

Measuring uncertainty in long term travel demand forecasting from demographic modelling: Case study of the Paris and Montreal metropolitan areas

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1. Introduction

For transportation and infrastructure planning, traffic forecasts by mode are essential. A clear understanding of long term trends is important for transport planning, a necessary step to elaborate scenarios and estimate relative costs (public vs. private transport). Uncertainty on traffic forecasts may have an impact on reimbursement scheduling for investment, as well as for scenarios for operating costs. Even the best projections are based on models and assumptions, thus raising the question of their accuracy. Indeed, long term investments are risky and it is important to cope with uncertainty.

Even though models based on demographic tendencies are probably those which resist best long term analysis, it remains crucial to take into account uncertainty in long term modelling and try to measure it in the form of a margin of error with confidence intervals. This paper will present such an approach based on long term travel demand forecasting with a demographic approach applied to the Paris and Montreal metropolitan regions. Three main sources of uncertainty or errors will be discussed: calibration of the model, behaviour of future generations, and demographic projections. One main source of error, the calibration of the model, will be illustrated with the Paris – Montreal comparison. The other two sources of error will be discussed with the Paris example.

2. Presentation of the Age-Cohort model

2.1 The model

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

The "Age-Cohort" model can be treated as a model of analysis of variance with two main factors (age and generation):

$$\pi_{a,k} = \alpha_a + \gamma_k + \varepsilon_{a,k}$$

Where:

- $\pi_{a,k}$: measures a characteristic or behavior (daily kilometres, number of trips per day,...) observed at the date t (year of the survey) where $t=a+k$ (a is the age of the individual reflecting the life cycle and k his generation, defined by his date of birth);
- α_a : measures the behavior of a generation of reference at the age a. This allows us to calculate a « Standard Profile » of the life cycle;
- γ_k : measures the gap between the cohort k and the generation of reference γ_{k^0} ;
- $\varepsilon_{a,k}$: is the residual of the model (which includes all other factors).

The unit of measurement used is the standard five years cohort which is usual in demographic analysis. It was used both for the definition of the generations and for the description of the standard life profiles, with the exception of age groups with small samples which required to be aggregated (individuals aged 85 years and older were classified in the age group "85 and over", and the individuals born before 1907 were grouped with the generation group "1907-1911").

In order to be able to distinguish between life-cycle and generation effects, the calibration of an Age-Cohort model (based on the analysis of variance) requires data on the mobility behavior of individuals for at least two observation periods. With two observations, there is no residue. However, it is preferable to have more observations to obtain a residual term taking into account factors not included in the model (i.e. income or price effects). In the present case we chose two cities with more than three surveys; Paris (Paris metropolitan region, or Île-de-France, with 4 Global surveys, 1976-77, 1983-84, 1991-92, 1997-98) and Montreal (Montreal metropolitan region: with 6 origin-destination surveys: 1974, 1978, 1982, 1987, 1993, 1998). The sample size for the Global surveys in Paris are around 10 000 respondent households (except for 1998 with 3 500) and in the 50 000 to 60 000 range for Montreal. The model for each case study was calibrated with these O-D surveys, which furnish detailed data on travel behavior on a typical week-day, and detailed demographic data by quinquennial age groups (observed and projected).

The following structural variables are explicitly taken into account:

- age (with its components of life-cycle and generation) and gender;
- spatial distribution for the zone of residence representing different density levels and distance to the centre of the urban area (Central City, Inner Suburbs and Outer Suburbs);
- level of motorization of the households (0 car, 1 car, 2 cars or more). This criterion, a proxy for the individual access to automobile, proves quite discriminatory relative to the zone of residence and the distance travelled which increases with motorization.

The model was adjusted for 3 categories of population: adult men, adult women and the young (under 25 years old, for whom motorization is generally determined by the characteristics of their parents rather than by their own).

Mobility is measured by two variables:

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

2.2. A first measure of the adequacy of the model

To compare globally the observed results with the model, for both regions, and both models (trips and distance) we adjusted a regression between the observations of the surveys and the estimates of the model at the finest level, i.e. crossing of the variables:

- zone of residence (3);
- motorization (3);
- gender (2);
- age groups (16) (05-09, 10-14, ... 85 or over);
- years of the data collection (4 in Paris and 6 in Montreal).

This gives us 1152 points for Paris and 1728 points for Montreal. These regressions indicate that:

- the R^2 is close to 1;
- the slope does not differ significantly from 1;
- the intercept does not differ significantly from 0 (except for Montreal).

Consequently, a first conclusion would be that in both study areas the Age-Cohort model is adequate to explain trips frequency and daily distance travelled (Table 1).

Table 1: The regressions of data from surveys on results from Age-Cohort models

Model :	R ²	Slope		Intercept	
		Parameter estimate	t value	Parameter estimate	t value
Paris region					
Number of trips	0.77	0.98	63.2	0.09	1.71
Daily distance travelled	0.94	0.99	141.5	0.21	1.75
Montreal region					
Number of trips	0.88	0.91	211.5	0.22	23.2
Daily distance travelled	0.97	0.99	433.3	0.31	10.6

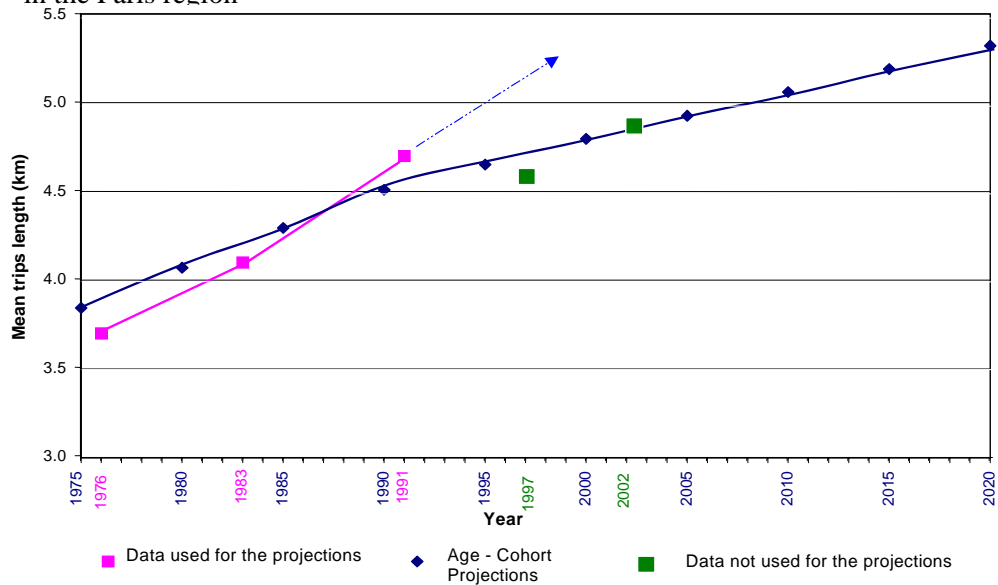
Sources: Calculations from Households transport surveys in Paris (1977, 1984, 1992, 1998).

Calculations from Montreal Metropolitan Area O-D surveys (1978, 1982, 1987, 1993, 1998).

2.3 Test of fitness of the model

To test the fitness of the model we can also calibrate the model on previous surveys and compare the results of the forecasts obtained from the model with of the observations of recent surveys (Figure 1).

Figure 1: Mean trips length : comparison between observed data and the projections in the Paris region



In an earlier publication (Madre & al., 1996), we calibrated two Age-Cohort models on the Paris region: 1) the daily trips frequency and, 2) the daily distance traveled. For both models we used the first 3 global surveys available (1977, 1984, 1992). The mean trips length was calculated by dividing the estimated daily distance travelled by the daily trips frequency. These calibrations indicated that there would be a rupture in the trend, a result which has been confirmed by recent data. In retrospective analysis, the model may help to detect errors due to changes in survey techniques (i.e. survey period extended to spring in Paris in 1997, or two members of the household interviewed in 1993 in Montreal instead of only one adult member) and give better estimations of trends than observed data. Eliminating these surveys in the calibration process may be necessary at times and thus improve substantially the fitness of the model.

2.4 Morning peak period projections in the Paris region

For infrastructure building, the maximum volume of traffic rather than the average traffic is decisive. In the Paris region, during the morning peak period (6:00 to 9:00 AM) the share of public transport surpass that of the private car. However, through the years, car traffic is increasing more rapidly than public transport. By 2020, car traffic could equal or even be slightly higher than public transport: the market share of car-driver trips should increase from 40% in 1990 to 44% in 2020, and the share of public transport would slightly decrease from 46% to 44%. The average 24 hours market share of public transport would shift slightly from 36% in 1990 to 35% in 2020.

Table 2: Morning peak period projection in the Paris region

Daily distance travelled	Public transport		Car drivers		All modes	
	x 10 ⁶ travellers.km	Average distance per person	x 10 ⁶ travellers.km	Average distance per person	x 10 ⁶ travellers.km	Average distance per person
2000	22.0	2.1	21.2	2.1	49.1	4.8
2010	23.8	2.2	23.6	2.2	53.7	5.0
2020	25.3	2.3	25.4	2.3	57.5	5.2

Sources: Calculations from Households transports surveys in Paris (1977, 1984 and 1992).

The more concentrated the peak period, the farther we are from an optimal use of the infrastructures. The projections give a very slight deconcentration of the peak with its share of 24 hours passenger*km decreasing from 28.1% in 1990 to 27.5% in 2020 for all modes, and from 25.7% to 24.2% for car drivers. As seen above, for public transport, it could maintain above 35%.

3. Uncertainty in Transport demand with an Age – Cohort approach

For long term transport planning, a rigorous measure of uncertainty in the projections is highly desirable. With the Age-Cohort approach, we can identify three main sources of errors:

- the error due to the structure of the model, for example a non-linear relationship. This type of error is the uncertainty due to the **calibration** of the model;
- the uncertainty due to the **behaviour** of future cohorts, which have not yet been observed (the gaps between future generations and the generation of reference are unknown);
- the uncertainty due to **population** forecasts. Even though demographic projections are generally quite reliable at a global level, changes in hypothesis of fertility rates, mortality rates, and migrations may change long term results. In medium term forecasting, changes in hypothesis of inter-zone migrations may simulate urban sprawl and have a significant effect on the results.

In the following sections, we will examine the impact of these 3 types of uncertainty in travel demand forecasting with the examples of the daily distance travelled model and the trips frequency model.

3.1 The Jackknife technique to estimate confidence intervals

The jackknife technique originated outside the field of survey sampling. It was first developed by Quenouille (1949 and 1956) who proposed to use jackknifing to reduce the bias of an estimator. Dubin (1958) suggested that the technique might also be used to produce variance estimates. The jackknife technique permits the estimation of confidence intervals (Särndal *et al.*, 1992).

We used this technique to evaluate the uncertainty of projections and calculate intervals of confidence. In the case of 4 observations, for example, the technique consists of starting with the 4 observations suppressing one observation and making an estimation of the three remaining years with the model. This is redone four times, once for each year. This permits to calculate the variance and confidence intervals (we chose the level of 95%) for each of the four projections compared to observed data.

3.2 Uncertainty due to the calibration of the model

We calibrated the model and calculated the confidence intervals for both Paris and Montreal metropolitan areas. This was done for a 20 years period (2000-2020 for Paris and 2001-2021 for Montreal). The jackknife technique as described above was used, based on 4 projections for Paris and 6 projections for Montreal, which allowed the calculation of variances. This comparison was done for the two mobility variables mentioned above (trips and distance) at different levels of analysis: global (total population), by zone of residence, by level of

motorization and by gender. We observed generally that the farther the forecasting horizon, the larger is the confidence interval and the less reliable is the model.

3.2.1 Calibration of global mobility and distance travelled

For both regions, the level of confidence chosen was 95%. For the Paris region, trips frequency is estimated with ± 0.38 trips in 2000 and 0.78 trips in 2020. The distance travelled is estimated with ± 2.3 km in 2000 and ± 2.6 km in 2020 (Table 3). For the Montreal region, trips frequency is estimated with ± 0.41 trips in 2001 and ± 0.54 trips in 2021. The distance travelled is estimated with ± 2.0 km in 2001 and ± 2.8 km in 2021 (Table 4).

Thus, the absolute error increases over time for all indicators. The relative error also augments for all indicators except for the distance travelled in the Paris region, where it is quite stable. In Paris trips frequency is estimated in the bracket of $\pm 11\%$ in 2000 and $\pm 21\%$ in 2020. The relative error for trips frequency in Montreal is in the bracket of $\pm 15\%$ in 2001 and $\pm 17\%$ in 2021. The relative precision for distance travelled in Paris is around $\pm 15\%$ during the period 2000-2020. Relative error for trips frequency in Montreal is in the bracket of $\pm 13\%$ in 2001 and $\pm 15\%$ in 2021 (Tables 3 & 4).

Table 3: Results of the model and confidence interval for the Paris region (Île-de-France):
Trips and distance.

Year	Trips frequency		Daily distance (km)	
	Model	Relative error at 95%	Model	Relative error at 95%
2000	3.55	$\pm 10.6\%$	18.8	$\pm 12.0\%$
2005	3.57	$\pm 13.7\%$	19.7	$\pm 12.4\%$
2010	3.58	$\pm 16.5\%$	20.4	$\pm 12.3\%$
2015	3.59	$\pm 19.2\%$	21.1	$\pm 11.8\%$
2020	3.61	$\pm 21.5\%$	21.7	$\pm 11.8\%$

Sources: Calculations from Households transports surveys in Paris (1977, 1984, 1992 and 1998).

Table 4 Results of the model and confidence interval for Montreal: Trips and distance.

Year	Trips frequency		Daily distance (km)	
	Model	Relative error at 95%	Model	Relative error at 95%
2001	2.68	$\pm 15.1\%$	15.2	$\pm 13.2\%$
2006	2.82	$\pm 16.0\%$	16.1	$\pm 13.7\%$
2011	2.94	$\pm 16.8\%$	16.9	$\pm 14.5\%$
2016	3.04	$\pm 17.1\%$	17.6	$\pm 15.3\%$
2021	3.13	$\pm 17.3\%$	18.2	$\pm 15.4\%$

Sources: Calculations from Montreal Metropolitan Area O-D surveys (1978, 1982, 1987, 1993 and 1998).

3.2.2 Calibration of global mobility and distance travelled by zone of residence

For the Paris region by zone of residence, the relative error is smaller for the trips frequency model for the Central City than for the Inner Suburbs. In the Central City, trips frequency is estimated at $\pm 11\%$ in 2000 and $\pm 20\%$ in 2020 and the distance travelled is estimated at $\pm 22\%$ in 2000 to $\pm 39\%$ in 2020. In the Inner Suburbs, trips frequency is estimated at $\pm 14\%$ in 2000 and $\pm 26\%$ in 2020 and the distance travelled is estimated at $\pm 21\%$ in 2000 to $\pm 32\%$ in 2020. In the Outer Suburbs, trips frequency is estimated $\pm 10\%$ in 2000 and $\pm 22\%$ in 2020

and the distance travelled is estimated $\pm 7\%$ in 2000 to $\pm 10\%$ in 2020. The relative error is smaller in areas where distances travelled are larger (Outer Suburbs vs Central City). (Table 5).

Table 5: Results of the model and confidence intervals for the Paris region by zone of residence: Trips and distance.

Zone of residence	Year	Trips frequency		Daily distance (km)	
		Model	Relative error at 95%	Model	Relative error at 95%
Central City	2000	3.60	$\pm 10.8\%$	14.5	$\pm 21.7\%$
	2005	3.56	$\pm 14.3\%$	15.3	$\pm 25.5\%$
	2010	3.51	$\pm 16.7\%$	16.0	$\pm 30.3\%$
	2015	3.45	$\pm 18.4\%$	16.6	$\pm 34.0\%$
	2020	3.39	$\pm 20.1\%$	17.1	$\pm 38.6\%$
Inner Suburbs	2000	3.51	$\pm 14.4\%$	15.9	$\pm 21.4\%$
	2005	3.53	$\pm 17.6\%$	16.6	$\pm 25.0\%$
	2010	3.54	$\pm 20.6\%$	17.2	$\pm 27.6\%$
	2015	3.57	$\pm 23.4\%$	17.9	$\pm 29.9\%$
	2020	3.59	$\pm 25.9\%$	18.5	$\pm 32.4\%$
Outer Suburbs	2000	3.56	$\pm 9.7\%$	22.9	$\pm 7.4\%$
	2005	3.60	$\pm 13.2\%$	23.6	$\pm 7.6\%$
	2010	3.62	$\pm 16.4\%$	24.2	$\pm 7.6\%$
	2015	3.65	$\pm 19.2\%$	24.7	$\pm 8.5\%$
	2020	3.69	$\pm 21.8\%$	25.1	$\pm 9.6\%$

Sources: Calculations from Households transports surveys in Paris (1977, 1984, 1992 and 1998).

For Montreal, the relative error is smaller than in Paris, this being partly due to larger distances travelled. By zone of residence, the relative error is almost homogeneous. In the Central City, trips frequency is estimated at $\pm 17\%$ in 2001 and $\pm 18\%$ in 2021 and the distance travelled is estimated at $\pm 15\%$ in 2001 to $\pm 16\%$ in 2021. In the Inner Suburbs, trips frequency is estimated at $\pm 13\%$ in 2001 and $\pm 15\%$ in 2021 and the distance travelled is estimated $\pm 12\%$ in 2001 to $\pm 14\%$ in 2021. In the Outer Suburbs, trips frequency is estimated at $\pm 15\%$ in 2001 and $\pm 17\%$ in 2021 and the distance travelled is estimated at $\pm 13\%$ in 2001 to $\pm 16\%$ in 2021 (Table 6).

Table 6: Results of the model and confidence intervals for Montreal by zone of residence: Trips and distance.

Zone of residence	Year	Trips frequency		Daily distance (km)	
		Model	Relative error at 95%	Model	Relative error at 95%
Central City	2001	2.68	± 16.6%	7.3	± 15.1%
	2006	2.83	± 18.4%	7.7	± 15.6%
	2011	2.95	± 18.8%	8.1	± 16.0%
	2016	3.05	± 18.7%	8.3	± 15.7%
	2021	3.14	± 18.5%	8.6	± 15.7%
Inner Suburbs	2001	2.66	± 13.2%	12.6	± 12.3%
	2006	2.78	± 14.0%	13.2	± 12.9%
	2011	2.89	± 14.7%	13.7	± 13.5%
	2016	2.99	± 15.1%	14.2	± 13.7%
	2021	3.08	± 15.3%	14.6	± 14.0%
Outer Suburbs	2001	2.69	± 14.7%	21.7	± 13.1%
	2006	2.82	± 15.4%	22.9	± 13.5%
	2011	2.94	± 16.5%	24.0	± 14.4%
	2016	3.05	± 17.4%	24.9	± 15.3%
	2021	3.15	± 17.5%	25.8	± 15.5%

Sources: Calculations from Montreal Metropolitan Area O-D surveys (1978, 1982, 1987, 1993 and 1998).

By zone of residence (Central City, Inner Suburbs and Outer Suburbs) for all zones of residence the Montreal model is more precise than for Paris for the estimation of trips frequency. For daily distance travelled the Paris model performs better in the Outer Suburbs than in the Central City and the Inner Suburbs.

3.2.3 Calibration of global mobility and distance travelled by level of motorization

For the Paris region, the relative error is smaller for the distance travelled model for people with 2 or more cars. Trips frequency of individuals in households without a car, is estimated at ± 12% in 2000 and ± 25% in 2020 and the distance travelled is estimated at ± 24% in 2000 to ± 42% in 2020. Trips frequency of individuals with one car is in the bracket of ± 9% in 2000 and ± 15% in 2020 and for the distance travelled at ± 19% in 2000 to ± 27% in 2020. Trips frequency of individuals with 2 or more cars is estimated at ± 12% in 2000 and ± 25% in 2020 and for the distance travelled at ± 2% in 2000 to ± 5% in 2020 (Table 7).

For the Montreal region by level of motorization, the relative error is similar for both models. Trips frequency of individuals in households without a car, is estimated at ± 21% in 2001 and ± 30% in 2021 and the distance travelled is estimated at ± 23% in 2001 to ± 37% in 2021. Trips frequency of individuals with one car is in the bracket of ± 13% in 2001 and ± 15% in 2021 and for the distance travelled at ± 11% in 2001 to ± 13% in 2021. Trips frequency of individuals with 2 or more cars is estimated at ± 15% in 2001 and ± 16% in 2021 and for the distance travelled at ± 13% in 2001 to ± 13% in 2021 (Table 8).

Table 7: Results of the model and confidence intervals for the Paris region by level of motorization: Trips and distance.

Motorization	Year	Trips frequency		Daily distance (km)	
		Model	Relative error at 95%	Model	Relative error at 95%
0 car	2000	3.06	± 12.4%	12.7	± 24.4%
	2005	3.05	± 16.6%	13.5	± 29.3%
	2010	3.03	± 19.5%	14.3	± 33.6%
	2015	3.01	± 22.3%	15.0	± 37.3%
	2020	2.99	± 25.3%	15.6	± 41.7%
1 car	2000	3.51	± 8.7%	17.1	± 19.3%
	2005	3.49	± 10.9%	17.3	± 21.1%
	2010	3.48	± 12.8%	17.5	± 24.0%
	2015	3.47	± 14.4%	17.7	± 25.4%
	2020	3.48	± 15.4%	17.8	± 27.0%
2 or more cars	2000	3.87	± 12.3%	24.2	± 2.5%
	2005	3.89	± 16.1%	25.2	± 3.0%
	2010	3.90	± 19.4%	25.9	± 3.1%
	2015	3.92	± 22.6%	26.6	± 4.1%
	2020	3.93	± 25.3%	27.2	± 5.3%

Sources: Calculations from Households transports surveys in Paris (1977, 1984, 1992 and 1998).

Table 8: Results of the model and confidence intervals for Montreal by level of motorization: Trips and distance.

Motorization	Year	Trips frequency		Daily distance (km)	
		Model	Relative error at 95%	Model	Relative error at 95%
0 car	2001	2.03	± 20.9%	7.4	± 23.0%
	2006	2.13	± 24.4%	8.0	± 26.9%
	2011	2.22	± 25.9%	8.6	± 30.2%
	2016	2.32	± 28.0%	9.2	± 33.7%
	2021	2.41	± 29.9%	9.7	± 37.1%
1 car	2001	2.82	± 13.5%	16.2	± 11.4%
	2006	2.98	± 14.3%	17.2	± 12.2%
	2011	3.11	± 15.6%	18.1	± 13.5%
	2016	3.23	± 15.2%	18.9	± 13.5%
	2021	3.32	± 14.8%	19.6	± 12.8%
2 or more cars	2001	2.84	± 15.5%	18.9	± 13.2%
	2006	2.97	± 15.3%	19.9	± 12.6%
	2011	3.08	± 14.8%	20.8	± 11.8%
	2016	3.19	± 15.5%	21.6	± 12.3%
	2021	3.29	± 15.7%	22.4	± 12.5%

Sources: Calculations from Montreal Metropolitan Area O-D surveys (1978, 1982, 1987, 1993 and 1998).

By level of motorization the Montreal model for global mobility is more precise for individuals living in motorized households (1 car and 2 or more cars). For distance travelled the Montreal model is more accurate (relative error) for the households with 0 or 1 car. For the Paris model the accuracy in distance travelled is better for the multi-motorized.

3.2.4 Calibration of global mobility and distance travelled by gender

An analysis by gender shows that in the Paris region for both indicators of mobility (global mobility and distance travelled) the relative error is lower for men. Male's trips frequency is estimated with $\pm 11\%$ in 2000 and $\pm 20\%$ in 2020 and the distance travelled is estimated with $\pm 9\%$ in 2000 to $\pm 8\%$ in 2020. For the female, the trips frequency is estimated with $\pm 11\%$ in 2000 and $\pm 23\%$ in 2020 and for the distance travelled with $\pm 16\%$ in 2000 to $\pm 17\%$ in 2020 (Table 9).

For the Montreal region by gender, the relative error is similar for both models. Male trips frequency is estimated with $\pm 16\%$ in 2001 and $\pm 18\%$ in 2021 and the distance travelled is estimated with $\pm 14\%$ in 2001 to $\pm 16\%$ in 2021. For the female, the trips frequency is estimated with $\pm 15\%$ in 2001 and $\pm 17\%$ in 2021 and for the distance travelled with $\pm 13\%$ in 2001 to $\pm 16\%$ in 2021 (Table 10).

Thus, by gender, we observe a greater variance for women in Paris but in Montreal we observed no gender difference in the precision of the model.

Table 9: Results of the model and confidence intervals for the Paris region by gender: Trips and distance.

Gender	Year	Trips frequency		Daily distance (km)	
		Model	Relative error at 95%	Model	Relative error at 95%
Male	2000	3.58	$\pm 10.9\%$	23.1	$\pm 9.3\%$
	2005	3.57	$\pm 13.9\%$	24.0	$\pm 9.6\%$
	2010	3.57	$\pm 16.2\%$	24.8	$\pm 9.3\%$
	2015	3.57	$\pm 18.5\%$	25.6	$\pm 8.6\%$
	2020	3.57	$\pm 20.4\%$	26.3	$\pm 8.2\%$
Female	2000	3.52	$\pm 10.8\%$	14.8	$\pm 15.9\%$
	2005	3.56	$\pm 14.3\%$	15.6	$\pm 16.3\%$
	2010	3.58	$\pm 17.5\%$	16.3	$\pm 16.6\%$
	2015	3.61	$\pm 20.5\%$	17.0	$\pm 17.1\%$
	2020	3.64	$\pm 23.1\%$	17.6	$\pm 17.0\%$

Sources: Calculations from Households transports surveys in Paris (1977, 1984, 1992 and 1998).

Table 10: Results of the model and confidence intervals for Montreal by gender: Trips and distance.

Gender	Year	Trips frequency		Daily distance (km)	
		Model	Relative error at 95%	Model	Relative error at 95%
Male	2001	2.77	$\pm 15.5\%$	15.9	$\pm 13.5\%$
	2006	2.89	$\pm 16.4\%$	16.7	$\pm 13.8\%$
	2011	3.00	$\pm 17.3\%$	17.4	$\pm 14.7\%$
	2016	3.09	$\pm 17.8\%$	18.0	$\pm 15.6\%$
	2021	3.16	$\pm 18.0\%$	18.5	$\pm 15.7\%$
Female	2001	2.60	$\pm 14.6\%$	14.6	$\pm 13.0\%$
	2006	2.74	$\pm 15.7\%$	15.6	$\pm 13.8\%$
	2011	2.88	$\pm 16.3\%$	16.5	$\pm 14.5\%$
	2016	3.00	$\pm 16.7\%$	17.3	$\pm 15.3\%$
	2021	3.10	$\pm 16.8\%$	18.0	$\pm 15.6\%$

Sources: Calculations from Montreal Metropolitan Area O-D surveys (1978, 1982, 1987, 1993 and 1998).

4. Other sources of error

The hypothesis on the behavior of future cohorts and the demographic projections are other possible sources of error. Even though somewhat less important than the calibration errors, they may not be negligible. Let us examine below, with the Paris example, these two additional sources of uncertainty.

4.1 Impacts of the uncertainty due to the behaviour of future cohorts

Generally, projections based on an Age-Cohort model for transportation demand rely on the hypothesis that the behaviour of future generations not yet observed in surveys will have the same behaviour as the last generation observed correctly in available surveys (assumption designed here as “medium”). To modify this last assumption we estimated two trends, first on the last two generations observed, and secondly on the last three generations observed. Comparing the results of projections obtained from the medium assumption described above and the latter two assumptions, we could estimate the impact of uncertainty of the behaviour of future cohorts on mobility.

We estimated two trends for future cohorts:

- “cohorts2”, is built from the linear trend deduced from the gaps of the cohorts born from 1981 to 1985 (generation 1983) and from 1986 to 1991 (generation 1988);
- “cohorts3”, is built on the trends calculated from generation gaps of 5 year cohorts corresponding to generations 1978, 1983 and 1988.

For both models (trips and distance), we compared the results of the scenarios of “cohorts2” with “medium” and “cohorts3” with “medium”.

4.1.2 Impact of the behaviour of future cohorts on trips frequency

When we use a trend to estimate the behaviour of future cohorts our estimation of trips frequency (Table 11) is higher than when we make the assumption that the behaviour of future generations will be stable. In 2030, this difference is significant when we measure the trend with “cohorts2” (+14%) than the model with “cohorts3” (+8%).

By zone of residence and for the trips frequency, the gap between the use of a trend and the medium scenario diminishes when we move away from the Central City. In 2030, with “cohorts2” the gap is +30% in the Central City, +23% for the Inner Suburbs and +3% for the Outer Suburbs; for “cohort3”, these figures are, respectively, 14%, 15% and 1% .

By level of motorization and for the trips frequency, the gaps between the estimations are higher for the non-motorized. In 2030, with “cohorts2” the gap is +31% for non-motorized persons, +17% for individuals with one car in their household and +7% for multi-motorized persons, for “cohorts3” these figures are, respectively, 16%, 10% and 4% .

By gender, the gaps between the estimations are higher for the males. In 2030, with the model with “cohorts2” the gap is +25% for the males and +4% for the females, with “cohorts3” these figures are, respectively, +16% for males and +0% for females.

Table 11: Impact of the behaviour of future cohorts on trips frequency and on distance travelled

	Year	<i>Trips frequency</i>			<i>Distance travelled (km)</i>		
		Scenario:			Scenario:		
		Medium	cohorts2	Cohorts3	Medium	Cohorts2	Cohorts3
	2000	3.48	3.50	3.49	16.7	16.6	16.7
	2015	3.45	3.64	3.56	18.0	18.1	18.3
	2030	3.45	3.93	3.73	18.8	19.0	19.8
Zone of residence							
City of Paris	2000	3.55	3.60	3.57	11.3	11.3	11.3
	2015	3.39	3.76	3.57	11.7	11.3	11.5
	2030	3.30	4.30	3.75	12.0	10.7	11.3
Inner suburbs	2000	3.47	3.50	3.49	14.0	14.0	14.1
	2015	3.51	3.80	3.70	15.2	15.6	15.8
	2030	3.57	4.39	4.11	16.0	17.1	17.6
Outer suburbs	2000	3.45	3.45	3.45	21.3	21.2	21.3
	2015	3.44	3.48	3.45	22.5	22.5	22.8
	2030	3.43	3.52	3.47	22.9	23.0	23.9
Motorization							
0 car	2000	2.98	3.02	3.00	9.6	9.7	9.7
	2015	2.89	3.23	3.06	10.3	11.1	10.9
	2030	2.84	3.73	3.29	10.8	13.1	12.4
1 car	2000	3.46	3.48	3.47	15.7	15.6	15.7
	2015	3.40	3.60	3.52	15.9	15.4	15.9
	2030	3.42	4.01	3.78	16.2	14.8	16.2
2 or more cars	2000	3.78	3.80	3.80	22.1	22.1	22.1
	2015	3.73	3.86	3.81	23.2	23.6	23.8
	2030	3.69	3.95	3.83	23.7	24.4	25.0
Gender							
Male	2000	3.52	3.56	3.55	20.2	20.1	20.2
	2015	3.49	3.84	3.70	21.1	20.9	21.1
	2030	3.49	4.35	4.04	21.7	20.7	21.5
Female	2000	3.44	3.44	3.44	13.4	13.4	13.5
	2015	3.42	3.46	3.43	15.1	15.5	15.8
	2030	3.42	3.55	3.43	16.2	17.5	18.1

Sources : Calculations from Households transports surveys in Paris (1977, 1984, 1992 and 1998).

4.1.3 Impact of the behaviour of future cohorts on distance travelled

As for the trips frequency model, the use of a trend to estimate the behaviour of future cohorts gives a higher estimation of the daily distance travelled (Table 11). However, the difference is inferior with the use of “cohorts2” than with the use of “cohorts3” to estimate the trend of the behaviour of future cohorts. In 2030, this gap is + 1% when we take the trend of “cohorts2” and 5% with “cohorts3”.

By zone of residence for the daily distance travelled, the use of a trend for the behaviour of future cohorts underestimates in the Central City (in 2030, -10% with “cohorts2” and -6%

with “cohorts3”), overestimates in the Inner Suburbs (in 2030, +7% with “cohorts2” and +10% with “cohorts3”) and gives a slight overestimation in the Outer Suburbs (in 2030, +0% with “cohorts2” and +4% with “cohorts3”).

By level of motorization, the use of a trend for the behaviour of future cohorts overestimates the daily distance travelled for non-motorized people (in 2030, +21% with “cohorts2” and +15% with “cohorts3”), underestimates for individuals with one car in their household (in 2030, -8% with “cohorts2” and 0% with “cohorts3”) and gives an overestimation for multi-motorised people (in 2030, +3% with “cohorts2” and +6% with “cohorts3”).

By gender, the use of a trend for the behaviour of future cohorts overestimates the daily distance travelled for the male and underestimates for the female. In 2030, with “cohorts2” the gap is -4% for the male and +8% for the female, respectively these figures are for the model with “cohorts3” -1% and +12%.

As we found earlier, the model performs better for the daily distance travelled than for the trips frequency: the results of different scenarios at the horizon 2020 are more stable for distance travelled than for trips frequency.

4.2 Impacts of the uncertainty of demographic projections

We used 4 scenarios for the demographic projections.

The first scenario called "medium" relies on the assumptions that the rates of fertility of each zone are maintained at their level estimated for 1999 (last census used for the projections) to the horizon of projection, the evolution of the death rates follows the trend of the profiles of mortality observed since the censuses of 1982 and 1990 and the inter-zone migration rates are maintained by sex and age over the whole period of projection.

We consider three other scenarios that keep the same assumptions for the rates of fertility and mortality, but the migratory rates affecting the balance of migration are modified as follows:

- scenario " migration+": the rates increase by 0,001 at any age and over all the period of projection;
- scenario " migration-": the rates decrease by 0,001 at any age and over all the period of projection;
- scenario “migration0”: the rates are null at all ages (there are no more in or out-migration).

The main difference between this last scenario and the “medium” scenario is due to urban sprawl but also to the absence of international migrations in scenario “migration0”.

Based on census figures for 1999, the number of inhabitants is different for each scenario. For instance, the difference between the “medium” and the “migration0”scenarios is explained by:

- a global migratory deficit following the trend observed in the 90’s: more people leave the Paris region and than settle into it;
- urban sprawl: the demographic deficit is important for the Inner Suburbs and the City of Paris, while the Outer Suburbs have a surplus.

The tests of sensitivity shown below illustrate the impact of these scenarios on mobility forecasts. In terms of mobility ratios (trips per person or km per person), the different

scenarios give very similar results since, by construction, the model uses the same ratios at a disaggregated level, the slight differences observed by zone of residence being due to aggregation. However, in volumes, important differences are encountered between different scenarios since the different levels of population give different weights of sub-regions and consequently affect the global results.

Compared to the “medium” scenario, the scenario “migration-“ underestimates the total number of trips in 2030 by -3% and the two other scenarios overestimate it by +3% (Table 12). In each zone of residence, the scenarios “migration-“ and “migration+“ give exactly the opposite results: in 2030 -3% for “migration-“ and +3% for “migration+“. While the “migration 0“ scenario overestimates the total number of trips in the denser areas (+10% for the Central City [City of Paris] and +16% for the Inner Suburbs) and underestimates this figure for the Outer Suburbs by -8% .

Table 12: Impact of demographic projections on the total number of trips and on the total distance travelled by zone of residence.

	Year	<i>Total number of Trips per day</i>				<i>Daily passenger-kilometres (million km)</i>			
		Scenario:				Scenario:			
		Medium	Migration -	Migration +	Migration 0	Medium	Migration -	Migration +	Migration 0
	2000	35.6	35.6	35.6	35.7	171.0	170.9	171.2	171.2
	2015	37.6	36.9	38.1	38.9	196.2	192.4	198.7	197.7
	2030	39.2	37.8	40.2	40.5	213.8	206.0	219.2	214.7
Zone of residence									
City of Paris	2000	7.1	7.1	7.1	7.1	22.8	22.7	22.8	22.8
	2015	6.6	6.5	6.7	7.1	22.7	22.2	23.0	23.5
	2030	6.0	5.8	6.2	6.7	21.9	21.1	22.5	24.1
Inner Suburbs	2000	13.0	13.0	13.0	13.1	52.6	52.6	52.7	52.9
	2015	13.4	13.1	13.5	14.6	58.0	56.8	58.7	62.5
	2030	13.4	13.0	13.8	15.5	60.3	58.1	61.8	69.5
Outer Suburbs	2000	15.5	15.5	15.5	15.5	95.6	95.5	95.7	95.5
	2015	17.7	17.4	17.9	17.2	115.6	113.3	117.0	111.7
	2030	19.7	19.0	20.2	18.3	131.6	126.8	134.9	121.1

Sources : Calculations from Households transports surveys in Paris (1977, 1984, 1992 and 1998).

The number of passenger-kilometres, for 2030, is underestimated with the “migration-“ by -4% , overestimated with the “scenario +” by 3% and the scenario “scenario 0” gives the same result as the “medium” scenario .

In each zone of residence, the scenarios “migration-“ and “migration+“ give the same results as for the whole population (-4% for “migration-“ and +3% for “migration+“). In the Central City and for 2030, the scenario with zero migration gives +10% of total distance travelled; this figure is +15% for the Inner Suburbs and -8% for the Outer Suburbs. Thus these differences counterbalance each other at the regional level, because new inhabitants should settle in peripheral zones where the average distance travelled per inhabitant is the highest. The result shown before in terms of frequency is different, because the average number of trips per person is quite uniform in the different zones of residence.

The different scenarios give more or less the same results in terms of the total number of trips and in terms of the total number of passenger-kilometres; the main differences in the results coming from the projection of the population rather than from mobility itself.

5. Conclusion

In long term forecasting with an Age-Cohort model, we can identify three main sources of errors: errors in the calibration of the model; uncertainty of the behaviour of future generations, and errors in population projections. We used the jackknife technique to calculate confidence intervals. We observe that the longer the forecasting period, the larger is the uncertainty. However, the Paris - Montreal comparison shows that for projections at a relatively global level, very large samples do not improve significantly the precision of the model.

The demographic approach outlines the structural determinants for long term trends of mobility. It gives generally good results with errors in the 10-15% range even for long term forecasting. The error may reach higher levels (in the range of 30-40%) but mainly for variables with small values or with small sample size. For more refined analysis the size of the survey is important but the loss of precision is not necessarily dramatic. Furthermore, sampling techniques (non proportional) may improve reliability of under-represented variables or population categories. In retrospective analysis, the model may also help to detect errors due to changes in survey techniques and give better estimations of trends than observed data.

A good knowledge of the main sources of error and its measure is important to give benchmarks on the predictive capacity of a model and thus reduce uncertainty in the planning process.

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