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Projection of the daily mobility and CO2 emission in Hanoi using a demographic-based model

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Abstract

This paper mainly aims at better understanding the impact of changing demographics on the long-term evolution of daily mobility, using a demographic-based model to estimate the distance traveled by each transportation mode, by zone of residence and by different demographic groups. The second objective is to measure the future CO2 emission caused by transport activities.

Keywords: Age-Cohort Model, Daily mobility, Distance traveled, CO2 emission,

1. Introduction

Long-term travel demand forecasting are essential for urban transport planning (Armoogum et al., 2009). Household travel surveys are the most commonly used statistical surveys to analyze daily mobility in an urban area and are also widely used worldwide by planners to develop these projections (Krakutovski, 2004). However, these are cross-sectional surveys, meaning that they provide only a snapshot of mobility during one day of a single year. Because cross-sectional surveys are confined to a specific point in time, they have limitations for long-term travel demand forecasting (Madre, 1989), (Gallez, 1994). Because travel behavior tends to be different over time, efforts to predict future travel behavior based only on most recent cross-sectional surveys seems to be inappropriate. For instance and more recently (Grimal, 2011) have found that long-term income elasticities with respect to transport behavior cannot be drawn from cross-sectional analysis. Long-term travel demand modeling, based on data collected at different points in time during a

long enough period, seems to be the most appropriate way to take into account the impact of changes in travel behavior for long term forecasting (Kitamura, 1990). The main objective of this paper is to give some elements for a better understanding of the impact of changing demographic on the long-term evolution of daily mobility in Hanoi city using a demographic-based model to forecast mobility patterns such as: trip frequency, distance travelled, average trip distance. A second objective is to estimate the CO2 emission of city until 2030.

2. Literature reviews

The demographic-based model, or the Age-Cohort-Period model has been studied for travel demand in developed countries for cities like Montreal, Paris (Armoogum, 2009) and Lille (Krakutovski, 2004). Developing countries began to use this forecasting approach for cities such as Sao Paulo, Brazil (Madre et al., 2000) and Puebla, Mexico (Bussière et al., 1996) and Ciudad Juárez, Mexico (Tapia-Villarreal, 2014). In fact, time (or period), age of an individual (life-cycle position),

and year of birth or cohort are linked to specific travel behavior activity (Armoogum, 2009). In other words, the samples from different cross-sectional surveys change from one year to another, but it is possible to follow cohort of persons defined by their year of birth (Gallez, 2004), using a pseudo-panel approach (Deaton, 1985). To evaluate these effects (age, generation and period) on transport behavior, and to make long-term projection of mobility, researchers of the French National Institute for Transport and Safety Research (INRETS)¹ developed a demographic approach for forecasting. The construction of this dynamic model for transport demand was made in the 80's mainly based on work developed by (Madre, 1989) (Madre et al., 1996) first for car ownership, then for mobility. They established that it was possible to use pseudo panel data sets to forecast travel demand with reliable results (Figure 1).

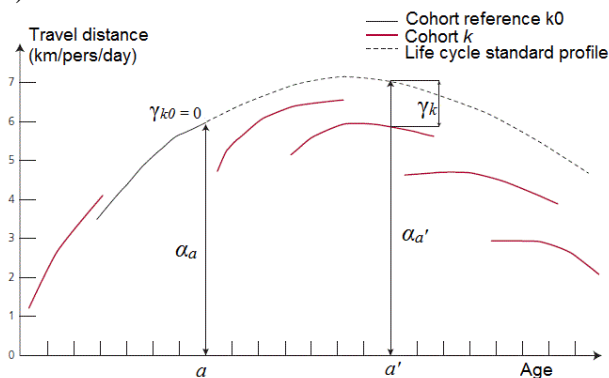


Figure 1: Life-cycle standard profile and travel activity
Source: based on (Gallez, 1994)

In most cases, the regression parameters applied on different cities indicates that the Age-Cohort model estimates appropriately travel activity by the analysis criteria (e.g. gender, zone of residence, age, etc.). In relation to forecast precision, [Dejoux et al., 2009] have found that the demographic approach for long term forecasting with an Age-Cohort model applied to Paris and Montreal, gives generally good results with errors in the 10-15% range. Errors can reach higher levels (in the range of 30-40%) mainly when the size of the sample is very small.

In addition to age and cohort effects previously mentioned, and in an effort to take into

account urban form and transport behavior dynamics, researchers have applied Age-Cohort model in order to forecast travel demand by zone (Tapia-Villarreal, 2014). In general, they have shown that travel distance declines with density and this trend seems to continue in the future in many cities of developed countries.

Relating to on-road GHG emission inventory, based on travel demand forecasting, we could estimate the CO2 emission for Hanoi city.

3. Methodology

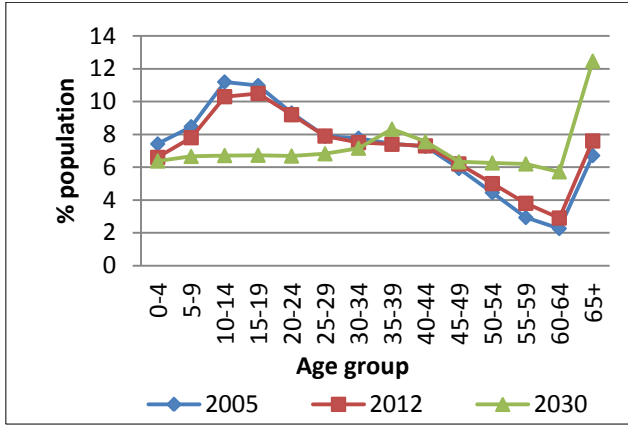
3.1. Travel demand modeling

Ageing of the population, urban sprawl will change travel patterns. To illustrate this phenomenon, we applied a demographic-based projection model of travel behavior in the period of 2005–2030 in Hanoi for measuring various elements of daily mobility such as trip frequency, distance travelled, average trip distance. The model, based on the demographic trends in a longitudinal analysis, reveals the complex role of the age factor which, in a dated temporal context, consists of a combination of three inter-linked dimensions:

- The stage in the life cycle, which expresses the influence of age on travel behavior. By evaluating the effects of the stage in the life cycle, it is possible to obtain a characteristic curve for those changes which can be related to age (we shall refer to this as the standard life profile).
- The generation (or cohort), which takes into account travel behavior on the basis of membership of a group of individuals born during the same period, who therefore share a common 'life experience'. Introducing this generation gap effect (which can be measured by means of differentials) allows us to place this profile in a long-term perspective.
- A complete Age-Cohort-Period model, which is not considered here, would take into account the period effect, which expresses the influence of the overall economic context on behavioral changes. In such a model, the period effect expresses the importance of socio-economic factors which affect all individuals and households simultaneously (e.g. changes in legislations, cost of fuel).

The Age-Cohort model supposes that age and generation behaviors shall be stable during the time till the horizon of projection.

¹ From 2011, The French National Institute for Transport and Safety Research (INRETS) and the French Central Laboratory of Roads and Bridges (LCPC) were merged to become The French institute of science and technology for transport, spatial planning, development and networks (French: *Institut français des sciences et technologies des transports, de l'aménagement et des réseaux*, IFSTTAR).



Furthermore, this article will examine whether the transition of population (slower population growth and aging) leads to the decrease of travel demand by motorcycles and cars (which could mean an increasing demand for public transport and demand-responsive transport) and hence the decreasing of CO2 emissions?

Table 1: Demographic changes in Hanoi city (in thousand pers.)

Year	2005	2012	2030
Population	5691	6719	9300
Male	2806	3292	4538
Female	2885	3427	4762
Central city	1731	2118	1934
Inner suburbs	1434	1863	2815
Outer suburbs	2527	2737	4551
Average age	29.3	30.8	36.4

Source: Population projection based on census

3.2. Presentation of the age-cohort model

The description of the Age-Cohort Travel Demand Forecast Model is taken from (Dejoux et al, 2009)

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

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

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

Where:

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

The unit of measurement used is the standard five years cohort used in demographic analysis, with the exception of age groups with small samples which required to be aggregated (individuals aged 65 years and older were classified in the age group '65 and over' and the individuals born before 1940 were grouped with the generation group '1936-1940').

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. It is preferable to have three or more observations to obtain a residual term taking into account factors not included in the model (i.e. income or price effects). But in Hanoi, we only have two sources of survey data with large sample size:

- First, the Household travel survey in 2012/2013, in the study of transport master planning in Hanoi City until 2030, with a sample of 18000 households.
- Second from the JICA study in the Programme of the Comprehensive of Urban Development of Hanoi city in 2005 with the participation of 20.000 households.

The following variables have been considered in the model's specification:

- Age (with its life cycle and generational components) and gender.
- Zone of residence: we have identified three concentric zones with diminishing density from the centre to the outer suburbs. The denser zone is the central city (in Hanoi, the population density is greater than 10.000 pers/km²), the inner suburbs show less density (from 2.000 to 10.000 pers/km²) and the outer

suburbs with very low densities (the rest of the region) with approximately 1000 pers/km².

At these two points in time (2005 and 2012/13), age and gender should have similar impacts on travel demand patterns which rise as we get farther from the centre. We have run 6 models of variance analysis by crossing the following variables: three zones of residence and two genders. Mobility is measured by two variables:

- Global mobility or frequency of trips (average number of trips per person for a typical week day);
- Distance traveled (number of kilometers travelled per person for a typical week day).

3.3. The model for projection of mobility

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

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

Where:

- $t = a + k$ (a is the age of the individual reflecting the life-cycle and k his generation, defined by his date of birth);
- α_a : measures the behavior of a generation of reference at the age a . This allows us to calculate a 'Standard Profile' of the life cycle;
- γ_k : measures the gap between the cohort k and the generation of reference γ_{k0} ; Since the gaps in cohorts for recent generations tend to disappear we took the last observed cohorts gap for future generation (Madre et al., 1995).

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

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

Where:

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

3.4. Model fitting

As the model only provides five-year results, we had to estimate the results for the survey years by linear interpolation. To make a more comprehensive comparison between the observations and the results of the model, we calculated regressions among the observed values

and the model's estimations at the most detailed level, i.e. by crossing the following variables:

- zone of residence (three zones);
- gender (2);
- five-year age groups (14);
- survey dates (2).

We had approximately 168 points for 2 surveys. To validate the model we need that:

- the R² value be close to 1;
- the gradient be close to 1;
- the constant be not significantly different from 0.

The 'Age-Cohort' model seems well suited with travel demand forecasting as all the above conditions were met (see table) :

Table 2: Regression between the observed values and the age-cohort model estimations.

Model	R ²	Gradient		Constant	
		Param. estimated	t-value	Param. estimated	t-value
Distance travelled	0.98	0.98	88.2	0	2.92
Trip rate	0.99	0.99	273.6	0	1.48

Source: Household travel surveys 2005 & 2012

The mean trip length was calculated by dividing the estimated daily distance travelled by the trip rate.

4. Results

4.1. Estimation of travel demand

Firstly, we estimated the average number of trips made on a standard weekday. While trip rate is projected to remain fairly stable from 2005 to 2013 in the Hanoi (approximately 2.6 trips per person per day) and to 2030. But in 2030, the trip rate is quite different among zones: in the city center the trip rate is highest and in the outer suburbs, this rate is lowest.

Men make more trip than women in both 2005 and 2012 (respectively 2.69 and 2.74 vs 2.6 and 2.66 trips per day). But in 2030, this rate decrease for both men and women Because of population ageing.

Table 3: Projection of trip frequency in the Hanoi city by sex and zone of residence

Year	2005	2012	2030
Male	2.69	2.74	2.62
Female	2.60	2.66	2.58
City center	2.68	2.93	3.24
Inner suburbs	2.66	2.50	2.72
Outer suburbs	2.61	2.36	2.26

4.2. Forecast of the distance travelled

The total distances travelled in Hanoi city is increasing. The reason of this increase is that from 2008, the urban sprawl was expanded, so that the average distances travelled per person has risen from 15.4 km to 17km between 2005 and 2012 and could reach 20km in 2030. Men also travel greater distances than women.

Living further from the centre lightly increases the distance travelled in 2005, individuals residing in the central city covered an average of 14.8 km/day, while those in the inner and outer suburbs covered, respectively, 15.4 and 15.9km. But in 2030, the distances travelled in city by the inhabitants of city-center is greatest because the trip rate in this area is the highest among 3 zones.

Table 4: Projection of distance travelled (km/day)

Sexe	2005	2012	2030
Male	17.3	19.2	19.7
Female	13.4	14.7	15.5
City center	14.8	17.5	19.1
Inner suburbs	15.4	16.7	18.8
Outer suburbs	15.9	17.9	16.3
Average	15.4	17.3	17.6

4.3. Estimation of average trip distance

Table 5: Average trip distance (km/trip)

Year	2005	2012	2030
Male	6.4	6.9	7.5
Female	5.2	5.5	6.0
City center	5.5	5.9	5.9
Inner suburbs	5.9	6.7	6.9
Outer suburbs	5.9	6.9	7.2
Average	5.8	6.3	6.7

We see here the average trip distance to rise between 2005 and 2030, from 6.4 km to 7.5 km by men and from 5.2 km to 6.20 km by women. With regards to zone of residence, the average distance is higher in the suburbs: 5,9km compared with 5.5 km in 2005 and 6.9 compared with 5.9 in 2012 and this trends continues to 2030.

4.4. Projection of CO2 emission

Following the ASIF approach promoted by IEA (Lee Shipper, 2011), the CO2 emission from the transport activities is calculated from these factors as follows:

- A-transport activities, measured in passenger.km based on travel surveys;

- S - mode share; measured in passenger.km, based on travel surveys too;
- I - energy consumption (in liter/km);
- F - CO2 emission factor (CO2/liter);

so, $CO_2 = A \times F \times I \times S$, is the CO2 emission quantity for each mode of transport.

Table 6: Energy consumption and CO2 emission factor

		Energy consumption (L/100km)		CO2 emission (g/L)
		Moto	Car	
Gazole	Urban	-	8.3	2661
	Rural	-	4.4	2661
Essence	Urban	3.2	9.2	2313
	Rural	2.5	5.8	2313

Source: Based on study of (NREM, 2014)
Gazole=Diesel Fuel ; Essence=Petrol

Table 7: Modal split by trip number

Mode/Year	2005	2012	2030
Bicycle	46.1%	13.9%	14.0%
PT	2.0%	11.0%	22.0%
Car	1.1%	2.8%	16.0%
Motorcycle	47.7%	69.8%	44.0%
Others	3.1%	2.5%	4.0%
Total	100.0%	100.0%	100.0%

Source: Base on study of (TEDI, 2013)

Table 8: Modal split by distance travelled

Mode/Year	2005	2012	2030
Bicycle	14.8%	4.6%	8.0%
PT	4.6%	16.6%	26.0%
Car	7.6%	9.5%	23.0%
Motorcycle	70.6%	66.7%	35.0%
Others	2.4%	2.6%	8.0%
Total	100.0%	100.0%	100.0%

Source: Estimated from study of (TEDI, 2013)

The modal split forecasting was obtained from the study of (TEDI, 2014), in which there are significant changes in the mode shares for Hanoi city in 2030: the public transport increases by 22% in trip rate and 26% in distance travelled. Indeed, 2 lines UMRT² are now constructing in Hanoi and will be operated after 2022. Besides, the price of car is expected to decrease by Trans-Pacific

² UMRT: Urban Mass Rapid Transit.

Partnership Agreement (TPP) and the policy of motorcycles restrictions will be implemented in near future. So the motorcycles share (by distance travelled) is forecasted to decline from 66.7% in 2012 to 35% in 2030. The car share will should increase to 23% .

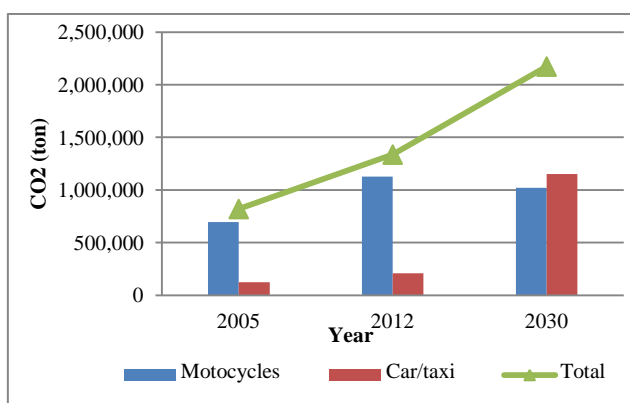
In this study, we have estimated the CO2 emission from private transport only, i.e. from motorcycle and car.

Table 9: Parameters for the CO2 emissions calculation

Parameters	2005	2012	2030
Distance traveled (km)	15.4	17.0	17.6
% motorcycle by distance	70.6	66.7	35.0
% car by distance	7.5	11.5	23.0
occupation motorcycle (pers/vehicle)	1.17	1.2	1.22
occupation car (pers/vehicle)	2.3	2.3	2.3
CO2/ km of moto (g/km)	58	58	58
CO2/ km car (g/km)	196	196	196

Table 10: CO2 emission by modes and through the year (ton)

CO2 emission	2005	2012	2030
Motorcycles	695,000	1,128,000	1,020,000
Car/taxi	124,000	208,000	1,152,000
Total	819,000	1,336,000	2,172,000



Graphic 1: CO2 emissions during the time

CO2 emission increases over the years (figure 1). Between 2005 and 2012, it is mainly due to motorcycles, but in 2030, it is mainly emitted from cars. Emission from motorcycles in 2030 are even less than in 2012. However between 2012 and 2030, the CO2 emission by motorcycles could still increase because we have not any policies

concerning the motorcycles using restriction until now.

4. Conclusion

Urban travel demand in Hanoi will be influenced by a number of structural factors, namely demographic, ageing, the urban form. Because of the low fertility rate and the longevity, the percentage of elderly is greater increasing.

From now to 2030, we have observed urban sprawl, and this trend could continue until 2050. Therefore, in 2030 we could have almost half of the population living in the outer suburbs.

The age-cohort model predicts major changes in the travel demand in the future. We observe the differences in travel demand between men and women. Men have a higher mobility than men in both trip rate and trip distance, but the difference between genders is decreasing like in most other countries in the world.

Travel demand will increase irrespective of their zone of residence. This increase will involve trip frequencies, daily distance travelled and global volume of trips. This will occur in a context of continuing urban sprawl and dependency on motorized modes. Based on the forecasting of modal split, we could estimate CO2 emission from private transport modes in Hanoi. The CO2 estimation shows that despite a significant shift to public transport, private car should be much increasing; thus, the CO2 emission are still on a rising trend.

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