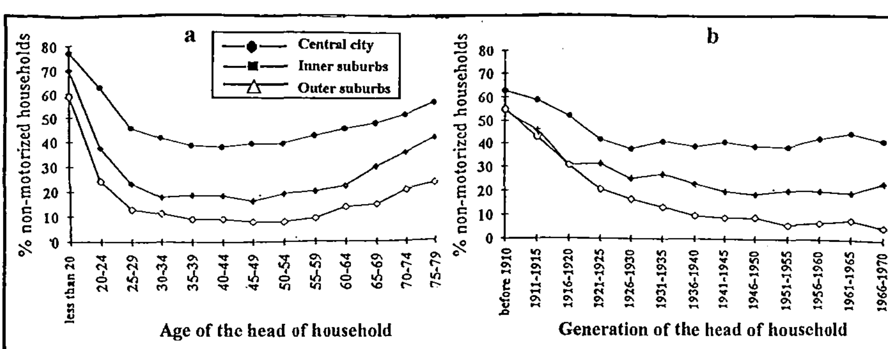

Figure 1 **% of non-motorized households according to the age of the head of the household:**
a) standard life-cycle profile for the generation 1946-1950;
b) generations gap for the age group 35-39 years

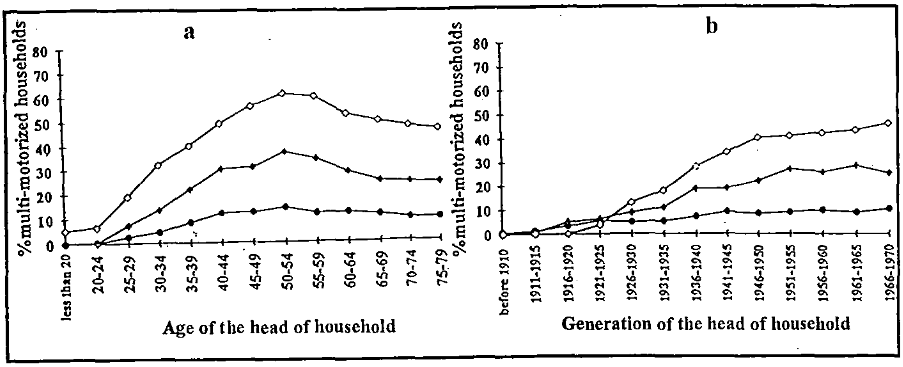

Figure 2 **% of multi-motorized households according to the age of the head of the household: a) standard life-cycle profile for the generation 1946-1950; b) generations gap for the age group 35-39 years**

Global mobility

Both the per capita daily mobility and the choice of mode can be described either in terms of number of trips or of distance travelled. Both measures give very different results.

Number of daily trips

Figures 3 to 5 show patterns of daily per capita mobility according to various characteristics, in terms of the Standard Life Profile of the generation 1966-1970 (part a of figures) and in terms of the Generation Gaps (part b of figures). Figure 3a shows that mobility defined in terms of daily trips per capita is closely linked to the life cycle. Mobility grows from childhood up to the age group 20-24, reaches a peak in the 25-29 or 30-34 age group depending on the zone of residence, and steadily declines afterwards along the life cycle. These results are very similar to those observed by Bussière in Montreal (Bussière 1990). Furthermore, the differences in global mobility vary little with the place of residence, the number of trips being more dependent on the life pattern (school, work, shopping,...) than on the choice of mode. Globally, the average number of daily trips observed was 3.48 for the Paris metropolitan region in 1991, compared to 3.66 for the central city, 3.37 for the inner suburbs and 3.49 for the outer suburbs. The generation gaps, as calculated by the model, are illustrated in Figure 3b for the age group 20-24 years. We find that mobility is higher for the generations born in the first half of the century and decreases thereafter, which could imply decreased mobility in the future. The number of daily trips is higher for the central city than for the suburbs. Furthermore the rise in mobility is higher for women, probably due to a rise in the participation rate in the labor force, and the generation gaps by gender for the young generations tend to disappear (Figure 5b). The level of motorization of the household positively affects the level of daily mobility from the early twenties onward (Figure 4a). The average number of daily trips observed in 1991 in the Paris Metropolitan Region was 3.48 for the total population compared to 3.01 for persons in non-motorized households, 3.51 in motorized households and 3.76 in multi-motorized households. The generation gaps as shown for the age group 20-24 (Figure 4b) have tended to decrease since the baby boom with a diminution in the mobility of the younger generations, which we could explain, at least partially, by their de-motorization.

In Grenoble, based on the household surveys, we observed a diminution in general mobility between 1979 and 1992. The per capita daily mobility has dropped from 4.39 to 3.84 (-12.5%), the decrease being observed for both sexes, for both the central city and the inner suburbs and for all levels of motorization. However, mobility is higher for motorized households than non-motorized (in 1992 it was 2.82, 3.81 and 4.30 for individuals belonging, respectively, to households with zero, one and two or more cars).

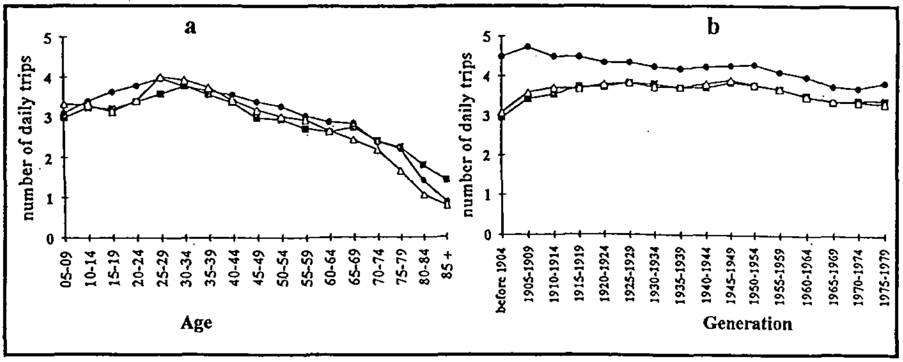

Figure 3 Number of daily trips by zone of residence and by age:
a) standard life cycle profile for the generation 1966-1970;
b) generation gaps for the age group 20-24 years

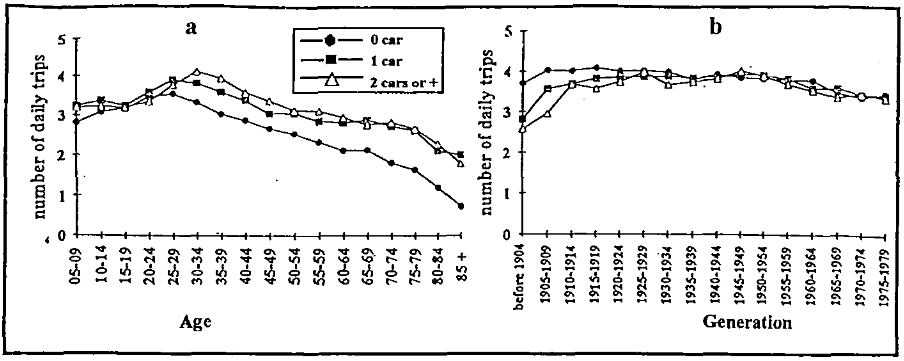

Figure 4 Number of daily trips by level of motorisation and by age:
a) standard life cycle profile for the generation 1966-1970;
b) generation gaps for the age group 20-24 years

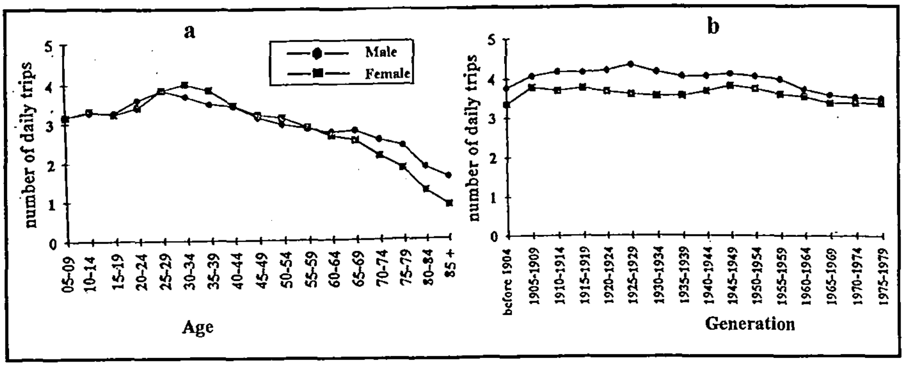

Figure 5 **Number of daily trips by sex and by age:**
a) standard life cycle profile for the generation 1966-1970;
b) generation gaps for the age group 20-24 years

Daily distance travelled

The daily distances travelled show quite distinct patterns. They are closely linked to the life cycle and therefore to age, as we can see in Figures 6a and 7a. However the distances travelled vary considerably according to place of residence and to sex. The distances travelled are much higher in the outer suburbs than in the inner suburbs and the central city. The average daily distance travelled as observed in 1991 in the Paris metropolitan region was 16.2 kms, compared to 11.0 for the central city, 13.4 for the inner suburbs and 21.1 for the outer suburbs. Differences by sex were also quite significant with 19.8 kms for men compared to 12.8 kms for women. We also find a strong positive link between distance travelled and motorization (Figure 7a). The average daily distance travelled was 9.2 kms for persons in non-motorized households compared to 15.8 with one car and 21.5 kms for households with two or more cars. A rapid glance at generation gaps (part b of Figures 6 to 8) shows that the differences of behavior between gender tend to diminish but that the distances tend to rise for both sexes and that the other indicators also show tendencies towards increasing distances linked to motorization and to urban sprawl.

Grenoble shows similar results. Even though the total number of trips travelled has diminished since 1979, a trend observed in most French cities, the average daily distance travelled has increased by 27% between 1979 and 1992, from 3.0 kms to 3.8 kms.

Average distances per capita travelled matched to population gives the number of person-kilometers, which can be used as an indicator of future travel demand, since even a stable or decreasing average mobility could mean more traffic in a context of significantly increasing distances travelled. We will use this concept to analyse travel modes in the next section.

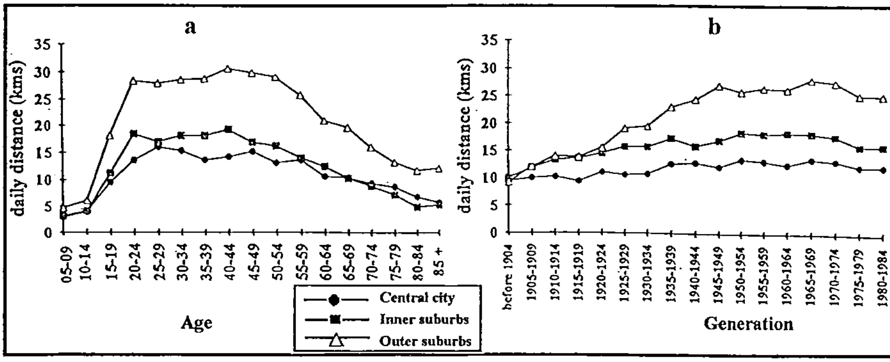

Figure 6 **Daily distance travelled by zone of residence and by age:**
a) standard life cycle profile for the generation 1966-1970;
b) generation gaps for the age group 20-24 years

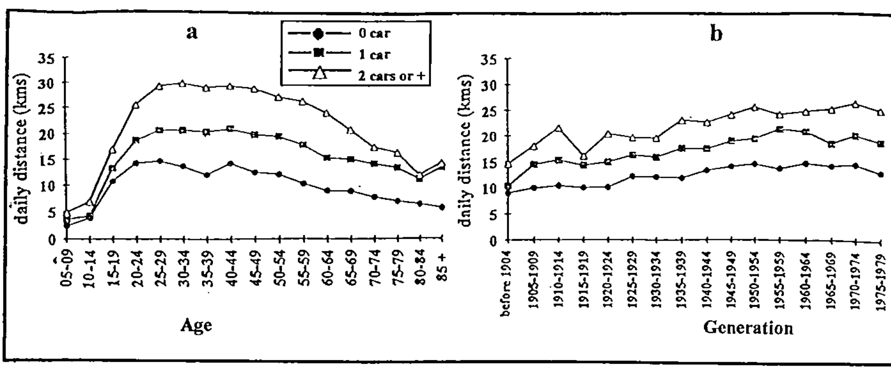

Figure 7 **Daily distance travelled by level of motorisation and by age:**
a) standard life cycle profile for the generation 1966-1970;
b) generation gaps for the age group 20-24 years

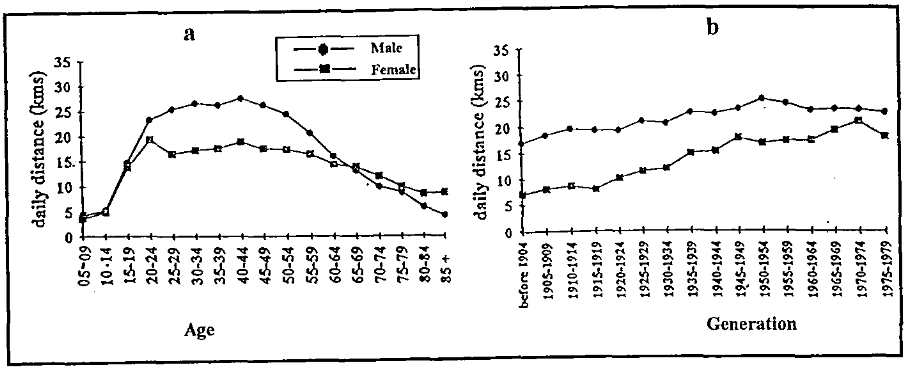

Figure 8 **Daily distance travelled by sex and by age:**
a) standard life cycle profile for the generation 1966-1970;
b) generation gaps for the age group 20-24 years

Choice of mode

In this section, mobility is considered in relation to choice of mode, using the methodology summarized earlier. The analysis of modal choice takes into account variables of age, sex, zone of residence, and level of motorization of the household. In the Paris Metropolitan Region, the observed number of trips per capita has diminished slightly between 1977 and 1991 (from 3.49 to 3.48) which has led to a small increase in the total number of trips (+9.0%) due to population effects. However, with the increase in average distance travelled, this has lead to a significant rise (+30.4%) in the number of person-kilometers. By travel mode, between 1977 and 1991 the observed pattern in the Paris region (Table 1) indicates a rise in the proportion of "car drivers" (24.7% to 33.2%), "car passengers" (7.7% to 10.2%) and "transit" (18.2% to 19.1%). The diminution of "walking" (42.2% to 34.1%) can be explained mainly by slower growth of this mode compared to the motorized modes. Even though the differences in gender diminish, they remain important in 1991: 40% of the trips of men are made as "car drivers" while the same percentage is made by women "walking". The spatial distribution of modal split is rather stable: the farther we are from the central city, the less "transit" and "walking" are used and the more the car is used.

Table 1 **Observed choice of mode (in %) in Paris, 1977-1991, and Grenoble, 1979-1992**

	Paris				Grenoble			
	1977	1991	1977	1991	1979	1992	1979	1992
Mode	trips		distance		trips		distance	
Car driver	24.7	33.2	37.4	45.0	29.6	42.7	48.2	59.8
Car passenger	7.7	10.2	9.5	10.3	9.8	12.2	15.5	15.4
Transit	18.2	19.1	37.5	36.5	7.7	11.9	12.4	14.1
Walking	42.2	34.1	8.0	4.3	40.0	27.6	7.7	4.2
Other	7.2	3.4	7.6	4.0	12.9	5.6	16.2	6.5
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

The portrait rendered by distance travelled is quite different. We observe a much stronger domination of the "car driver" mode which reaches 45.0% in 1991, a slight diminution in transit and a very low proportion of walking which accounts for only 4% of the person-kilometers in

1991. The results for Grenoble for the period from 1979 to 1992 show similar patterns in a context, however, of a much lower use of transit. The daily mobility has diminished from 4.39 to 3.84 which has led to a diminution of total trips of 11.0%. However, in terms of person-kilometers, we observe a rise in mobility of 12.4%. As in the case of Paris, most of this rise has been taken over by the car drivers. We observe nonetheless a slight rise in transit usage due to supply effects deriving from the implementation of an efficient light rail system.

PROJECTIONS

The aging of population and urban sprawl

The three main demographic factors which will affect the future car fleet volume are the growth of population, aging and urban sprawl (Table 2). The two sites were each divided into three concentric zones: the central city, the inner suburbs and the outer suburbs.

Table 2 Comparison of demographic data in Paris and Grenoble, 1990 - 2010

	Paris				Grenoble			
	C	IS	OS	T	C	IS	OS	T
Population ('000)								
1990	2 150	3 981	4 513	10 664	150	216	190	556
2010	2 120	4 116	6 033	12 270	137	218	259	614
Population growth (%)								
1990-2010	-1.4	3.4	33.7	15.3	-9.1	1.2	36.3	10.4
Density (Pop/Ha)								
1990	204.2	60.7	4.0	8.9	83.2	10.2	1.5	3.8
2010	201.2	62.8	5.4	10.2	75.4	10.1	2.1	4.2
Household growth (%)								
1990-2010	0.5	8.4	42.9	19.1	-6.0	11.7	46.2	17.3
Distribution of total population								
1990	20.2	37.4	42.4	100	27.1	38.8	34.1	100
2010	17.3	33.5	49.2	100	22.3	35.6	42.1	100
% 65 years and over								
1990	15.2	10.8	8.7	10.8	13.9	8.7	11.3	11.0
2010	13.9.	12.4	10.9	11.9	19.8	13.0	13.9	14.9
Average age of head of household								
1990	48.1	47.6	46.8	47.4	48.1	47.6	49.9	48.5
2010	48.4	49.5	48.9	49.0	51.3	51.6	51.4	51.5

Notes:
Definition of the zones: C: central city; IS: inner suburbs; OS: outer suburbs

Paris:		Grenoble:	
C:	City of Paris	C:	City of Grenoble
IS:	"petite couronne", ie departments 92,93,94	IS:	SIEPARG less Grenoble
OS:	"grande couronne" or rest of Ile-de-France	OS:	RUG less IS and C
T:	Total	T:	Total

The densities observed in each zone for the two sites vary considerably in 1990. However, in each case, the central city represents sufficient density for viable transit and the possibility of road congestion (204 inhabitants per hectare in Paris and 83 in Grenoble), and the outer suburbs have in each case very low densities, in the 1.5 to 4.0 range. The inner suburbs represent more significant variations since they vary from a low 10.2 in Grenoble, to a high of 60.7 in Paris. This typology, as we have seen by the results, yields valuable insights regarding the impact of the urban form on motorization. In the two study areas, the rate of population growth will be rather slow, in the 10%

to 15% range over the whole projection period covered, 1990-2010. This reflects a low birth rate which is characteristic of most Western industrialized cities. The rapid diminution in the birth rate from the sixties will have a important impact on aging. If we measure aging by the proportion of population 65 and over in each metropolitan region and each zone, we find that the aging is similar in the two sites: 10.8% in Paris and 11.0% in Grenoble. However the spatial distribution in each site is quite different, namely, the population in the outer suburbs is younger in Paris than in Grenoble. If we compare now the projected evolution, we find very contrasting results linked to the post-baby boom curve mentioned above. The aging process will be more rapid in Grenoble (from 11.0% to 14.9%) than in Paris (from 10.8% to 11.9%). The rate of aging will raise the average age of the head of the household in most areas. In 2010, it will reach its maximum in the inner suburbs in the two study areas. To these phenomena we may add the tendency of a reduced size of household which will lead to a higher rate of growth of household than of population (or lesser diminution). These tendencies are the result of natural increase, external and internal migrations, and family behavior. These combined effects will give for the horizon year 2010 a strong tendency towards sprawl. In both sites, the central city will see its population diminish, the inner suburbs more or less stabilize, and the outer suburbs grow in the 33% - 36% range. In 2010 the weight of the outer suburbs in both areas will be in the 42% to 49% range.

Calculation of projections

The projections are made in accordance with the following steps: (1) Calculation of the distribution by age of the variable studied [M(a,g,t)] at the horizon of projection "t" applying the model described above: $M(a,g,t) = A(a) + B(g)$. Since $t = g + a$, we obtain: $M(a,g,t) = A(a) + B(t-a)$; (2) Sum the elementary rates thus obtained using the demographic projections P(a,t) by age groups (number of individuals or of households).

To determine the behavior of the young, we must also extrapolate the lags between the trajectories of future generations. This exercise is delicate and presupposes an initial attempt to assess the reliability of the lags estimated for the last observed generations. We found that the projections seem more reliable if we extrapolate the behavior of future generations (not yet born) on the basis of the second-last survey rather than on the most recent one, which gives an incomplete portrait of the last generation and is therefore likely to be biased. Furthermore the additive model of analysis of variance does not guarantee that the rates will be positive, and in the case of percentages that they do not exceed 100%. It is therefore necessary to introduce constraints in the projection program to assure consistency.

Growth of motorization: slow in the center, fast in the outer suburbs

The reduction in the rate of non-motorized households (Table 3) would be low in dense areas (central city of Paris and of Grenoble, inner suburbs of Paris) and higher in the outer suburbs. The density will always determine behavior: around half of the households will remain without a car in the central city of the Paris region, less in Grenoble (19% in 2010) and in the 7% to 11% range in the outer suburbs. The increase in second car ownership should persist, especially in the outer suburbs. The rates of multi-motorization should, however, decrease with higher densities, and therefore with the size of population of the areas. The evolutions of motorization which we have discussed and the migration of population from the central city to the suburbs lead to similar projections for the two sites. Globally, the projections give a significant increase in the number of cars for the period 1990-2010: close to 40% in Paris as well as in Grenoble. In dense areas, the growth of the car fleet should be controlled. During the next twenty years it should not be higher than 10% in the central city and 25% in the inner suburbs. However, in the outer suburbs, the expected growth is greater than 60%. The results are mainly due to age effects, accentuated by urban sprawl.

Table 3 Evolution of motorization and mobility in Paris and Grenoble, 1990-2010

	Paris				Grenoble			
Variable	C	IS	OS	T	C	IS	OS	T
Motorization								
% of non-motorized households Age-Cohort Model)								
1990	51.8	31.1	17.3	31.5	32.0	15.7	15.7	20.9
2010	49.0	29.3	11.3	28.0	27.4	9.8	7.5	13.5
% of multi-motorized households (Age-Cohort Model)								
1990	7.0	18.7	32.7	20.8	15.1	32.6	39.6	29.2
2010	9.4	24.4	44.1	28.5	19.0	42.1	58.2	42.4
Number of private cars ('000) (Age-Cohort Model)								
1990	601	1,374	1,806	3,781	55	90	80	226
2010	659	1,617	2,971	5,246	58	112	144	414
Var.%	9.7	17.7	64.5	38.7	5.5	24.4	80.0	38.9
Mobility								
Mobility (per capita daily trips) (Age-Cohort Model)								
1990	3.64	3.38	3.44	3.46	3.93	3.95	*	3.94
2010	3.50	3.28	3.32	3.34	3.21	3.64	*	3.47
Var. %	-3.8	-3.0	-3.4	-3.5	-18.3	-7.8	*	-11.9
Mobility (per capita daily distance in kms) (Age-Cohort Model)								
1990	10.8	13.2	20.1	15.6	11.44	15.92	*	14.06
2010	11.0	13.2	21.6	16.9	12.24	15.78	*	14.39
Var. %	1.9	0	7.5	8.3	7.0	-0.9	*	2.3
*Mobility (travellers*kilometers - '000,000) (Age-Cohort Model)*								
1990	21.9	48.8	83.9	154.2	1.59	3.13	*	4.73
2010	22.3	50.9	121.1	194.3	1.59	3.17	*	4.76
Var %	1.8	4.3	44.3	26.0	0	1.3	*	0.6
Choice of mode								
Choice of mode: car-drivers (in % of nb of trips (Trend Model)								
1990	15.7	30.4	41.2	31.7	33.7	45.9	*	40.8
2010	15.1	33.1	51.1	38.5	36.8	51.7	*	46.3
Choice of mode: car-drivers (in % of distance travelled) (Trend Model)								
1990	31.3	43.2	47.7	44.0	56.2	60.1	*	58.8
2010	29.3	46.7	55.3	50.1	60.9	66.8	*	64.9
*Distance travelled daily: car-drivers (in travellers*kms - '000,000) (Trend Model)*								
1990	6.9	21.1	39.8	67.8	0.90	1.88	*	2.78
2010	6.5	23.8	67.0	97.3	0.97	2.12	*	3.09
Var.%	-5.8	+12.8	+68.3	+43.5	7.8	12.8	*	11.2

Sources of observed data: Grenoble: General Census of the Population, 1975, 1982, 1990;
Paris: Global Transport Surveys, 1976, 1983, 1991.

* Not estimated because of lack of data; in those cases Total = C + IS. Those totals of Paris and Grenoble are therefore not directly comparable; for instance, the growth of travellers and kilometers by +0.6% in Grenoble could be compared to +3.5% in Paris (C + IS) for total mobility, and for car drivers only +11.2% in Grenoble corresponds to +8.2% in Paris.

The projection of the automobile fleet appears rather robust since we have tested alternative approaches for its establishment: (1) the product (comprised of the number of households multiplied by the average number of cars per household), resulting from the rates of non-motorization and of multi-motorization (main hypothesis), or calculated directly; (2) the product as the result of the number of adults per household multiplied by the number of cars per adult, which describes slightly better the behavior at the end of the life cycle; (3) an additive model of the analysis of the variance or multiplicative logit model; (4) an aggregated approach for the total metropolitan region or a disaggregated approach with three zones (main hypothesis); for the total metropolitan area of Grenoble. This last hypothesis leads to a projection of the car fleet in 2010 which is approximately 5% higher.

However, the evolution of the car fleet does not automatically condition travel demand. For this reason, we have adjusted the models on the basis of individuals to forecast the mobility by mode. In terms of daily trips the Age-Cohort Model gives a decrease in the general per capita mobility in both urban areas. In Paris, it diminishes from 3.46 in 1990 to 3.34 in 2010 (-3.5%) and in Grenoble from 3.94 to 3.47 (-11.9%), the decrease being somewhat stronger in the central city than in the suburbs. In terms of average daily distance travelled, we observe an increase of 8.3% in Paris and of 2.3% in Grenoble. The figure of Grenoble is underestimated since it does not take into account the outer suburbs. Mobility in person-kilometers should increase substantially, as we can see by the Paris estimation of an increase of 26%. Here again, Grenoble is underestimated.

In terms of choice of mode we find that the increase of multi-motorization, urban sprawl and increase in distances travelled will in the future induce a significant increase in the importance of the car relative to other modes, in terms of number of trips and of distance travelled (Table 3). The person-kilometers will also increase significantly. Figure 9 gives the estimated values of modal split for the period 1975-2010, in terms of daily trips (part a) and in terms of distance measured in person-kilometers (part b).

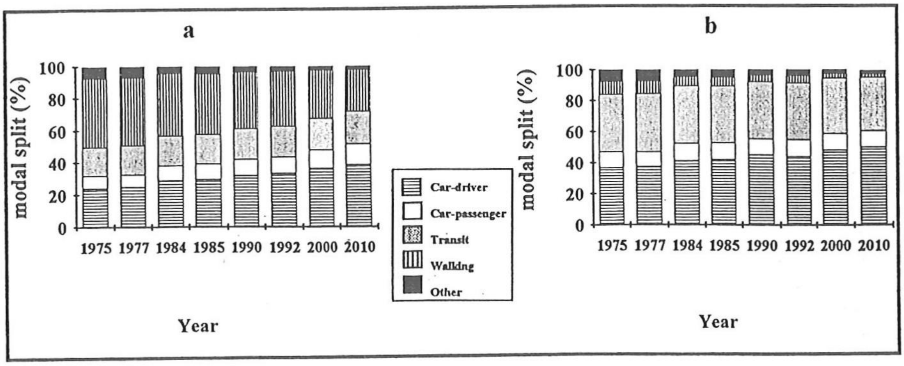

Figure 9 **Adequacy of the model in the modal split:**
a) of daily trips;
b) in terms of distance

CONCLUSION

The main quality of the spatially-disaggregated Age-Cohort Model is its ability to account for structural factors such as: (1) the rapidity of the aging of the population which is stronger in the suburbs than in the central city and differentiated generation gaps which will maintain the growth of motorization and of mobility in the outer suburbs; (2) persistence of a strong proportion of non-motorized households in the central city, diffusion of the second automobile in the suburbs, and the convergence of behavioral patterns by gender; (3) finally, urban sprawl which favors the growth of population in areas where the growth of demand is highest. Taking such factors into account often leads to non-linear trends and the phenomenon of saturation. The explosion of the car fleet in the outer core of cities and the increase of distances travelled will be main issues in urban transportation problems during the next decades. Since the density of these areas will remain low, it is difficult to imagine a substitution effect in favor of transit for local trips; so we can expect higher traffic flows. However, the growth of multiple car ownership in the suburbs may increase the adaptability of patterns of traffic, depending on the flexibility of schedules and destinations. The exchanges with the denser central city will depend largely on employment location which itself will depend on the relative attractiveness of the centre. If employment remains in the centre, we can imagine a form of complementarity between the automobile use—facilitated by the second car—and efficient public transport which would serve main lines. The LASER light train service in Grenoble is a good example of this. In the long run, it will be necessary to control the invasion of the centre by cars coming from the outer suburbs (through urban pricing, regulations, etc...). However, if activities move into the suburbs, the trips will be more diffuse and the adaptation of public transit will be more difficult. In different urban contexts, such as North American cities where the center cities have much more difficulty competing with the suburbs in terms of attractiveness, the impact of similar socio-demographic structural factors would result in future problems which would be difficult to solve if no action is taken. Our current research on the Montreal case will, in the near future, give us insights regarding this question.

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