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# Mobilities and Long Term Location Choices in Belgium

## "MOBLOC"

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# MOBILITIES AND LONG TERM LOCATION CHOICES IN BELGIUM

# "MOBLOC"

## SD/TA/04A


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# Abstract

Mobility and transport evolve with time and the passing generations. Interactions are numerous between daily mobility and household migration (house moving implying a municipality change). New residential choices induce at the same time new mobility behaviours, based on an extensive and probably excessive use of the private car in daily trips (home-work/school, shopping, leisure ...). The MOBLOC project aims at investigating the cycle linking long-term society evolution, residential choice, transportation demand and the resulting accessibility evolution. Final results consist in interacting models for residential migration and daily accessibility, Belgian population forecasts at municipality's level and a municipality based origin-destination matrix for work/school, with indication of the modal split for each destination. A fitting car accessibility model and a propensity to move model were designed in the first phase. The remaining models and their interactions will be proceeded in the second phase.

Since the MOBLOC project involves several models and interactions, we first describe the global applied methodology. Then, we present the technical aspects of each model. The project scheme is mainly composed by the residential migration models and the accessibility models. Further models are necessary to complete the full scheme.
The residential migration model describes the individual behaviour of migration. A migration here is defined as a change in the municipality of residence between two firsts of January. The span is thus annual and the observed migration "intercommunal" (from a given municipality to another one). Such a definition is imposed by the available data. This model predicts the municipality of each individual according to both socio-econo-demographic variables and municipal characteristics. It is actually split up into two sub-models: a propensity to move model and a localization model. The first one gives the probability to move for each individual while the subsequent one assigns a new residence municipality for people who migrated.
Then, the accessibility models use the aggregate results on a municipality base. There are two independent accessibility models, one for private car and one for public transport. Their outputs are travel times between each pair of municipalities, by car and by public transport. These allow the computing of municipal accessibility indicators to several opportunities. These indicators are in turn processed in the localization model, thereby modelling the loop and the interaction between the daily and the long term mobility.
Additional models are necessary: a gravity model estimates the commutes between each municipality pair, a modal split model isolates the travel demand by car. Evolution models should be designed in order to simulate several evolutions.

After the description of the global methodology, let us now focus on the technical side of each model.

The accessibility model computes travel times between two municipalities according to the mode (bi-polar accessibility). Two different modes are considered: car and public transport (without distinction between train, bus, tram or metro). The first achieved step is the choice of representative points for each Belgian municipality. Since the link should be done between the localization choice and the constraints of commuting

duration, computations rely on a municipal travel demand matrix for home/work purpose. Since it should be the most constraining part of the trip, the traffic is modelled during the morning peak hours.

The calculations of the public transport model should be carried out thanks to a unique database integrating timetables of every Belgian public transport operators. In this regard, the collaboration with SRWT (Société Régionale Wallonne des Transports) could be very helpful. The expected results consist in a matrix of the travel times for each municipalities pair.

In the car accessibility model, after the choice of a point to represent a municipality, a simplification of the road network is carried out. Since we work at the municipal level, we consider here motorways and level 1, 2 and 3 national roads. The connection of representative points to the network is performed when necessary by the mean of connectors. A heavy task, then, consists in checking road intersection on the network. Free flow speed and road capacity are set according to the type of the road and their lanes number. A traffic assignment using the Wardrop hypothesis is performed on the demand matrix afterwards. This demand matrix is derived from the O/D matrix of home/work – or school – journeys provided by the Socio-Economic Survey of 2001. The outputs of the traffic assignment are the travel times. Improvements of the current model could be tested in the future.
Since simulations will be proceeded to estimate accessibility over time, travel demand will have to evolve. This demand is updated by calculating new margins for the O/D matrix: one given by the localization model, the other by an estimation of the employment per municipality.
The flow between two municipalities is then determined through a gravity model reflecting interactions between two municipalities. This takes into account the "weights" of these municipalities and their distance. Parameters of the model can be estimated thanks to two matrices: the O/D one from the national census of 2001 and the matrix of Euclidian distances between the pairs of municipalities.

Regarding the residential migration model, the chosen technique for its first component, the propensity to move model (which try to predict whether an individual moves or not), is a binary logistic regression. It is calibrated with exhaustive individual data from the Socio-Economic Survey (2001) and the National Register which keeps track of everyone's municipality of residence in Belgium and of household evolution in term of structure or size. The output variable is the change (or not) in municipality between two first of January for an individual.

First of all, literature review and exploratory analysis helped us to pre-select variables (among available ones which could be incorporated into the model). Correlations between variables were also taken into account in order to avoid co-linearity problems between covariates. This, for example, led us to prefer the education level rather than the activity status, or to choose the housing tenure type among housing-related variables. Let us note that an important transformation task was carried out on the data in order to clean them and to adapt them: e.g. for interpretation convenience and to limit co-linearity, household variables such as households type and size were combined

in a composite variable. For the same reasons, the creation of transition variables (transformation between two static variables) was also helpful.
Choices of the covariates and data manipulation were also affected by constraints related to the project objectives:

- the objective of future simulation conducted us to prefer explanatory variables whose evolution is possible to achieve;
- the wish of taking into account the past (and to a lesser extent short-term future) of the individuals, since this extremely valuable information is available in the data led us to create transition variables.

After the pre-selection of the variables, the logistic regression model could be designed. Different models were tested. For each of them, the most significant of the pre-selected variables were kept, according to statistical tests. Further tests were also performed on the discrimination power of the models. These considerations led us to choose the simplest one. The main result for the propensity model (besides having a predictive model) is that four variables really stand out of the crowd according to their significance: the household evolution (simultaneous to the migration), the relation with the household head, the housing tenure type and the age class.

The propensity to move model was constructed and tested in the first phase of the MOBLOC project while the localization model remains to be completed in the second phase. Nevertheless, the following aspects of this model were yet discussed. First, the technique is more complex than the one used for the propensity to move model. Discrete choice methods will be used as they allow to deal with multiple alternatives and include explanatory variables related to both alternatives (municipalities) and deciders. The model structure has also already been addressed. Since the number of alternatives is important, hierarchical choice has been chosen (first, choice of potential alternatives, and then final choice) and different criteria considered in order to group the municipalities. These groupings have to be tested to keep the most valuable one for the residential localization modelling.
The input data globally consists in the same input data as for the propensity model, but also includes characteristics of the Belgian municipalities in order to measure their attractiveness. For this purpose, accessibility indicators such as the accessibility to job opportunities, schools or health care services should be built from the travel time matrices calculated by the accessibility models. Other factors which could influence the location choice (such as property price) could be added. The output variable is the new localization of each individual, in the best case at the municipality level.

Finally, since the ultimate objective of the MOBLOC project is to simulate projections, we plan to make evolve all the explanatory variables thanks to evolution models. Aggregate methods, such as demographic forecasts, would be useful, but we also consider disaggregated techniques as the residential migration model works at the individual level. Basic methods would first be operated, but could be refined afterwards. For instance, transition matrices could be computed in order to model household transition between two consecutive years; others variables such as activity status, level of education or the housing tenure type should be predicted thanks to simple regression according to other covariates.

As a conclusion, let us say that the global scheme of the MOBLOC project has been concretized since some bricks -propensity model, accessibility models methodologies- were developed. At the end of the second phase, we should not only have further models for the residential migration modelling and for accessibility, but also a measurement of the interactions between these elements, as well as tools to simulate evolutions of population or travel demand according to scenarios. Besides providing a better understanding of the studied behaviours, simulations could help authorities in their decisions in terms of land use or daily mobility policies.

# I. Introduction

## A. Context

Mobility and transport evolve with time and the passing generations. Interactions are numerous between daily mobility and household migration (here defined as house moving implying a municipality change). The evolution of the transport system has deeply modified the barrier of distance and has largely opened the choices in term of residence place. The continuing urban sprawl phenomenon resulting from these modifications has itself resulted in a strengthening of the property and housing market in certain territories, pushing people (young couples in particular) towards a residential localization which is further and further away from the traditional, urban activity centres. The tensions between daily and residential mobility have therefore increased, notwithstanding the recent rise in energy costs. This in turn generates unsustainable effects on society and environment.

But these new residential choices have in parallel induced new mobility behaviours, based on an extensive (and probably excessive) use of the private car in daily trips (home-work/school, shopping, leisure ...). Social life itself (visits to friend and family) has become more spatially dispersed. One already knows that the propensity to change residence is determined by a number of individual or household characteristics such as age, citizenship or income, but the effects of long-term trends as population ageing, the evolution of the household/family structure on both residential choices and mobility behaviours remain so far largely unanticipated.

This research project aims at analyzing retroactions between demographics and the evolution of mobilities at different time-scales. In particular, localization choice for household, daily accessibility and internal migrations appear to have strong interactions. Broadly speaking, a mechanism of this interaction can be described as follows: traffic evolution impacts accessibility, which itself, together with long-term societal changes, affects internal population migration and household localization, which in turn influences mobility (traffic) and accessibility. The analysis of this interaction requires two complementary intertwined modelling approaches: the first centred on the residential migration and the second on the evolution of accessibility.

## B. Objectives

The project objective is to investigate the cycle linking long-term society evolution, residential choice, transportation demand and the resulting accessibility evolution. On the societal trends side, particular attention will be paid to the population ageing effects, evolution of family cell structure and inter-generational relationships, but other variables such as land-use and standards of living trends will also be considered for potential inclusion in the models. The project objectives include simulations of scenarios for the future in Belgium. On the transportation side, emphasis will be put on the evolution of transportation demand and resulting traffic conditions.

At the end of the project, the final results will include:

- the developed models (residential migration, accessibility and so on), their methodologies and their connections,
- Belgian population forecasts at municipalities level;
- a municipality based origin-destination matrix for work/school and other purposes, with some indication of the modal split for each destination (for each period in the model)

## C. Structure

This report describes the work achieved during the first phase of the project. Therefore it is mainly focusing on the accessibility model and on the propensity to move model, first step in the migration model (the second one being the localization model).
The report is structured as follows. The global methodology underlying development of the different models is first presented. Then these models are detailed. On one hand, the transport models include the accessibility models (for private cars and public transport) and the demand model as well as a modal split model. On the other hand, the migration model has been split in two steps: propensity to move and localization. In this first phase of the project, the propensity to move model was fully developed. Therefore we describe here the data used, the structure and the obtained results. Concerning the localization model, this report will only highlight the available data as well as the general methodology which should be deeply explored in the second part of the project. In a forecasting view, all the models must be used in conjunction with evolution models. This will also be developed in the second phase of MOBLOC but this report already gives an overview on how they would be built.
A last section explains how the models developed during this project could help as support to the decisions and finally some conclusions drawn from these two years of research are summarized.

# II. Global methodology

Thus let us first describe the global methodology of the project. This could be based on a presentation of the data flows through the inputs and outputs of each model and the interactions between them. For that purpose, the figure 1 (Pattern of the MOBLOC Project) below will be very helpful.

The main objective of MOBLOC is to draw up a link between residential migration and daily mobility. Thus the two main bricks of the project are the residential migration model and the accessibility model. As the figure shows, other models will be necessary to reach this goal. Indeed, we need to determine some inputs or to establish relation between them.

The inputs of the residential migration model are individual data. It includes age, gender, level of education, household evolution, previous migration and the current (at time Y) residential municipality. The final output is the new residential municipality (one year after, Y+1). This model has been split up into two sub-models: a propensity to move model and a localization model.
The first one uses some of the individual information to predict if a migration occurs (i.e. if a individual moves) between the years Y and Y+1 (from a municipality to another – not inside a given municipality). If the answer is yes, then the localization model will simulate the localization choice between the 588 other Belgian municipalities.
The technique used for the propensity model is a binary logistic regression while the localization model will resort to a more sophisticated discrete choice model. But these methodology topics will be further detailed in following section.

As one of the individual characteristics is the activity status, a data aggregation at the municipal level provides the number of working people per municipality which is one of the inputs of the transport model and more precisely of the travel demand model.

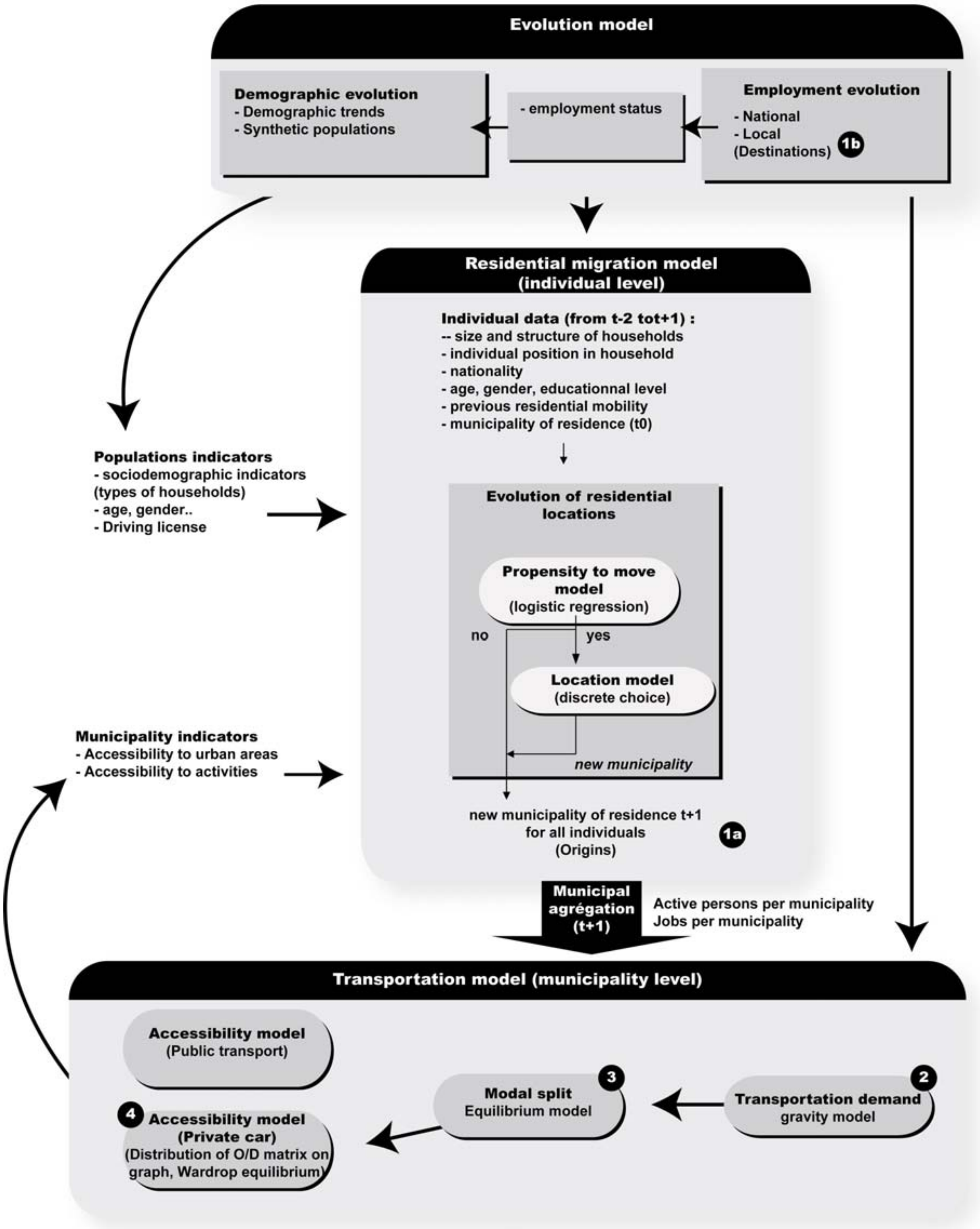
Travel demand model is indeed based on two inputs: the number of working people and the number of jobs per municipality.
These are the margins of an O/D matrix from which a gravity model will build all the inner cells. Let us remark that for now, this matrix only takes into account the work-home trips (demand) because of the used inputs. Even if this assumption is very restrictive, it is a first good approximation considering the available data (as we consider the peak hours). It is nevertheless possible to improve the model described later in this report.
The next step of the transport models is a modal split model. Its purpose is to compute from the global O/D matrix another one concerning only the trips achieved by car. This step is necessary to provide a feasible input for the private vehicle accessibility model which is an essential brick of the project.
This model uses Wardrop equilibrium paradigm to assign the traffic on the roads network. Its output is a matrix of the travel time between each municipalities pair (during the morning peak hours on a working day) by car.

The public transport accessibility model is another independent model. It computes the same travel times, but there by public transport. Let us point out that these times are not directly related to the travel demand because they are based on the supply. The PT accessibility model will not be updated at each step of the simulation as we do not know how the service will evolve in the next years.

At the end, the travel times (PV and PT) between municipalities will be used to compute different accessibility indicators (to employment, schools, hospitals...). They will be included as inputs of the localization model (the second step of the residential migration model) to measure the attractiveness of the municipality.

These models will be used in a prospective way so that it will be necessary to update the input values for the residential migration model. Let us remind that this model works at an individual level which implies to find adapted techniques. This is the role of the evolution models. They include different kinds of techniques at different levels: aggregate and disaggregate, e.g. demography trends, synthetic population...

**Figure 1 – Pattern of the MOBLOC Project**



# III. Methodologies and results of the models

## *A. Transportation models*

### 1. Accessibility model

Within the context of the MOBLOC project, two accessibility models have been developed, one relating to private vehicle (PV) transport and the other to public transport (PT). Accessibility is defined here as the "the greatest or least ease of moving from a Point A to a Point B (ease in the B to A direction is not necessarily the same)" (Reymond et *al*., 1998). Therefore, through these models, the objective is to provide a measurement of this ease for some specific spatial points. In this project this ease of movement is expressed in the traditional manner of journey time, whilst at the same time being aware that other criteria such as cost or even comfort may be taken into consideration.

Except for their intrinsic interest, the aim of these models within the context of this research project is to contribute to the coupling of the different models designed to analyze the feedback between demographic trends and mobility. In fact the origins and the main scientific interest of MOBLOC are based on the articulation of these accessibility models, the propensity to move and the localization models. From the accessibility point of view, this articulation can be specified in two complementary points. On one hand, accessibility models play a role in the localization choice of individuals, especially for workers, as they determine, for each journey to work, if the required time is acceptable and therefore if the place of residence is adequate. On the other hand, these accessibility models are used to calculate the modal split of home/work journeys.

Given these specifics, accessibility modelling requires several preliminary phases which are detailed in the first three subsections. The last two subsections present the results obtained up to now.

#### a) Choice of the representative points in the municipalities

Given the general objective of the MOBLOC project, which is based on model coupling, there is a large constraint, i.e. the PV and PT accessibility modelling for all 589 Belgian municipalities. In fact, to guarantee the greatest degree of consistency at the model coupling level, the models must have the same spatial precision, i.e. the 589 municipalities here. On this scale and given the density of the Belgian transport network, simplifications have had to be undertaken in order to enable the calculation to be completed in a reasonable time. More specifically this simplification consists, both for the PV and the PT models, of choosing for each municipality a point considered as representative of its centrality according to the network or the urban areas. This comes back therefore to assimilating the accessibility from this point to that of the whole municipality; over short distances this simplification certainly imposes a constraint, but on the other hand, at country level, this premise seems to be a realistic one.

Given that the municipalities are generally a grouping together of different localities, it was not easy to choose a single point representing the municipality. In a concern for objectivity, though, systematic rules have been drawn up in accordance with the type of municipality. To do this, this phase is based on a typology of municipalities in "urban areas" (Van Der Haegen et *al.*, 1996). This typology differentiates four types of municipalities: agglomerations, suburbs, commuter residential zones and other non-polarized municipalities. For each centre of agglomeration (i.e. 17 municipalities) we use the hypercenter (for example for Brussels - the Grand Place). The representative points of the municipalities in the *Brussels-Capital* region will also be determined by their centre. In the case of the other municipalities (suburbs, commuting areas and non-polarized municipalities), the point will correspond to the localization with the most frequent PT stop during the working days. The choice of points is identical for the PT and PV model in order to enable the two accessibility models to be compared.

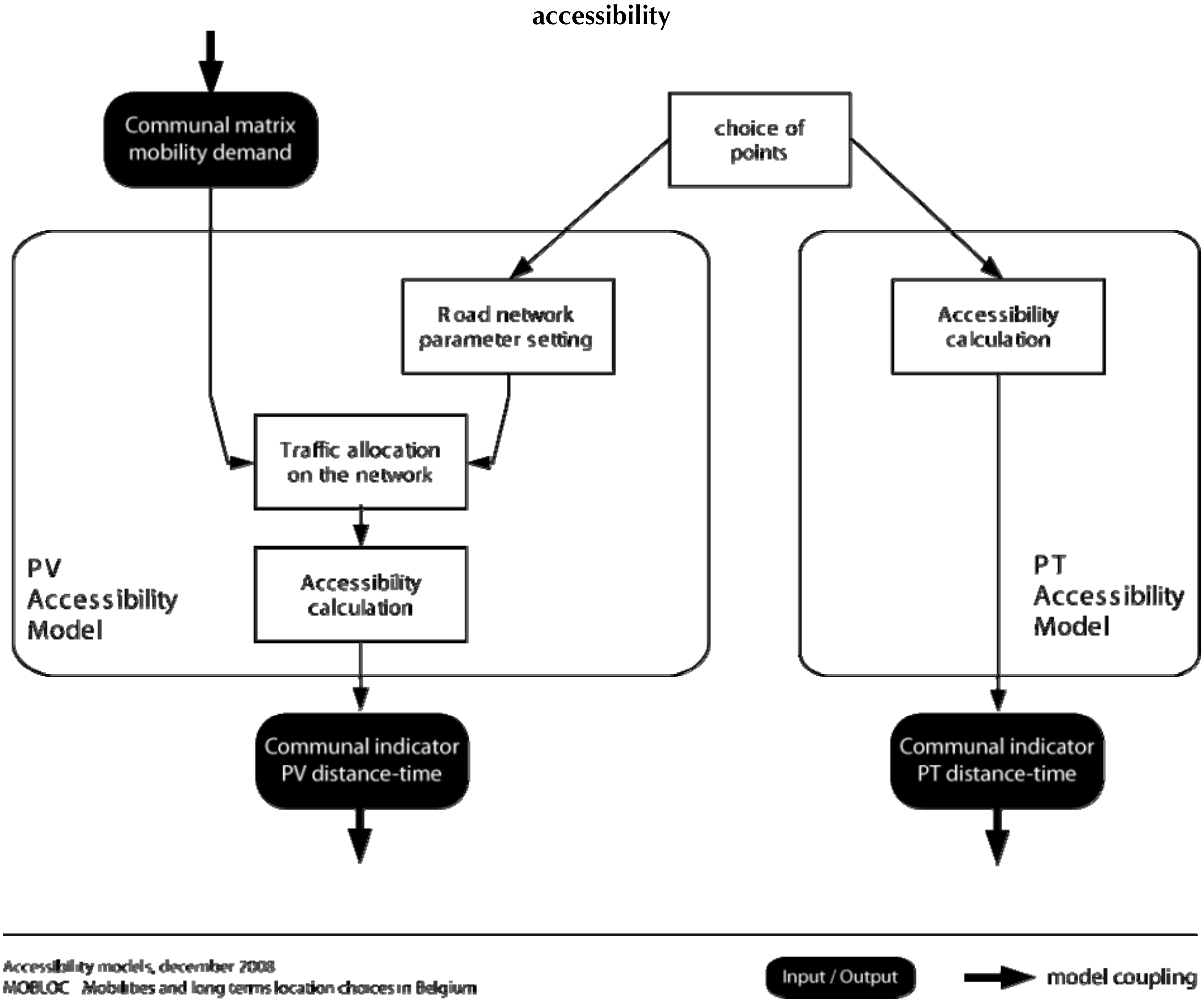
**b) Phases in the modelling process**

In the case of the PV accessibility model, the *input* corresponds to an origin/destination matrix of workers and students using the car as the main mode for their home/work or home/school journey. In the first iteration, this data was sourced from the 2001 INS Socio-Economic Survey.

The *outputs* of these two accessibility models will be a square matrix of the minimum/optimum access times between each pair of municipalities. These outputs (i.e. travel-time indicators) are then used for the coupling of the models.

The large phases of the accessibility modelling (Figure 2) consist, for the PV, in traffic assignment on the network to consider congestion in the calculation of access time; as far as PT is concerned, it is a question of calculating journey and access time based on timetables. We will come back to this further.

**Figure 2 – Methodological phases of PV and PT modelling and accessibility**




Given that these accessibility models play a role in the modelling of residential choices, the determination of the model parameters is oriented in this sense. Therefore, as we know that at the time of choosing a residence, workers take their home/work journey into consideration to ensure the feasibility of their work schedule (including their time-budget for travel within acceptable limits, i.e. on average one hour according to Zahavi, 1979), the main constraint on this choice will be the access time during the morning peak on a week day. Due to this fact the accessibility models shown here correspond to a journey time calculation between municipalities on a Tuesday between 7.00 am and 8.00 am.

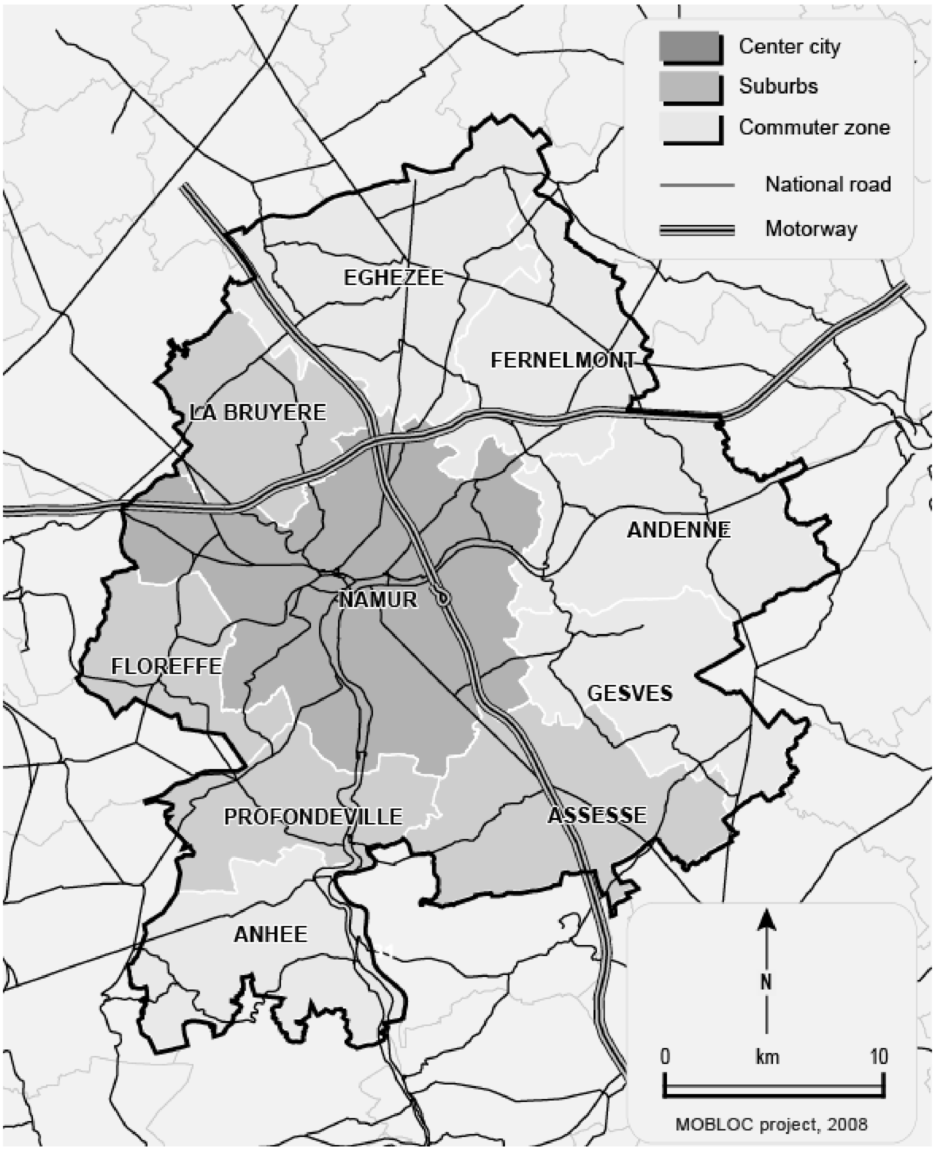
It is important to specify that for the PT modelling, accessibility is calculated once for the entire simulation period. In fact, as far as PT is concerned, it is not possible for us to know which new roads will be implemented in the future and therefore the premise is that the PT operators will adapt to a potential increase in demand by maintaining the constancy of current accessibility. This does not exclude, in future developments of the models, the integration of new potential roads or the formulation of scenarios.

#### c) Choice of test zone

Initially the accessibility modelling work was carried out in a test zone. The objective of the preliminary modelling in a test zone was essentially methodological in order to develop and validate the modelling procedures on a "spatial sample" to enable more flexibility and responsiveness than across the whole country. This phase also enabled any possible technical or methodological problems to be highlighted and dealt with in an efficient way given the restricted calculation time on a small area.

The adopted test zone corresponds to the urban region of Namur (Figure 3). This has the advantage of encompassing diverse types of urbanization (dense zone, suburb, commuter residential houses and a more rural zone); furthermore it offers facilities to control the area, given the presence of the GRT (*Transport Research Group*) in Namur.

**Figure 3 – Test Zone: Urban region of Namur**




The urban region of Namur, as defined in the work of Van Der Haegen et *al*. comprises the following municipalities: Namur, Eghezée, Anhée, Andenne, Assesse, Floreffe, Gesves, Profondeville, Fernelmont and La Bruyère.

After these preliminary methodological definitions, we will now look in detail at the procedures and the results obtained for each of the accessibility models.

#### d) Public transport accessibility model

##### *(1) Methodology*

The SRWT (Société Régionale Wallonne de Transports) information technology service is used to compute the PT communal accessibility matrix. Initially the objective was to calculate the best itinerary between two municipalities during the morning peak hour. However the INFOTEC system has been designed through consultative logic by its users, so that it requires a certain adaptation by us in the formulation of the queries for access time.

More specifically, given that this system was developed from the point of view of user logic, queries have been built based on specific departure and arrival times. It is not possible to vary these two parameters simultaneously in order to obtain an optimum journey within a certain time-window (for example from 7.00 - 8.00 am). However, by targeting the peak hour, or in other words the time of the greatest frequency of PT, a certain number of tests have shown us that the access times are comparable based on different criteria.

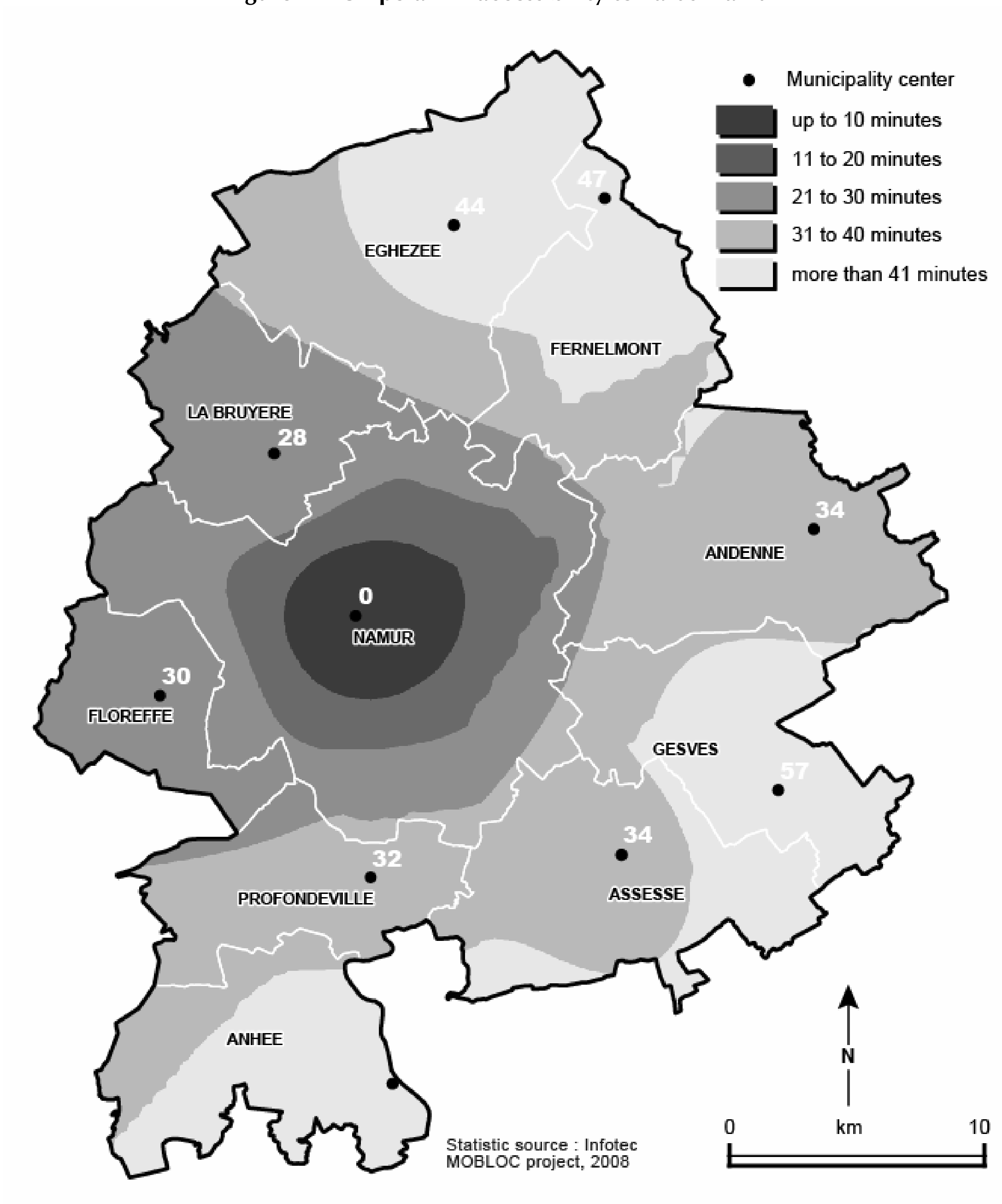
##### *(2) Data*

The accessibility calculation for public transport requires a certain amount of data concerning the roads, stops and timetables of the public transport system. Therefore we initially collected data at a more detailed level. Unfortunately it was impossible to obtain such a quantity of data for the whole country in a reasonable time period. Faced with these difficulties we called upon SRWT and thanks to their database of integrated timetables for the different Belgian public transport operators (De LIJN, STIB, TEC, SNCB), they are able to calculate the journey itineraries for every single point in Belgium. Moreover, this service can be consulted free-of-charge *via* their website: www.infotec.be. In case that SWRT would not be able to fulfil our needs, we could address other organizations like SNCB who also have a website able to calculate itineraries between two points.

##### *(3) Results*

The matrices of the times obtained in each accessibility model may be represented in a GIS. Using an IDW (inverse distance weighted) interpolation, information for inter-communal access times can be calculated on all the spatial points of the study.

**Figure 4 – Unipolar PT accessibility towards Namur**




### *(4) Perspectives*

As regards the public transport accessibility issue, the expected results are the calculation of a municipal matrix of the optimal time by public transport based on the data provided by SRWT.

#### e) Private car accessibility model

In the case of PV accessibility, apart from the choice of communal points, another simplification is required, namely that of the road network. We have chosen, in the light of inter-communal accessibility, to only consider motorways and level 1, 2 and 3 national roads. Therefore we sometimes had to create connectors (*i.e.* "virtual roads") locally if the communal point was not located on the network.

Two perspectives were explored to calculate the PV accessibility at municipality level. The first consists of "overturning" the gravity model, or in other words, estimating the access times between municipalities based on the home/work flow, according to a friction of distance (disregarding the network). However this method raises the problem of the interpretation of the coefficients of the friction of distance; and in addition it presumes that journeys purely follow a gravitational logic. The second perspective, which was finally adopted, consists of estimating speeds in accordance with the breakdown of the origin/destination flows on the network, then calculating the best itinerary.

### *(1) Methodology*

**Setting the network parameters**

Setting the parameters of the network involved a heavy first phase of intersection verifications. It was therefore necessary to verify that a node (intersection of two road arcs) corresponded effectively to the possibility of a change of direction on the ground. In our test zone these verifications were carried out with orthophotos. Although rare, some errors were nevertheless revealed and corrected.

The second phase consisted of fixing a speed in free flow which comprises one of the parameters of the traffic assignment model. The speeds of non-motorway sections have been fixed based on the nomenclature of national roads (1, 2 or 3 figures).

The last important parameter concerns road capacity. In a conventional manner (according to MET, Ministère de l'Équipement et des Transports) the capacity of a motorway is 2000 PVU (passenger vehicle units) per hour and per traffic lane. This capacity can however vary depending on the geometry of the roads, and the composition of the traffic. As far as the roads in urban areas are concerned, the conventional capacity is 1200 PVU per hour and per traffic lane. We have not yet taken this into consideration in our Namur test zone (this point will be the subject of a subsequent improvement to the model). Outside agglomerations, this value varies between 1400 and 2000 PVU per hour and per lane. For the moment we decided to estimate this capacity by the number of traffic lanes multiplied by a conventional value of 2000 PVU/h. Following a necessary control and calibration phase, this value may be readjusted.

**Principle of a traffic assignment model**

The model adopted is based on the Wardrop hypothesis (1952). It is based on the relationship between the time to travel along a road and vehicles flow rate; therefore equilibrium is being sought so that no user may improve his/her journey time only by changing his/her itinerary. Based on a balancing algorithm, the flows are initially divided over specific sections then, thanks to a performance function, the speed in free flow is reduced based on the flow. Outside the equilibrium there are roads enabling an alternative access to arrive at the destination. The flows are therefore divided at each iteration in a way that all the roads used become equivalent in terms of journey times. At equilibrium, this signifies that the journey times in all roads used are equal and that these journey times are inferior to those of unused roads. The equilibrium of the division of flows is therefore done at agent and group agent level.

Following this balancing procedure, a speed is allocated to each road section. Then the accessibility matrix is calculated between each municipality thanks to an algorithm of the shortest road (Dijkstra, 1959). The output obtained is, as was the aim, a municipality-based matrix of access times.

Tool Used: CiudadSim (http://www-rocq.inria.fr/metalau/ciudadsim/welcome.htm)
The traffic assignment program used, CiudadSim, was developed by Lotito within INRIA. It is used with Scilab, a software application that enables the easy manipulation of large matrices.

**Accessibility Calculations**
The entire demand has been broken down into a period of one hour which corresponds to a scenario of an hour in the morning peak hour. The road network used intentionally exceeds the perimeter of the municipalities in the test zone so that the roads which pass through both the adjacent municipalities and the test zone can be taken into consideration.

#### *(2) Data*

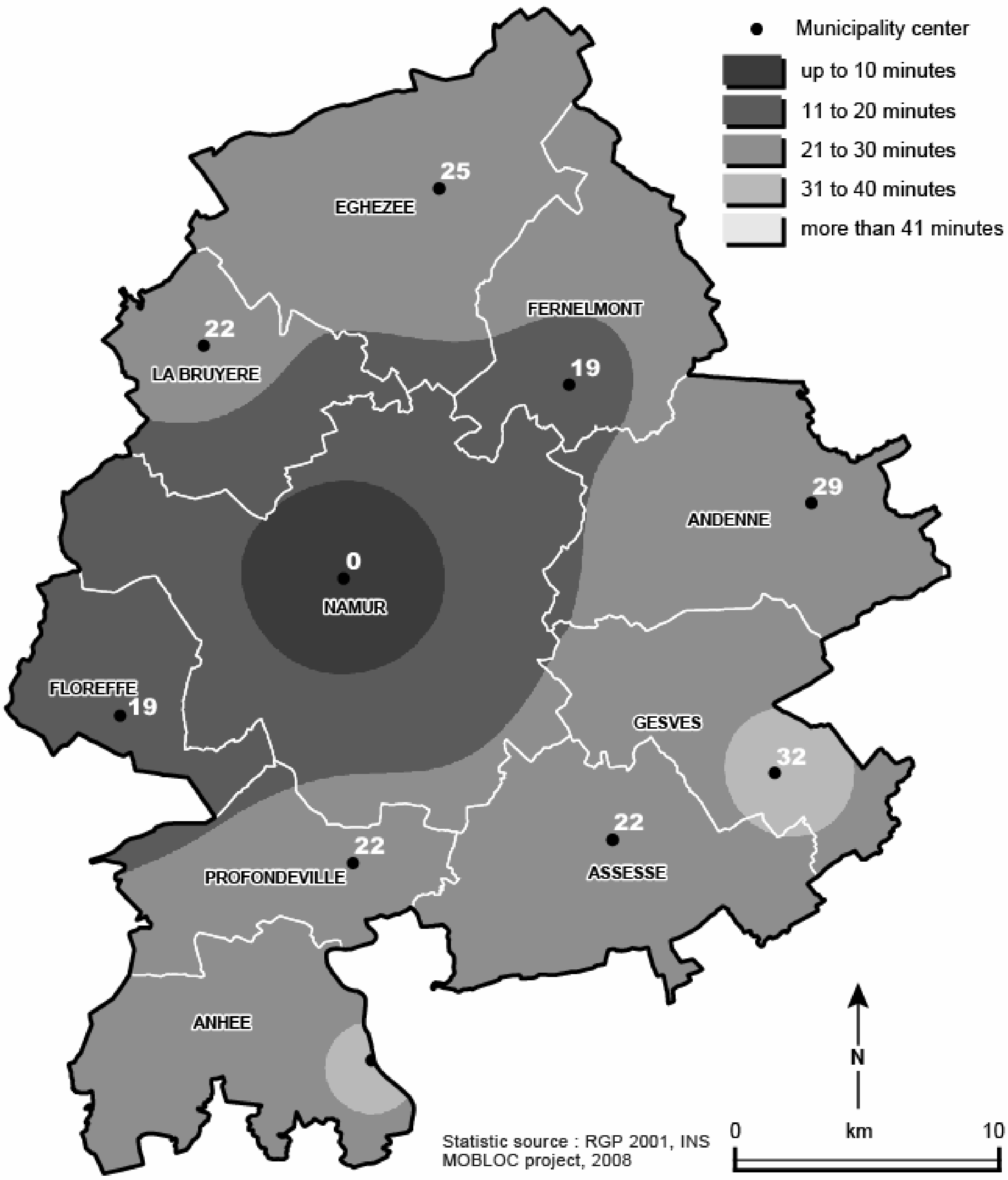
The data required is on one hand mainly the travel demand matrix (O/D matrix of home/work or school journeys) and on the other hand, the roads network itself and its parameters. In the current state, the diagonal of the demand matrix, corresponding to the people residing and working in the same municipality, is not taken into consideration as such in the accessibility model; however one can improve this point, for example thanks to an impedance calculation in accordance with the density of urban areas which enables the restoration of the friction induced by infra-communal travel.

#### *(3) Results*

The test zone results obtained may be mapped using interpolation. By again making use of the same value classes, we are then able to compare PT and PV accessibility. For our test zone, the comparison of figures 4 and 5 clearly shows better accessibility by private car during the peak hour.

We managed to set up and check the whole road network at the Belgium extent. The road network parameter setting is now achieved. As regards the traffic assignment, despite several sets of parameter we built and tested, it appeared that CiudadSim was not able to handle the amount of data at the extent of the whole country. It's the reason why no further results could be released up to now.

**Figure 5 – Unipolar PV accessibility towards**




### *(4) Perspectives*

As regards the private car accessibility issue, the expected results concern the traffic assignment on the road network, for which we have to find another program. In December 2008, different traffic assignment programs were considered but no decision was taken at that time.

Another perspective consists of the calculation of a municipal matrix of the optimal time by private vehicle. This matrix will allow the calculation of the indicators related to accessibility needed in the models coupling.

And last but not least, traffic counting will be implemented in the model to estimate more precisely the traffic jam.

## 2. Travel demand model (gravity)

In order to simulate accessibility over time, we need to estimate the travel demand at each time period. This estimation consists in two successive steps. First, we need to calculate the margins of the O/D matrix; this will be provided by the localization model and some estimation of employment per municipality. Then, we are able to ventilate this mobility demand using a gravity model.

### a) Methodology

Considering the availability of data at municipality level, we choose to develop a gravity model. In this kind of model, the spatial interaction between two points is a function of the masses of these points (attractiveness and emissivity) and of the distance between them.

To improve performance and consistency with reality, two constraints are included in the model:

- The number of people who come to work in a municipality cannot exceed the number of jobs available in this municipality
- The number of commuters in a municipality may not exceed the number of employed residents in this municipality.

Then, this model can be formalized in the following manner:

$$F_{ij} = A_i . B_j . O_i . D_j . d_{ij}^{-b}$$

With:

- *Fij*: flow between i and j
- *Oi*: number of employed residents in municipality i
- *Dj*: number of persons working in j
- *dij*: distance between i and j
- *-b*: friction of the distance (parameter)

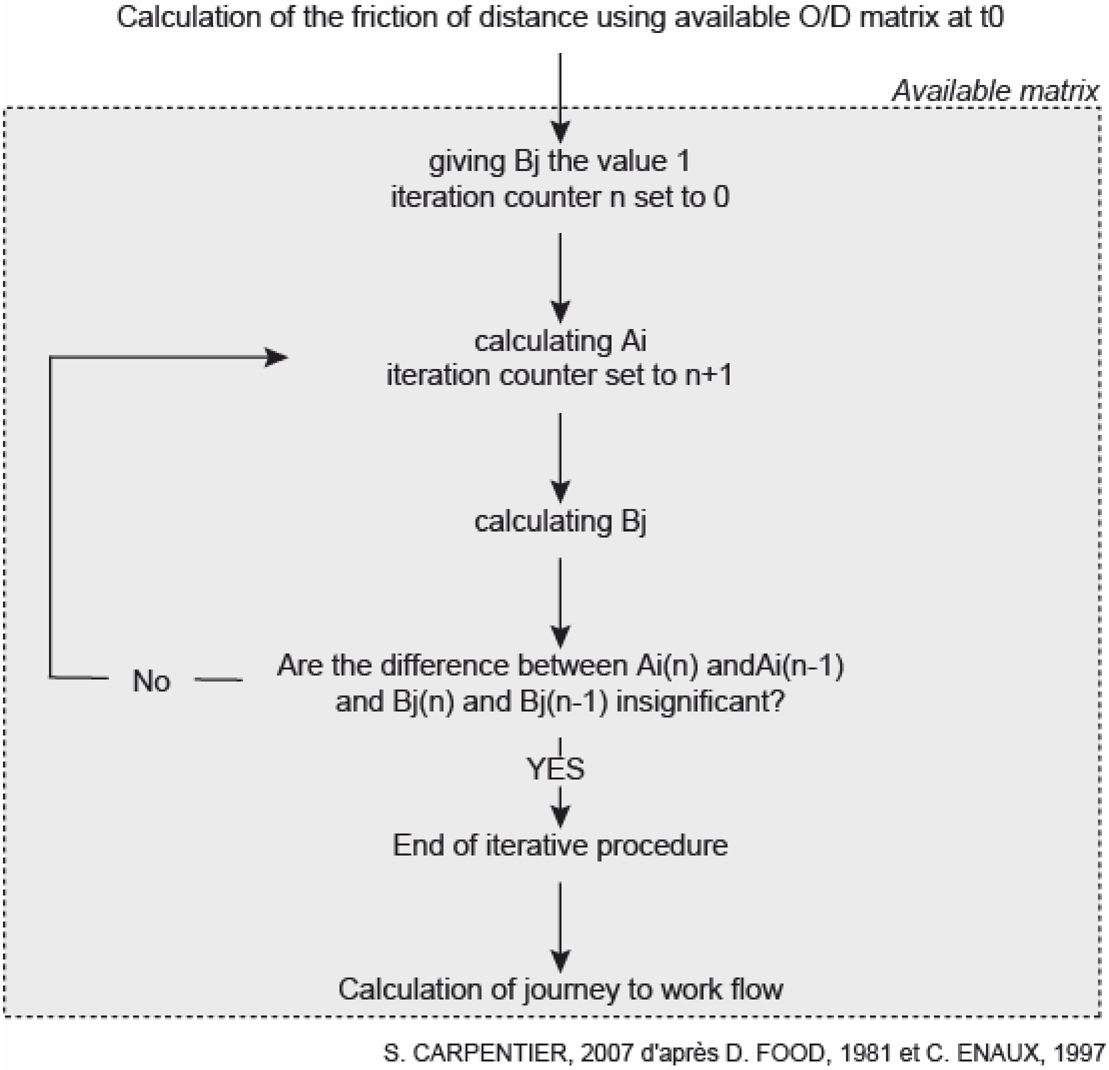
Ai and Bj are the parameters to calculate

$$A_i = \frac{1}{\sum_j B_j . D_j . d_{ij}^{-b}}$$

$$B_j = \frac{1}{\sum_i A_i . O_i . d_{ij}^{-b}}$$

The two parameters are estimated simultaneously, the calculation is therefore an iterative procedure as described in the following figure.

**Figure 6 – Iterative procedure for the doubly constrained gravity model**




### b) Data

This kind of model does not require much data. At $t_0$ we need a complete O/D matrix to estimate the parameters of the model, and a distance matrix between all pairs of municipalities. For the next steps ($t_{0+1}$, $t_{0+2}$...), only the margins of the O/D matrix (i.e. the number of jobs per municipality and the number of working people) and the distance matrix are needed. The distance between two municipalities can be seen in different ways (in travel time, Euclidean distance...); in this project, we choose to use a Euclidean distance. Indeed, we cannot use the travel time (accessibility) since the gravity model itself is used to calculate the accessibility.

The initial O/D matrix is given by the Socio-Economic Survey of 2001. For the next time periods, the margins of the O/D matrix will be given by the localization model and some estimation of employment per municipality. The Euclidian distance matrix will be calculated with a GIS.

### c) Perspectives

The gravity model is a classic, but strong way to assign traffic between spatial units. However, considering the very strong polarization of jobs in the Brussels region, a simple gravity model may not allow a robust estimation of flows. Some improvements, such as taking into account constraints on margins or a barrier (between regions) effect should improve the quality of the model.

## 3. Modal split

Modal share is an important issue to know which part of the home/work trips is really achieved by car. Indeed, if the number of car drivers is too huge because overestimated, traffic assignment will lead to network saturation. It then would be impossible to compute accessibility indicators.

### a) Methodology

Two possibilities were considered:

- apply modal split on the O/D matrix cells (computed by the traffic demand model);
- apply modal split on the margins of this O/D matrix.

The first alternative has been chosen because modal choice usually depends not only on the trip origin but also on the trip destination. The modal split model will thus have as input an O/D matrix with all modes included and as output an O/D matrix only for car driver trips. This output will then be used by the private car accessibility model.

A first approximation would be to keep the modal share observed for each O/D matrix cell computed from the data provided by the Socio-Economic Survey of 2001. These are exhaustive (for work-home trips) even though there will be cells with zero values because there are O/D pairs that no one performs for work purpose (for example, between two small municipalities far from each other).

This method could be a first and easier way to proceed but not very efficiently, especially if we consider that we would like to observe a modal share evolution in the forecast. This would indeed lead to a static description of the modal share and not to a dynamic modelling. This is the reason why we want to build a more sophisticated model (but still simple enough because modal split is not the main "brick" of the project we want to focus on).

The main idea is to model the modal split (MS) according to accessibility at the previous step (in our case the year before): $MS_t = f(AccPV_{t-1}, AccPT)$. One way to build the f function would be to observe if there is a link between the modal split and the difference (or the ratio) between the accessibility by private car and the one by public transport.

### b) Resources – data

For this modal split model, data of the Socio-Economic Survey of 2001 could be used, either for original O/D matrix modal share or to calibrate the model : $MS_t = f(AccPV_{t-1}, AccPT)$. The accessibility considered here is bipolar so that function calibration could in theory be based on more than 300.000 points (588*589 pairs of municipalities) but let us keep in mind that we will not consider diagonal elements and the cells (i,j) which are empty due to the lack of people living in the municipality i and working in the municipality j.

### c) Perspectives

Model building will be conducted during the second phase of the project. As the time remaining allows it, some improvements are considered. A first idea to investigate would be the use of an iterative computation of both the modal part and the private car accessibility. But let us remember that accessibility computation is very time-consuming and that such an option would be very ambitious.

On a different note, one could include other (exogenous) factors in the model that can have an effect on the modal choice. This suggestion comes from the fear of a too high inertia of the model and from impact of a lot of factors in the choice. Individual characteristics such as distributions of age, gender, level of education or driver license ownership, as well as of more external variables such as fuel prices could influence the decision.
Including such influences on the modal choice would be very interesting and relevant but of course depends on the data availability. It is for example not so easy to model the link between fuel prices and a modal choice, and furthermore to predict the evolution of the fuel prices. This could nevertheless be included in different scenarios.

## *B. Residential migration model*

As already indicated, the migration model has been split up into 2 sub-models: a model for the propensity to move and one for the residential localization. First we will focus on the propensity to move model before coming back to the localization one which is downstream.

### 1. Propensity to move model

Let us first expose recent trends of residential migration in Belgium during the past decades and a set of explanatory variables to study this event. In other words through this point we will lay the emphasis on the basic but crucial elements for explaining and modelling residential migration. Then we will present our works on modelling the propensity to move throughout different steps which lead to the definition of a propensity to move model. Finally we will conclude with the perspectives about this model.

Before going deeper in methodologies it should be mentioned that we could access to a first database (*National Register* - **NR**) describing states at successive 1st of January at an individual level from 2001 till 2006. That means that we cannot observe any real events but the ones deducted from transitions between two consecutive firsts of January. A second source of data is the national census (Socio-Economic Survey) – **ESE 2001**) achieved in October 2001 giving only one shot information.
Moreover, it must be clearly defined that by residential migration we only consider migrations between two municipalities since the data does not allow investigating migration within a same municipality.

#### a) Residential migration: a concise overview

First of all, we studied the evolution of residential migrations between municipalities for the last decades. Figures highlight two main trends. On one hand residential migration is rising. Since 1988, figures in residential migrations have strongly increased, growing from 379,000 in 1988 to 481,000 in 2004. The calculation of an index which corrects the effects of differences in age structure (age structure of the Belgian population has

been getting older for the last decades), shows that the propensity to move has increased at all ages from 0 to 65.
On the other hand we observe that the periurbanization process is ongoing and getting larger on the Belgian territory whilst young households are looking for cheaper housing and building plot. Different factors can be exposed to explain these trends. Among them, we should mention more frequent household transformations that increase residential mobility and the "deadlock" of ancient periurban areas that force in particular the younger ones who leave their parent's home to go farther and farther away (Eggerickx et *al.,* 2008).

**b) Pre-selection of variables for the propensity model**

Let us remind that given the available data, we defined that a residential migration occurs for an individual when his/her residential place (municipality) is different between two successive firsts of January. So migration inside the same municipality or multiple migrations in one calendar year are not detectable in the data since we only have the records of the municipality for the place of residence at each 1st of January.
The measured "risk" reflects thus the fact that the residential municipality at a 1st of January is different from one year to the next one. This "event" is quite rare since it concerns 4% of the Belgian population each year.

The explanatory variables were selected according to a literature review (e.g. Debrand et *al*., 2005 or Henley, 1998) and their availability through the National Register or the Socio-Economic Survey of 2001. We are dealing with individual characteristics as well as housing and area of residence characteristics.

> As *individual characteristics* we selected age, gender, nationality, household type, number of individuals per household, position in the household (i.e. the link with the head of household), the highest education level successfully completed, the activity status and type of activity, and if a migration occurred the year before.
>
> As *housing characteristics* we considered the type of housing (house, flat…) and housing tenure type.
>
> As regards *area of residence characteristic*, we took into account the urban/rural profile of the municipality (downtown, rest of the city, old and recent periurban areas, rural areas).

In order to explore what could be the most relevant covariates we built some contingency tables with these explanatory variables and the binary variable "Has an individual moved? Yes or no". We will not expose the results in details but just indicate which categories of people have the highest (and the lowest) propensity to move for each covariate we selected.

| Variables | Categories having the highest propensity to move | Categories having the lowest propensity to move |
|---|---|---|
| Age | 19-29 | 55-74 |
| Gender | Men | Women |
| Nationality | Congolese RDC | Turk |
| Household type | Cohabitants without children | Married couple without children |
| Number of people per household | 1 individual | 4 individuals |
| Position in the household | Other (than head, partne or child) | Partner |
| Previous migration (the year before) | Migrated the year before | Did not migrate the year before |
| Place of residence | Agglomeration (downtown excluded) | Small cities |
| Highest educatiuon level successfully completed | High education | Primary or no instruction |
| Activity status | People looking for a job | Retired |
| Housing tenure type | Renters in the private sector | Owners |
| Type of housing | Apartments | 4 front houses |

On the basis of the previous observations and of practical considerations we selected only a group of these variables. We could indeed not keep whole the set for the following reasons:

- On one hand we recommended the propensity to move model to focus mainly on individual characteristics; so it excluded de facto the urban/rural profile of the area of residence and the type of housing.
- On the other hand we found some limits provided by the data for the upcoming steps. Indeed, in the second phase of this project, we plan to achieve forecast for municipalities or group of municipalities. So we already need to know which variables will be available for extrapolation. The problem is that extrapolation needs individual data at least at two dates, and yet for some explanatory variables such as education level, occupation status, or housing tenure type, we only have data at one date i.e. October 2001, from the 2001 Socioeconomic Survey.

We thus had to consider which are the most essential variables from the 2001 Socioeconomic Survey. Here are explained the most crucial choices:

*Education level versus activity status:*

Since the highest education level successfully completed and the activity status are strongly associated, we decided to keep only one from these two variables. We finally chose the education level for two main reasons:

- Firstly, the way activity status and activity types have been built in the ESE2001 survey is not satisfying: the variable "activity status" contains modalities of responses that are not exclusive: one can be student and at the same time in activity; so we wondered how people answered one rather than the other category. As regards "activity types", the main critic is that in the 2001 census a distinction is made between workers and employees in the private sector, but not in the public sector so that we cannot compare one same position in the two sectors.

- Secondly, education level is a "capital" that one cannot lose contrary to activity status; hence, it is a more stable variable in time and easier to project in a near future. In comparison, occupation status or activity types might change from one year to the other according to the conjuncture or socioeconomic policy. Therefore, these are variables more volatile and then would be more difficult to manage for forecast.

In this context and given that education level is generally as good as activity status as a proxy for the socioeconomic profile of individual we preferred selecting education level.

*Housing tenure type:*

We have also kept in the set of variables the housing tenure type because it is just essential to analyze residential migration: this variable largely discriminates people in migration depending on whether they are renter or owner, or whether they are renter in a public or private housing. For instance the ratio of migrating people is more than 3 times higher for renters in a private housing than for owners of their housing.

Extracted from the Socio-Economic Survey of 2001, housing tenure type at individual level is only available at one date (October 2001). However trends provided by the National Institute of Statistics shows that it is a stable state through times, especially in Belgium where ownership is traditionally high: between 1991 and 2001, the percentage of people who are residential property owners increased from 65.4 to 65.9%, and forecast concerning potential impact of an economic uncertainty on becoming residential property owners do not seem significant in the Belgian market (Vanneste et *alii*, 2007). In this context, it appears that this variable would be stable during time, and not so complex to project in a near future.

An additional disadvantage for the housing tenure type is that it is given at the household level. That means that if the head of household answers that he/she owns his/her housing then each household's member is as well considered as owner. This makes problems especially if we are interested in leaving parents-household phenomenon because if a young adult lives with his parents' owners in 2001, he is then also owner. As we have only data at one date, once he leaves his parents' home he will be still considered as owner whatever the new housing. Despite these reluctances, we have included this essential variable and try to deal with its drawbacks.

Here are described the currently pre-selected variables and their modalities:

- *Age* (years over January, the 1st) - 6 modalities: 0-18, 19-29, 30-44, 45-54, 55-74, 75 and more.
- *Gender* - 2 modalities: Male, Female
- *Nationality* - 8 modalities: Belgian, Congolese, Moroccan, Turk, citizens from the 12 new EU members, citizens from the 15th former EU members and citizens from West European countries non EU members (Switzerland, Norway, Iceland,..), rest of East Europe (Balkans, Byelorussia, Russia, Ukraine), rest of the world.

- *Household Types* - 8 modalities: Married couple without children, Married couple with children, cohabiting couple without children, cohabiting couple with children, single-household, one-parent family, collectives and households "others" (with more than one family kernel).
- *Position in the household* – 4 modalities: head of household, spouse (wife, husband, partner), child, others. The position is determined in relation to the head of household.
- *Number of people per household* – 6 modalities: 1, 2, 3, 4, 4 or more, 5 or more. The total amount of modalities depends on household types and except for single-household and couple without children, the last class is open.
- *Highest education level successfully completed* – 5 modalities: no instructions or primary, secondary school (inferior), secondary school (superior), higher education, no answer.
- *Housing tenure type* - 5 modalities: owner, private renter, social renter, renter of a free housing, no answer.
- *Residential migration at the previous year* – 2 modalities: yes, no.

**c) Methodological choices to build the model**

The technique used is the binary logistic regression. The original idea was to use discrete choice model for the residential migration model. For this purpose, it was planned to use BIOGEME (software developed by Michel Bierlaire from the EPFL (Lausanne)). Since we faced some problems with the size of the database and given that, for the propensity model (first part of the migration model) we had a binary dependant variable and therefore considered to choose a logit function, we decided to make a binary logistic regression rather than a discrete choice model. We were indeed more familiar with this technique in the SAS software. Nevertheless discrete choice model remains the technique we plan to use for the localization model because it offers more possibilities when there are a lot of alternatives and we have already improved our knowledge on this topic.
There are different ways to conduct a logistic regression. At a time, our ambition for the propensity model was to deal with panel data methods. In using a five-year period database, we first explored how to build a model on the basis of the years 2001 to 2005. For this purpose, we built a person-year database: five observations per individual. But at the end, this method had some drawbacks in our case so that we finally opted for a simple binary regression model.

We had two main constraints when building this model:

*Annual step for the migration and for the projections*

When we started to build the model for propensity to move, the question arose about how to express the temporal unit of the dependent variable (and explanatory variables). As we had information at each 1st of January it seemed obvious that the most useful and simplest way to study migrations would be based on an annual step, which would estimate residential migration within one year, i.e. between two consecutive 1st of January.
Nevertheless it appeared rapidly that the same step should later be used in the forecast so that we had first to develop the design of the second phase of MOBLOC and investigate how to achieve demographic projections. Demographic methods

generally use a five-year or a ten-year step. The question was then: may demographic method be adapted to an annual step? We finally concluded that it was possible and therefore we decided to keep the annual step as temporal unit.

*Take advantage of the dynamic dimension: past and anticipation effects.*

As we already mentioned, the available database is a sequence of states for the overall Belgian population during the 5-year period 2001-2005.

By convention in demography, when we refer to a "period", it means a period in years of time. For instance, the 2001-2005 period is a 5-year period in year of time; i.e. from 1st January 2001 till 31st December 2005. However, in this section and in particular here below we also use the terminology of the "transition period" which refers to the year between 2 firsts of January, e.g. the transition period 2002-2003. This results from the use of observed differences of states between two consecutive 1st of January.

Data from the National Register provides the socio-demographic profile each year (while data from the 2001 Socioeconomic Survey supplies some other variables, but only in October 2001). We so want to take advantage of the dynamic dimension conveyed by this database.

Indeed, it seems obvious that past information in the life of an individual can help to explain his/her migration behaviour. For example a change in the household's structure or size (which can reflect events such as separations, births or unions) can increase (or decrease) the probability for change in residential municipality. At the same time we also want to test effects from anticipation. For instance, testing whether an observed migration for a couple in the transition period Y and Y+1 may be explained by the fact that this couple has a baby in the transition period Y+1 Y+2. They could have anticipated the birth by looking for a bigger housing the year before.

While building the model which has to explain migration between years Y and Y+1, we looked for a suitable way to include this dynamic dimension. Rather than simply use the state variables at the first of January of the years Y-2, Y-1, Y, Y+1 and so on, we decided to use the state variables only at time Y and to create transition variables which describe variation in the state variables between two successive 1st of January.

These transition variables have been created for variables from the National Register i.e. household structure and size, position in the household and nationality. But for anticipation we have only considered household transitions (variables related to household). Regarding the Socio-Economic Survey of 2001 variables, as they are only available in October 2001, it was not possible to create transition variables.

These transformed variables are helpful to add in the model a "temporal depth" of one or more years back or forward. From a statistical point of view, transition variables as a substitute of a sequence of temporal successive states have the great advantage to handle multicolinearities or autocorrelation, which could occur when using these states as explanatory variables in the model. Moreover, they make easier the interpretation of the results since transition variables implicitly suppose an event (although not observed).

At a last point, it should be said that since dynamic database allows catching unobserved heterogeneity, we add in the model an autoregressive dimension which is the dependent variable at the previous year (did an individual move the year before?).

#### d) Transformation of variables

Before creating transition variables, we studied and applied specific treatments for intrinsically highly associated variables such as household types and number of people per household. Indeed, e.g. single households have all one person living, while married or cohabitant couples with no children are all composed of two members. In other cases, the association between household type and household size is not univocal so that we wanted to keep information from both variables. As a consequence, we created synthetic variables based on these two variables describing the household type and the number of people living in it.

Another variable transformation was the setting of transition variables. As already described, such a variable substitutes for 2 successive state variables. For each individual, if these two successive state variables are identical then the value of the transition variable is "no change". If not, we first concatenated the two successive states and then we grouped these categories in less numerous modalities that could explain the migration behaviour.

For instance naturalization variable 0102 was built from two variables: nationality in 2001 (more precisely at 1st January) and in 2002. If this nationality has changed we distinguished two cases: if it was a nationality change towards the Belgian or the UE citizenship, then we consider it as a change i.e. naturalization; but if it was a change towards an other extra-European nationality, then we do not. Here, becoming Belgian or UE citizenship has been only seen as a change because becoming Belgian or a European citizen might encourage a long stay in Belgium and the adoption of local residential migration behaviour.

In the same way, we redefined a lot of transitions, especially for the synthetic variable (household type and size).

#### e) Sample design

The question to use a sample rather than the entire base arose when we faced some problems with the size of the database and the calculation time. As there are more than 10 millions citizens in Belgium, we have about the same number of observations, which is more than necessary. We may indeed reasonably reduce the size of the sample without losing quality of information for the model.

The sample design was also a constraint and needed technical adaptations. Since the model deals with residential migration within the country we worked with an enclosed population that was people who were residents in Belgium at the considered years.

Furthermore, including the "temporal depth" - of one or two years in the past and one year after the reference year - implied to add the condition of being resident in Belgium during at least 3 consecutive years (or 4 consecutive 1st of January).

Furthermore as residential migration is a rare event (4% per year), we wanted to increase its frequency in order to improve the quality of the coefficients of regression (Allison, 1999). This is the reason why we oversampled the migrants. As a consequence the sample is based on a stratified random sampling in the overall Belgian population. Stratification has been done according to the dependent variable: for one year observed, we selected all people having changed from municipalities and, for the non-migrants,

we realized a simple random withdraw. The total number of individuals arises 2 millions and the percentage of annual migrants comes around 15%. It should be mentioned that we realized several sampling depending on the years of the studied migration. If we study the migration between the firsts of January of the years Y and Y+1, then we use the sample in which migrants in the transition period Y - Y+1 are oversampled.
Finally from each sample, we created two subsamples:

- the first one is composed of 70% of the individuals and is used for the model calibration,
- the second one with the rest 30% to test and validate the models.

The propensity model is based on the individual level. If we agree that the decision to migrate can be individual, nevertheless it could also be the decision of the household, or at least of the couple.
At first we wanted to integrate the household and individual units in order to take into account both units of decision. However we realized that drawing a sample on household units with a temporal depth was hardly impossible because the numerous household transformations do not allow the follow-up of everybody from the sample. Indeed, between two consecutive years one household can be divided into two households; and one individual can change from an household to another one. It is thus difficult to build a model with households as units and to study their migration behaviour with a temporal depth. Hence, we chose to limit the propensity to move model at individual level. However we included explanatory variables related to household characteristics and positions in the household that could help to take indirectly this second unit into account.

#### f) Model(s)

Given that the available data covers the five-year period from begin 2001 to end 2005 (1st January 2001… 2006), we finally concentrated on two transition periods: 2002-2003 and 2003-2004. The reasons for this choice are:

- First of all, since variables from the Socio-Economic Survey of 2001 (education level, occupation status, housing tenure type …) are only available at that time (in our individual database), the closest data from the National Register (household structure, nationality …) are thus those from the first of January 2002; that is why we first decide to study 2002-2003.

- But we also wanted to introduce, as explanatory variable, transformations in the household structure occurred in the past of the individuals (such as marriage, divorce, birth …). Unfortunately, the available data from the National Register only covers 2001-2005, so the only previous period that we could use to explain the period 2002-2003 was 2001-2002. In order to test the improvement of the quality of the model by adding older information, we decided to also study the transition period 2003-2004. We have to notice that the data from the Socio-Economic Survey of 2001 are less contemporary and so less relevant in the model for 2003-2004 than in the one for 2002-2003; that is why we have not chosen, for example, 2005-2006. If we want to estimate the propensity to move between 2005 and 2006, information from 2001 start to be out of date. So we chose to concentrate on migration between 2002 and 2003 and between 2003 and 2004. This implied that we fixed the maximum "temporal depth" at two years back because we had no information before 2001 from the National Register.

- Finally, the purpose (of studying two different periods) was also to determine if the results (parameters) from the models for 2002-2003 and 2003-2004 were comparable in time and led to the same interpretations. It was actually important that the model would be independent from the transition period it is based on, since it will be used to predict the migration behaviour in the future (population forecasting).

To sum up, we tested different sets of variables in order to:
- compare migration model for two different transition periods : 2002-2003 and 2003-2004,
- test the effects/advantages of adding older (delay) or future (anticipation) information.

The table below summarizes the five models tested and the variables selected (with their source) in each case:

| Dependant Variable | Models | Explanatory Variables (with sources) |
|---|---|---|
| Migration between 2002 and 2003 | Model 1 | Age in 2002 (NR) |
| | | Gender (NR) |
| | | Nationality in 2002 (NR) |
| | | Type and size of the household in 2002 (NR) |
| | | Evolution of the type of the household between 2001 and 2002 (NR) |
| | | Evolution of the type of the household between 2002 and 2003 (NR) |
| | | Link with the household head in 2002 (NR) |
| | | Evolution of the link with the household head between 2001 and 2002 (NR) |
| | | Evolution of the link with the household head between 2002 and 2003 (NR) |
| | | Migration between 2001 and 2002 (NR) |
| | | Education level successfully completed (ESE 2001) |
| | | Housing tenure type (ESE 2001) |
| | Model 2 | Age in 2002 (NR) |
| | | Gender (NR) |
| | | Nationality in 2002 (NR) |
| | | Type and size of the household in 2002 (NR) |
| | | Evolution of the type of the household between 2001 and 2002 (NR) |
| | | Evolution of the type of the household between 2002 and 2003 (NR) |
| | | Evolution of the type of the household between 2003 and 2004 (NR) |
| | | Link with the household head in 2002 (NR) |
| | | Evolution of the link with the household head between 2001 and 2002 (NR) |
| | | Evolution of the link with the household head between 2002 and 2003 (NR) |
| | | Evolution of the link with the household head between 2003 and 2004 (NR) |
| | | Migration between 2001 and 2002 (NR) |
| | | Education level successfully completed (ESE 2001) |
| | | Housing tenure type (ESE 2001) |

| Dependant Variable | Models | Explanatory Variables (with sources) |
|---|---|---|
| Migration between 2003 and 2004 | Model 3 | Age in 2003 (NR) |
| | | Gender (NR) |
| | | Nationality in 2003 (NR) |
| | | Naturalization between 2002 and 2003 (NR) |
| | | Naturalization between 2003 and 2004 (NR) |
| | | Type and size of the household in 2003 (NR) |
| | | Evolution of the type of the household between 2002 and 2003 (NR) |
| | | Evolution of the type of the household between 2003 and 2004 (NR) |
| | | Link with the household head in 2003 (NR) |
| | | Evolution of the link with the household head between 2002 and 2003 (NR) |
| | | Evolution of the link with the household head between 2003 and 2004 (NR) |
| | | Migration between 2002 and 2003 (NR) |
| | | Education level successfully completed (ESE 2001) |
| | | Housing tenure type (ESE 2001) |
| | Model 4 | Age in 2003 (NR) |
| | | Gender (NR) |
| | | Nationality in 2003 (NR) |
| | | Naturalization between 2001 and 2002 (NR) |
| | | Naturalization between 2002 and 2003 (NR) |
| | | Type and size of the household in 2003 (NR) |
| | | Evolution of the type of the household between 2001 and 2002 (NR) |
| | | Evolution of the type of the household between 2002 and 2003 (NR) |
| | | Evolution of the type of the household between 2003 and 2004 (NR) |
| | | Link with the household head in 2003 (NR) |
| | | Evolution of the link with the household head between 2001 and 2002 (NR) |
| | | Evolution of the link with the household head between 2002 and 2003 (NR) |
| | | Evolution of the link with the household head between 2003 and 2004 (NR) |
| | | Migration between 2001 and 2002 (NR) |
| | | Migration between 2002 and 2003 (NR) |
| | | Education level successfully completed (ESE 2001) |
| | | Housing tenure type (ESE 2001) |
| | Model 5 | Age in 2003 (NR) |
| | | Gender (NR) |
| | | Nationality in 2003 (NR) |
| | | Naturalization between 2001 and 2002 (NR) |
| | | Naturalization between 2002 and 2003 (NR) |
| | | Naturalization between 2003 and 2004 (NR) |
| | | Type and size of the household in 2003 (NR) |
| | | Evolution of the type of the household between 2001 and 2002 (NR) |
| | | Evolution of the type of the household between 2002 and 2003 (NR) |
| | | Evolution of the type of the household between 2003 and 2004 (NR) |
| | | Evolution of the type of the household between 2004 and 2005 (NR) |
| | | Link with the household head in 2003 (NR) |
| | | Evolution of the link with the household head between 2001 and 2002 (NR) |
| | | Evolution of the link with the household head between 2002 and 2003 (NR) |
| | | Evolution of the link with the household head between 2003 and 2004 (NR) |
| | | Evolution of the link with the household head between 2004 and 2005 (NR) |
| | | Migration between 2001 and 2002 (NR) |
| | | Migration between 2002 and 2003 (NR) |
| | | Education level successfully completed (ESE 2001) |
| | | Housing tenure type (ESE 2001) |

We used the stepwise procedure (Allison, 1999) selecting one by one the variables which are significantly related to the explanatory variable conditionally to the previously entered variables. This procedure can also eventually remove one of these covariates thereafter, if it has lost its significance due to the addition of an other variable.

In our models, all of the explanatory variables removed from the regression because of lack of significance concerned naturalization:

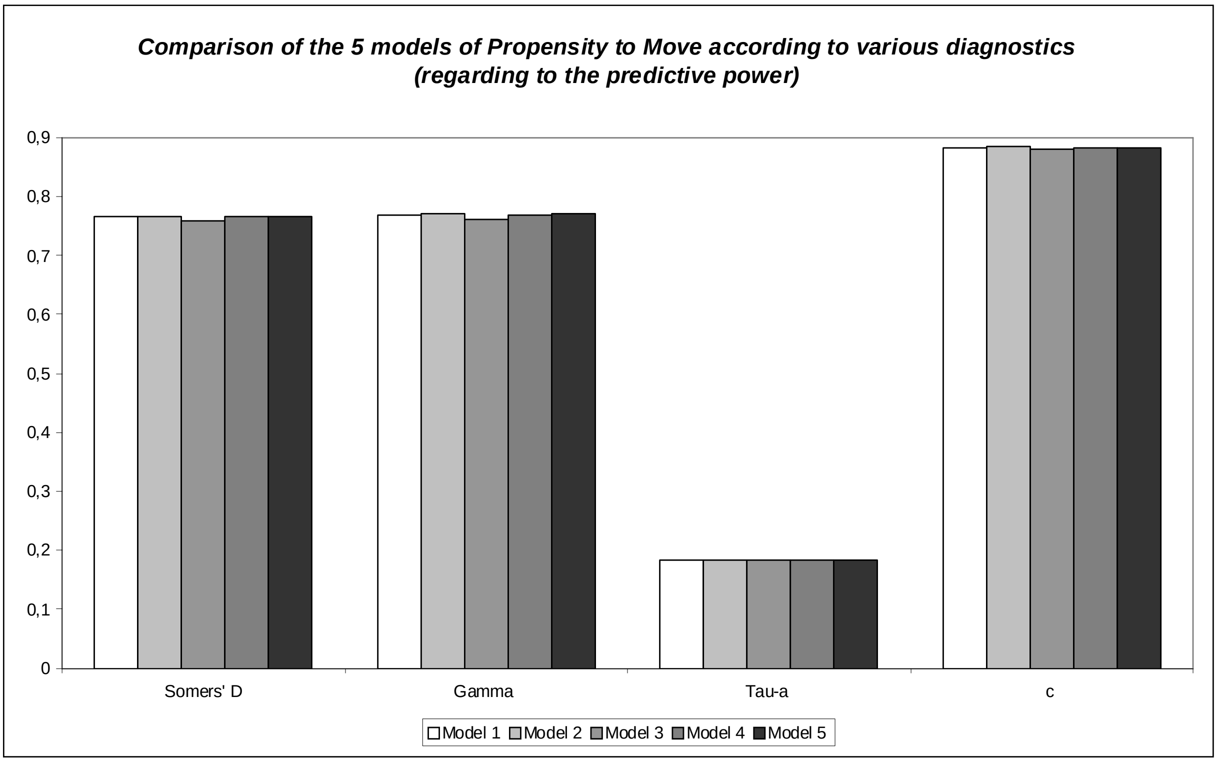
- naturalizations between 2001 and 2002 and between 2002 and 2003 for models 1 and 2;
- naturalization between 2003 and 2004 for models 4 and 5;

Then we have compared these models thanks to some global criteria such as AIC and log Likelihood. We present here below the different likelihood ratios of our models:

| Tests on the Likelihood Ratios | | | |
|---|---|---|---|
| | ***Khi-2*** | ***ddl*** | ***Pr > Khi-2*** |
| *Model 1* | 502377,9 | 215 | < 0,0001 |
| *Model 2* | 505456,7 | 301 | < 0,0001 |
| *Model 3* | 511072,5 | 219 | < 0,0001 |
| *Model 4* | 511247,3 | 306 | < 0,0001 |
| *Model 5* | 506794,7 | 394 | < 0,0001 |

The differences between the tested models are not huge. From these data we can assess that all our models have a good calibration: indeed, all khi-2 tests on likelihood ratios are extremely significant.

Another way to assess models performance relies on the discrimination: does the model well predict the behaviour of the individuals? Is somebody moving predicted as a mover? Does the model well separate the migrants from the non-migrants? If we have a look at the figure here below, we can see that principal diagnostics about discrimination (provided by the SAS software as outputs of the logistic regressions) show little amelioration between models 1 and 2 and from models 3 to 5. All four statistics have to present high scores if the models are well fitted.



The fact that model 3 seems to be worse than the first 2 models (regarding the predictive powers) can be explained by the loss of relevance of covariates coming from the census. The statistic *c* is an approximation of the area under the ROC Curve which also provides a measure of discrimination. As a general rule, when this area is between 0.8 and 0.9 one can consider the model have an excellent discrimination (Hosmer et *al.*, 2000). In our case values of c are close to 0.9 which means our models are really discriminatory.

As a conclusion about the models, we remark that the 5 models are really good. As the first one seems to be already more than satisfactory, we propose to use this one in the next steps of our project (i.e. for the micro-simulation phase).

We give here below the four most explanatory covariates of this first model (in a decreasing order) as they also appear in the following table for the first model:

- evolution of the type and size of the household between Y and Y+1
- housing tenure type
- evolution of the link with the household head between Y and Y+1
- age in Y (six classes)

**Are the Covariates of Model 1 Significant? (Migration between 2002 and 2003)**

| Covariates | ddl | Khi-2 | pvalue |
|---|---|---|---|
| Evolution of the type of the household between 2002 and 2003 | 74 | 59530,5 | <,0001 |
| Housing tenure type | 4 | 48683,1 | <,0001 |
| Evolution of the link with the household head between 2002 and 2003 | 12 | 32138,8 | <,0001 |
| Age in 2002 | 5 | 12677,9 | <,0001 |
| Type and size of the household in 2002 | 17 | 4079,0 | <,0001 |
| Migration between 2001 and 2002 | 1 | 3563,2 | <,0001 |
| Evolution of the type of the household between 2001 and 2002 | 74 | 2946,7 | <,0001 |
| Link with the household head in 2002 | 3 | 2458,2 | <,0001 |
| Highest education level successfully completed | 5 | 2384,8 | <,0001 |
| Evolution of the link with the household head between 2001 and 2002 | 12 | 590,0 | <,0001 |
| Nationality in 2002 | 7 | 218,0 | <,0001 |
| Gender | 1 | 34,2 | <,0001 |

The most significant variable is clearly the simultaneous transition of the household structure (type and size). Compared to the reference category (no change in the household structure between the two consecutive years), all the odd ratios are positive which means that any change in the household structure is correlated with an increasing probability to move (everything else being equal). The importance of this increase depends on the household structure change. Amongst the most significant, let us point out the people whose household structure were "married couple with children" and became "unmarried couple with/without children", "one-parent family" or "isolate". They have from 20 to 30 times more likelihood to move than people whose household structure did not change. Let us remember that family events are univocal in the data.

These people can be a child who left parents' home, or members of the couple which split up, or etc.
This can be related to another significant variable: the change of relation to the household head. For example, being a child status to a head or spouse status (or inversely) is related to a high increase of the probability to move (between 11 and 16 times more than in the case of no change).

An other important variable to predict the propensity to migrate is the housing tenure type. Renters in the private sector are 4 times more likely to move than owners.

Age class also appears amongst the four most significant variables. The less residentially mobile are 75 years old and more while the most mobile are the youngest (less than 18 years). The probability to move decreases with age (everything else being equal).

#### g) Perspectives

The propensity to move model has reached a satisfying degree of achievement; we performed some last validation tests to choose a model with sufficient quality in terms of predictive power and with a reasonable amount of variables whose values should evolve in the future. Let us remark that the more covariates we have, the more work we will have with the evolution of these covariates. Of course, this model could be lightly adapted or improved thereafter while working on the localization model or on the evolution of the explanatory variable (second phase). So nothing is definitive and improvements or modifications could still occur in the future if necessary.

### 2. Localization Model

As already mentioned, the migration model has been divided into 2 sub-models
During the simulation phase, the localization model will use the output of the propensity to move model to identify on which people the second model has to be applied. The calibration of this second model has to be achieved in the second phase of the MOBLOC project. We can nevertheless already expose the headways we made on the methodology to be adopted.

#### a) Data

The model will be calibrated with both the same data sources than for the propensity model (ESE2001 and NR) (but not necessarily the same variables), and further data sources: information about municipal accessibility (coming from the accessibility models) is obviously portentous in the core of the MOBLOC project. One could also think that real estate market influences decision on the destination of a residential migration or some satisfaction indicators of the inhabitants about their neighbourhood can also be interesting. This list is obviously not exhaustive.

The explanatory variables we propose to take into account for the localization model can be classified into 2 categories:

- variables related to the individuals (or their household) such as housing tenure type, age, type of household, education level and so on;

- variables related to the alternative of choice such as the output of the accessibility models, an indicator on the property price, the level of services, the ground occupation (typology of Van der Haegen), the satisfaction of residents about tranquillity and so on.

For this second class of covariates we have already considered that it would be more pertinent to transform variables so that they express a difference between the characteristics of the municipality that the individual leaves and the characteristics of each of the 588 alternatives. It would indeed lead to interpretations in terms of relative increasing/decreasing of the municipal characteristics.

Let us remember that the output of this model will be the new municipalities of residence of the people who moved (this output is thus related to individuals). There are so 588 alternatives for any individual leaving 1 municipality since there are 589 municipalities in Belgium and migrations occurring inside a given municipality can not be observed with the available data.

**b) Methodology**

Before any building of the model, all plausible explanatory variables will first have to be tested. Some statistical analyses are indeed necessary to know which covariates should enter in the model.

As each individual who decides to move has to choose between 588 alternatives (municipalities), discrete choice methods (Train, 2003) was chosen for modelling as well as possible his/her behaviour. This technique consists in determining the utility of each alternative and then computing the probability of choice of each alternative;

$$U_{in} = C_i + \sum_j PInd_{ij} \times VarInd_{jn} + \sum_k PMun_k \times VarMun_k + \varepsilon_{in}$$

With:

- $U_{in}$: utility of the alternative i for the individual n
- $C_i$: alternative specific constant
- $PInd_{ij}$: the parameters for individual covariate j and alternative i
- $VarInd_{jn}$: covariates related to the individuals
- $PMun_k$: parameters related to the alternatives (municipalities) characteristics
- $VarMun_k$: covariates related to the municipalities
- $\varepsilon_{in}$: random term (to model unobserved effects)

Once we have the probabilities for all alternatives, a random draw weighted on these probabilities will attribute the municipality where the individual settles down. Let us remark that the utility includes a random term which allows the model not to be deterministic.

There are different ways to model the unexplained part of the utilities: the logit model which takes i.i.d. Gumbel distributed random terms is the most commonly used even if has some drawbacks. The main one is that the logit formulation supposes independence between alternatives (proportional substitution – IIA assumption). Indeed we can not make this assumption in the case of residential localization because there are certainly correlations between alternatives (municipalities). For example, if we imagine two municipalities of same typology and being adjacent, these municipalities are likely correlated i.e. probabilities that an individual chooses one or the other should be closer to each other than to the probability of a municipality geographically away and belonging to another kind of typology.

There are methods to take into account some correlations between alternatives but these are not necessarily easy to implement.
The way we consider to solve this problem is to work with nested logit allowing capturing these correlations by grouping supposed correlated alternatives (group which have to be validated by the model). In fact, when working with such model the choice is modelled as hierarchical: you first opt for a group of (correlated) alternatives and then you make a final choice inside this group (called a nest). The difficulty is obviously to build these nests. Different possibilities could be imagined:

- making nests based on the employment areas or the living catchment areas (rather than choosing one municipality between 588 alternatives, an individual first selects a region where to settle down);

- making nests on the Van der Haegen typology (rather than choosing one municipality among 588, an individual first selects municipalities having the same profile responding to his/her desires);

- two levels of nests with one based on the employment area and the second reflecting the Van der Haegen typology or vice versa.

Another issue is that a municipality can belong to more than one nest. In this case we can determine that this alternative belongs to both nest i and nest j. This is the field of cross-nested logit models.

#### c) Perspectives and expected results

As explained above, all these considerations are crucial for the design of the modelling. This conception is a first (mandatory) step leading to a good definition of an acceptable model. Coming months of the project will bring us to work more deeply on this model.
We will also have to assess our models.

As results of this model, we will know on which covariates depends the localization choice when somebody decides to move. In the simulation phase, people who are supposed to move according to the propensity to move model will enter the second sub-model of residential migration to determine their new localization.

As we will also have information about their socio-demographic profiles, we will be able to evaluate the new mobility demand and so the impact of residential mobility on the daily one and perform new computations to update the PV accessibility indicators of municipalities.

## C. Evolution models

The final objective of MOBLOC is to use previously described models to perform some forecast. For this purpose, we need all the models inputs to evolve. This issue is so really critical while developing each model. Let us point out that, since the residential migration model works at an individual level and uses individual evolution to predict migration and new localization, therefore an individual evolution model (transition model) is necessary.

Furthermore, techniques such as synthetic population and demographic perspectives can provide aggregated evolution but they do not allow micro-simulation (following individual evolution).
Other methods are thus considered in complement with these aggregated techniques. The challenge would then be to control the coherence between both levels of results.

### 1. Aggregate level: demographic perspectives

These techniques are suitable for the evolution of the margins at the level of the municipalities or of groups of municipalities. To be reasonable, they could take into account 3 variables: age, gender and another variable such as household size. They include births, deaths and so on.

### 2. Individual level

Amongst explanatory variables, individual age and gender do of course not require sophisticated model to evolve.

#### a) Household transition

As *household transition* is one of the variables most related to residential migration, evolution of household size and type (for an individual) will be a crucial issue in the forecasting step.

##### (1) Methodology

The main idea is to credit each individual probabilities of having each household situation (at year Y+1) given his household situation the year before (Y).

##### (2) Data

For that purpose, the most suitable data is the longitudinal data from the National Register which give individual household situation at each 1st of January. We should use them through transition matrices. These would be built by taking into account situations between two consecutive years. It will allow giving transition probabilities for each individual according to his/her previous situation. A weighted random draw would then attribute the new household situation for each individual.

##### (3) Perspectives

Let us remark that the transition matrix can depend on the two considered years from which we build the matrix. It will be an interesting analysis to compare matrices built for different periods (two consecutive years) to see if there are significant differences in the household transition according to the time. If such differences are detected, we should adapt our methodology: build a "mean" matrix or try to model evolution of transition matrices (if any regular trend can be observed).

#### b) Activity status

Let us now concentrate on the *activity status*. This variable is indeed also of big interest because it conditions one major input of the "demand model" as this uses the number of working people per municipality.

How could activity status at an individual level be changed?
As available data only provides us the activity status at one time (October 2001), it is necessary either

- to find other longitudinal data to build an evolution model,
- to predict the activity status according to other covariates thanks to an explicit model.

The second solution has been kept. We could first use a simple regression to explain the activity status from the available variables of this step such as age, gender, education, etc. [status = f(age, gender, education)]

This status will then be aggregated at the municipal level to be used as input in the travel demand model (this is one of the two necessary margins: the number of working people per municipality). Caution will be taken regarding the coherence between others parts of the project. For example, the link with the travel demand model (gravity model) requires the total number of working people in all Belgium to be equal (or at least not too different) to the number of jobs in Belgium. This constraint must thus be included in the model which gives the activity status.

#### c) Others variables

Such evolution models should be built for example for level of education and housing tenure type with the same kind of methodologies.

# IV. Support to the decision

As we already mentioned above, the project objective is to investigate the cycle linking long-term society evolution, residential choice, transportation demand and the resulting accessibility evolution.

This project can improve the understanding of new mobility behaviours in the context of an extensive periurbanization through the Belgian territory. It aims at achieving forecast for future residential localization and accessibility demand, and in this way, it should be useful to appreciate the consequences from these new behaviours on transportation demand, as well as to manage the motorised traffic.

The first fitting sub-model built in this project (propensity to move) has as a main objective to determine how individual characteristics and cycles of life do have an impact on residential migrations. On the societal trends side, particular attention will be paid to the population ageing effects and to the evolution of the family cell structure in the coming steps (simulations). Age is here a key explanatory variable and the demographic perspectives would probably rely on different assumptions as the population ageing. As regards, evolution of the family cell structure, we also have created variables trying to reflect life-cycles related to the family history and household transformations. An evolution that is included in our model through a "temporal depth".

The second sub-model (residential localization) of the migration model will permit to know more about the variables which are determining the choice of localization. In this context, the transportation demand will be extrapolated from the new localizations of homes and places of work.

As regards the accessibility model, this model would stress the new trends concerning traffic and transport demand at the municipality level. Since the periurbanization process has often benefited from the decrease of commute times (e.g. to go to one's work), it also results from better communal accessibilities.
However - if it is possible to live in rural area without a too high increase of commute time - the extension of periurbanization could lead to more and new traffic congestion. Hence, travel times may increase and rural areas - targeted by the periurbanization process - could lose their attractiveness.

All these models are designed in interaction. For instance, the evolution towards a good or a bad accessibility for a municipality will be then one of the relevant explanatory variables to determine the residential choice of localization.
Interaction effects will favour a better understanding of residential mobility and to what extent residential and daily mobility as well as the accessibility profile of a municipality can interact.

# V. Conclusion

This report of the MOBLOC project allowed us to present the work achieved during the first two-year phase. We began with a description of the context in which our research takes place and the objectives we propose to reach. A global description of the different steps of modelling, supported by an overall diagram, followed with a brief explanation of the inputs and outputs of each of them and the numerous interactions which exist between them. Then, we focused on each of the models finalized or in way of achievement.

So we first detailed all the intermediate stages leading to the computation of the accessibility indicators of the Belgian municipalities (choice of representative points in the municipalities, setting of the network parameters, definition of a demand matrix...). In the frame of this project, the calculated accessibility is bipolar (from a given municipality to a second one) and is represented by journey times for two different modes. The first mode corresponds to the journeys achieved by car and relying on a demand matrix provided by the Socio-Economic Survey of 2001. The second one is for the public transport and takes account of the supply of the different Belgian public transport operators. The accessibility indicators will allow us to build later other indicators as accessibility to job opportunities, schools or health care services. These indicators will be integrated in the migration model (second sub-model). Till now, the methodology presented has been assessed on a test zone and gives realistic results.
As one of the objectives of the project is to realize simulations, input of the accessibility model will have to evolve. That will be possible thanks to a travel demand model which will be calibrated with the data of the Socio-Economic Survey of 2001. A modal split will also be useful to lead this part of the project: the main idea is to estimate the modal share in the projections phase according to the accessibility at the previous step. All these issues will be developed in the second phase.

We also presented the migration model which is decomposed in two sub-models: a first one called propensity to move model which predicts if an individual comes to migrate (regarding his/her characteristics) and a second one, the localization model, which will determine where the migrating individuals settle down. The propensity to move model is actually finalised. We tested several specifications of this model (which consists in a logistic binomial regression) and observed that the simplest one met our expectations. The more significant covariates of the model are the evolution of the type and size of the household and the evolution of the link with the household head which occurs while the considered period of potential migration, the housing tenure type, and the age of the individual.
Discrete choice methods will be used in the localization model. We already designed the structure of this second sub-model, and planed to work with a hierarchical nested logit model. It will allow us to decompose the choice of the decider in different steps and to handle correlation between the alternatives of choice (municipalities). Explanatory variables will include individual characteristics as well as municipalities' indicators.

Projections for the coming years being part of the objectives, all input of our different models will have to evolve. So we will recourse to demographic perspectives for the aggregate level and to simple regression to make evolve covariates such as the activity status or to transition matrices for covariates such as the household transitions.

The first two years of the project allowed us to build or to design the structure of the mandatory models in order to reach our objectives. Interactions and feed-back have been taken into account to guarantee that our project will be operational.
In the two coming years, models should be finalised to be able to achieve projections and simulations which will be useful for public services as support for the decision.

# VI References

ALLISON P., Logistic Regression Using SAS: Theory and Application, SAS Press, 1999

ANDAN O., POCHET P., ROUTHIER J.-L., SCHEOU B., Stratégies résidentielles des ménages et mobilité domicile-travail, Programme de recherche Transports Terrestres 1996-2000, Direction de la Recherche et des Affaires Scientifiques et Techniques, Octobre 1999

BERTRAND M., DUPONT V., GUÉRIN-PACE F., Espaces de vie. Une revue des concepts et applications, Paris, INED, Documents de travail, Paris 2003

BLIJIE B., The impact of accessibility on residential choice: empirical results of a discrete choice model, Delft University of Technology, 45TH Congress of the European Regional Science Association, Vrije Universiteit Amsterdam, 23-27 August 2005

BRÜCK L., MAIRY N., HALLEUX J.-M., MERENNE-SCHOUMAKER B., SAVENBERG S., VAN HECKE E., Les comportements résidentiels des ménages face à la problématique du développement durable, 2001

COURGEAU D., BACCAINI B., Analyse multi-niveaux en sciences sociales, Population (French Edition), 52e Année, No. 4, Nouvelles approches méthodologiques en sciences sociales, pp. 831-863, Jul. - Aug., 1997

DEBRAND T., TAFFIN C., Les facteurs structurels et conjoncturels de la mobilité résidentielle depuis 20 ans, Economie et statistique n° 381-382, pp. 125-146, 2005

DELAUNAY, D., L'inscription dans l'espace des biographies individuelles. Communication présentée à la XXIVe Conférence Générale de l'IUSSP, Salvador (Brésil), 18-24 aout 2001. (téléchargée sur le site de l'IUSSP).

DES ROSIERS F., THÉRIAULT M., KESTENS Y. and VILLENEUVE P., Landscaping attributes and house prices: looking at interactions between property features and homeowners' profiles, Paper presented at the 18th Annual ARES Conference, Naples, Florida, April 10-13, 2002

DES ROSIERS F., THÉRIAULT M., VILLENEUVE P-Y. and KESTENS Y., Landscaping and house values : an empirical investigation, Laval University, Paper submitted for presentation at the 17th Annual ARES Conference, Coeur D'Alene, Idaho, April 18-21, 2001

DIJKSTRA E. W., A note on two problems in connexion with graphs. Numerische Mathematik, 1, p. 269–271, 1959

EGGERICKX T., DEBUISSON M., DAL L., Les tendances récentes des migrations entre les arrondissements, In: Perspectives de Populations 2007-2060, Bureau Fédéral du Plan / DGSIE ed(s), Planning Paper, 105, p. 35-38, 2008

ENAUX C., Essai de modélisation spatio-temporelle des flux de déplacements de travail. Exemples de la région urbaine strasbourgeoise de 1975 à 1990, Thèse de doctorat, Université Louis Pasteur, Strasbourg, 265 p. (+ 1 volume d'annexes 107 p. + 3 disquettes), 1997

FOOT D., Operational Urban Models: an Introduction. London: Methuen & Co Publishing Company, 230 p., 1981

HALLEUX J.-M., Évolution des organisations urbaines et mobilités quotidiennes : espace de référence et analyse des processus, L'Espace géographique, Vol. 30, n°1, pp. 67-80, 2001

HENLEY A., Residential mobility, housing equity and the labour market, The Economic Journal, n° 108, pp. 27-414, 1998

HOSMER D. W., LEMESHOW S., Apllied Logistic Regression, 2nd Edition, 2000

IRWIN M., BLANCHARD T., TOLBERT C., NUCCI A., LYSON T., Pourquoi certains ne migrent pas : L'impact du contexte local sur la sédentarité aux Etats-Unis, Population (French Edition), 59e Année, No. 5, pp. 653-680, Sep. - Oct., 2004

PUSHKAR A. O., Modelling household residential search processes: methodology and preliminary results of an original survey, University of Toronto, 1998

REYMOND H., CAUVIN C., KLEINSCHMAGER R., (coord.), L'espace géographique des villes - Pour une synergie multistrates, Anthropos, collection Villes, Paris, 557 p., 1998

ROMANI J., SURIN'ACH J., ARTI M., Are commuting and residential mobility decisions simultaneous?: The case of Catalonia, Spain, Regional Studies, Vol. 37.8, pp. 813–826, November 2003

TRAIN K. E., Discrete Choice Methods with Simulation, Cambridge University Press, 2003

VAN DER HAEGEN H., VAN HECKE E., JUCHTMANS G., Les régions urbaines belges en 1991, Études Statistiques, n° 104, 1996

VANDENBULCKE G., Accessibility indicators to places and transports - Final Report, 2007

VANNESTE D.., THOMAS I., GOOSSENS L., Woning en woonomgeving in België, Sociaal-economische enquête 2001 , SPF Politique scientifique & SPF Economie – Direction générale Statistique, 2007

WARDROP J.G., Some theoretical aspects of road traffic research. Proceedings of the Institute of Civil Engineers. Pt. II, vol. 1, p. 325-378, 1952

WILLEKENS F., DE BEER J., VAN DER GAAG N., MicMac - From demographic to biographic forecasting, paper prepared for presentation at the Joint Eurostat-ECE Work Session on Demographic Projections, Vienna, September 21-23, 2005

ZAHAVI Y., The 'UMOT' Project. Report prepared for the U.S. Department of Transportation and the Ministry of Transport of Federal Republic Of Germany, 267 p., 1979