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Development of a dynamic integrated Land use – Transportation model

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ABSTRACT

There is a new growing interest in the development and the use of integrated land use and transport planning models in France. In this paper, we describe the steps of a current project which aims to integrate UrbanSim, a flexible land use model, and METROPOLIS, a dynamic traffic model, and to apply this integrated model to Paris region. We shortly present the two models and the common architecture, then we describe the fastidious but crucial step of collecting input data and calibration data for the study area. Paris region is one of the most important metropolises in the world : 12 000 km2, 11 millions inhabitants and 5 millions jobs. Most interactions between the land use dynamics and the transportation dynamics are taken into account in the short, middle and long term. All of this consists in a pioneering and innovative work, for a region where urban planning and fiscal policies are very important.

UrbanSim is a land use model developed at the University of Washington (USA). It is based mainly on microsimulation principle and three logit models (households and jobs localization choices and development type choice models) and a hedonic regression model (land price model). The data structure is based on a large grid which partitions the whole Paris region into 50 000 square cells by 500 meters. This high level of spatial resolution is really original in France but requires a huge amount of data and spatial analysis that we have performed thanks to the GIS tool.

METROPOLIS is a dynamic transportation model developed at the University of Cergy-Pontoise (FRANCE). It provides the user surplus as the measure of accessibility. This measure takes into account the time-dependent congestion situation of the transportation system. On the other hand, METROPOLIS can differentiate the users by their value of time and desired arrival time and some other behavioral parameters. The roads network contains more than 16000 links, the transit network contains about 4000 links.

An architecture bas been designed to integrate these two models within a coherent framework. A prototype of interface has been developed which allows input and output data to be exchanged in an automatic feedback process.

We use different sources to build the first database which concerns the input data : general census, numerical land use database, regional travel survey, the notary database of real-estate transactions, local land use plans, commercial and offices surfaces data, income tax files, … Since none of these sources is perfect, we had to develop innovative methods to realize data fusion and mixed databases. For example, we've managed to localize the 11 000 households

of the travel survey in the grid, we've associated the attribute of income from the tax files to the attributes of household in the general census. Five main tables are built : gridcells, households, jobs, travel times and logsum tables.

The second database concerns the calibration data. For each of the four UrbanSim models, we have developed a significant sample of individual observations from four sources : the general census, the travel survey, the land use evolution database and the notary database of real-estate transactions. Each observation contains the choice and a few alternatives These four files are presented in the article. They will be used at the next step of our project : the estimation of the models parameters thanks to an econometric software. We choose as period of calibration 1990 – 1999. We plan to achieve our project in the end of 2005.

ACKNOWLEDGMENTS

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INTRODUCTION

There is a long research history of integrated land use and transportation modelling. The relationship between transportation system performance and land use pattern is well established but the precise relations remain poorly understood. In this context, according to the American legislation on air quality and transportation system improvement (for example ISTEA, 1991) the planning process should include the long-term effects of any transportation project on urban patterns. Other countries in Europe are paying more and more attention to this aspect, too. The application of these legislations needs operational models. The purpose of this paper is to present the development of an integrated tool in Paris Region.

As far as concerned transportation modelling, **METROPOLIS** software has been developed over the past 10 years by THEMA laboratory (University of Cergy-Pontoise, France). METROPOLIS is a dynamic transportation planning model able to simulate large scale urban and suburban networks (till 200,000 links). This model uses the multi-agent methodology with a disaggregated representation of travellers. While using such a dynamic model (i.e. describing time of the day dependent congestion level), it is possible to compute the accessibility considering the time dependent condition of transportation system performance and the trips timing. Also, it has the possibility to capture the travellers' heterogeneity for the value of time (VOT) and the schedule delay cost parameters.

To model the land use pattern, there are a variety of models that have been developed constantly since the 60's. The complexity of the calibration is the main problem, which has been encountered with these land use models. The experience of Du Crest *(1)* on Lyon (France) who has used TRANUS *(2)*, is one of the most recent. **UrbanSim** is a new model that has been based on the previous experiences in the USA and resolves most encountered difficulties. UrbanSim uses a multiagent methodology and the disaggregated presentation of agents. It is a non-stationary dynamic model in comparison with the cross sectional equilibrium models such as TRANUS or MEPLAN *(3)*. It models the location behaviour of economic agents (households and jobs), the real estate development and the prices of land. So, it is not only a location model like DRAM/EMPAL *(4)* or an urban development one. All the entities are presented in a disaggregated way, which differentiates it with other models, which use aggregated and categorized representation of households and jobs.

Since UrbanSim doesn't model the demand and supply equilibrium, the location choices of households and of jobs as well as the jobs in relation with each other are disjointed. The interaction of these entities is presented by neighborhood concept. So, not only the characteristics of a cell but also the land use pattern of the neighboring cells play a role in the location choice process. Land price dynamics is modeled by hedonic formulation. All these hypothesis make the mathematical equations of the model linear or quasi linear, simple and fast to be resolved without requiring large calculation resources (for more information see *(5)*). UrbanSim has been chosen in our project, because it uses the recent modelling methods : discrete choice and hedonic models. It has also a flexible data structure that makes it adaptable to our case study, the Paris Region (12,000 sq.km, 11 millions inhabitants and 5 millions jobs). For example, it's possible to include your own variables, which are specific to your study area. Moreover, we had already experiences in the estimation of these kinds of models.

In the next section, we describe UrbanSim and METROPOLIS. Then, we present the integrated system architecture. Subsequently, we discuss the data collection for Paris Region and briefly the calibration procedure. Conclusions and perspectives constitute the last section.

DESCRIPTION OF URBANSIM

UrbanSim is a modular and flexible land use model, which can be used on large urban areas. It has been developed at the University of Washington by the team of Professor Paul Waddell. It has been released under an open source license that makes it freely accessible and easily customizable (see *(6)*). This model has been developed since 1996 following the discussions about new legislations in the United States concerning air quality, mainly after the conclusions of the TMIP (Transportation Modelling Improvement Program) international conference on land use modelling. It uses a multi-agent and a microscopic approach for urban modelling.

The study area should be divided into square cells forming a grid. There are three types of agents in the model: cells, households and jobs. UrbanSim simulates year-to-year changes in land use development for each cell as well as in the location of households and jobs. The modules (Figure 1) which calculate the intermediate variables and model the location choices are run sequentially for any simulated year. The operator can choose which modules to be run as well as their execution order. The model uses Discrete Choice Model (Multinomial Logit) to simulate the choices of agents and Hedonic formulation to determine the land prices. Here are listed the seven modules briefly described below:

FIGURE 1 UrbanSim Architecture

1. **Accessibility model**: this module transforms the transportation data provided by an external traffic model into two accessibility measures, which are used later in the model. The accessibility is computed for each cell as origin and as destination. We have:

   $$A_i^O = \sum_{j=1,J} E_j . e^{L_{ij}} \text{ or } A_i^D = \sum_{j=1,J} P_j . e^{L_{ij}} ,$$

   where $A^O{}_i$, is the accessibility of cell i as origin and $A^D{}_i$ as destination, P_j is the population that comes to the cell to work there, E_j is the jobs to which the people go and L_{ij} is the Logsum which is the surplus of the travellers. It is calculated by a traffic model that could be derived from a survey database or from the results of a classical assignment model.

2. **Economic and demographic transition model:** the evolution of the employment structure and of the demographic situation is represented by introducing the total number of jobs in each sector and the number of households in each category for every simulated year. This module chooses the households and jobs that are to be deleted or the characteristics of the agents who should be added. To create the new agents, the model uses a random drawing process that follows the same distribution as sample input database.

3. **Mobility models**: each year, some of the households and jobs move from one cell to another one. The rates of mobility are introduced for different categories and this module randomly subtracts these jobs and households by categories. The households are distinguished by their size and income and the jobs are categorized by their activity sector and whether they are home-based.

4. **Location choice models:** the new and moved entities will be located individually on the cells using a multinomial logit model. At first, the module determines for each cell if there is a free place or not. The utility of these cells that should be allocated is a linear function

of some variables and the logarithm of some others. These variables concern the characteristics of the cell including the related land use category, its accessibility as origin for households (to the jobs) and as destination for the jobs (from the population), density, age of land use and the land price. The neighborhood operates according to land use mix, density, average property value and local accessibility to retail and according to the jobs of the different sectors. Thanks to the neighborhood notion, this model includes the effects of accessibility to local services in households' location choice. It represents also inter and intra sector dependences for jobs location choice.

5. **Real Estate development model:** the cell's land use changes according to the predefined transition scenario from one type to another one. It is modeled from a real estate developer's point of view. Each simulated year, the model calculates the utility of any possible transition for all the cells and represents the choice of developing a cell by another MNL formulation. This utility function depends linearly on characteristics of the cell, for example existing and possible development types, policy constraints, land and improvement prices, proximity to highways and airports, recent developments in the neighborhood and finally the accessibility for the population to this cell.

6. **Land Price model**: the land price that intervenes in all the choices is determined by hedonic method by:

$$P_{ilt} = \alpha + \delta\left(\frac{V_i^s - V_{it}^c}{V_i^s}\right) + \beta X_{ilt},$$

where βX_{ilt} represents a linear function of the characteristics of the cell such as effects of the site, neighborhood, accessibility and policy effects. The term $\delta\left(\frac{V_i^s - V_{it}^c}{V_i^s}\right)$ represents the short term fluctuations of the prices due to the change of vacancy rate (V^s_i and V^c_{it} are the structural and current vacancy rates). This term represents the influence of demand on the market prices.

All the data are stored in a database managed by MySQL. Such a database facilitates the data exchange with other programs such as a traffic model or a GIS to visualize the results.

UrbanSim Inputs and Outputs

As listed in Table 1, an UrbanSim database includes some 35 tables that contain different types of information. The main data concern the three main entities of the model: Cells, Households and Jobs.

TABLE 1 UrbanSim data tables

For each Cell, the operator should enter Total housing units, Vacant housing units, Total non-residential surface, Vacant non-residential surface, Development type, Land value, Residential improvement value, Non-residential improvement value, Environmental constraints variables, Urban growth boundary, Name of the City, Name of the County and corresponding Traffic analysis zone.

The characteristics of the household are the total number of persons and the number of workers and children, age of the head, income and residence cell. For each job, we should enter its sector, its cell location and whether it is home-based.

The households and jobs can only be born, displaced or destroyed. The transformation of a family is realized by removing the last record and adding a new one. UrbanSim provides with the list of unchanged households and jobs among outputs. The added or moved one is listed in two tables with their characteristics as presented in inputs. The cells are dealt with the same way. They can have a transition and their new situation will be listed in a table.

METROPOLIS: A DYNAMIC TRANSPORTATION MODEL

METROPOLIS is a fully dynamic transportation model that is specially adapted for large networks. It is a mesoscopic event based model and uses a multi-agent methodology with a disaggregated representation of travellers. On the other hand, the supply system relies on a macroscopic formulation that computes travel time in function of the flow condition of the link.

Its main application on the Paris Region has been the QUATUOR project *(7)*, a three years project financed by the French Ministry of Transportation. It models the mode, departure time and route choices. The logit formula is used for these models. The dynamic assignment procedure can be determinist or stochastic.

The most important output computed by METROPOLIS is the surplus for any traveller's category and for any O-D pair. As the departure time choice is modeled by a continuous logit model, the surplus is given by:

$$L_{ij} = -\mu^{T}.\ln \sum_{k=VP,TC} \int_{T0}^{T1} \exp(-C_{ij}^{k}(u)/\mu^{T})du$$

where $C^{k}_{ij}(t)$ is the time dependent travel cost between zones *i* and *j* and where μ^{T} denotes the departure time choice heterogeneity parameter. (see also *(8)*)

INTEGRATION

We continue by presenting the architecture of the integrated system. We have developed the modules in such a way that the user can introduce the general parameters' values and visualize some major results. The key information transferred between the traffic and the land use model is the travellers' surplus matrix. To make a complete loop, we should feed a revised O-D matrix to the traffic model that is based on the new geographical distribution of population and jobs. This cycle is reproduced by time step that can correspond to one or more years according to the evolution of transportation system conditions and projects. Figure 2 presents the cycle of the integrated model.

FIGURE 2 The cycle of integrated model

In Figure 3, we show the software elements contributing to the integrated model. UrbanSim uses Eclipse environment as a generic graphical interface to (1) Manage scenario parameters, (2) Check data structure (3) Run simulations.

FIGURE 3 Software elements of integrated model

Both the land use and traffic models use MySQL DBMS for data storage. These data are structured in multiple tables. These tables can be viewed and edited by using "MySQL

Control Center”. METROPOLIS has its own graphical interface to manage: (1) Simulation parameters, (2) Supply data and (3) Demand data.

Since the Origin-Destination (OD) matrix is not directly provided by UrbanSim, a data preparation module is needed to build the O-D matrices that represent the trips generated by population and activities and their distribution on origins and destinations. We denote this module as TSM (Three Steps Model). This module uses the mathematical model calculating an Origin-Destination matrix for three purposes (home-work, home-shopping and others), based on three classical steps :

- Trips emissions and attractions (by purpose)
- Trips distribution (by purpose)
- Mode choice: Private cars - Public Transport

We use the specific demand model elaborated for the Paris region by IAURIF and which was calibrated with the last Global Transportation Survey in 2001.

Reversely, data produced by METROPOLIS cannot be used « as is » by UrbanSim. LSTTC (LogSum and Travel Time Calculation) is a data preparation module to convert these results to logsums and travel times as required by UrbanSim. UrbanSim uses a hierarchical structure to organize simulations. We start by a Base Year database and apply a scenario on it. A Scenario describes the modules to be run and the simulated years. If the traffic model is run offline (what is not our case), we will introduce the years for which new transportation projects will be realized. The next run uses a new scenario, which is based on the last one. So, we can have a tree of scenarios.

USMCC (UrbanSim-METROPOLIS Control Center) is composed of several scripts written in SQL, Python and Perl, to manage the data exchange and scheduling between the two models and subsequent modules.

To make the management of the whole process easier, we need a dedicated interface in charge of:

- Parameters
    - UrbanSim scenarios
    - METROPOLIS simulations parameters

    - TSM
- Models scheduling
- Results visualization

PARIS REGION

The Paris Region, namely Ile-de-France Region, embraces Paris and its suburbs. The city of Paris has about 2 million inhabitants, on a regional total of 11 million. The total number of jobs is 5.1 million. It covers 4,610 sq. miles (12,000 sq. km). Ile-de-France Region occupies 2% of the surface of France and represents 19% of the population, 22 % of the jobs and 29% of the GDP of the country. There are 3 administrative institutions : 1 “region”, 8 “departments” (counties) and 1300 “communes” (cities).

The land use is composed of built-up areas (30%), green areas (20%) and rural areas (50%). The public transportation network is diversified into:

- a main radial railway network, especially the RER lines (high speed train service between Paris and the suburbs)
- a subway network that provides comprehensive and timely service in the city centre
- a bus network to complement the rail services

The roads network is organised into a hierarchy and is more or less interconnected and often congested. The express network of the region is composed of 590 km of motorways and 250 km of expressways, making a total of 4,500 “lane-km”. Road traffic flows attain the highest levels known all over the country. The mode market shares for the home based work trips (2001) are: 50% Private cars, 36% Transit and 14% Bicycle/walk.

Urbanization structure

For 40 years, the Ile-de-France has managed to stem the rapid expansion of the agglomeration and to decentralize jobs in Paris to the suburbs. The principle of multi-cored structure was one of the main solutions to consider for urban organisation. So since 1965, the outer suburbs were structured around several poles, or five “new cities”. Accordingly, 44% of the population surplus, recorded in Ile-de-France between the 1975 and 1999 census, settled in these areas. The multi-core structure prompted the introduction of administrative facilities, universities, businesses, etc. Significant investment allowed for the development of transportation networks, considered essential for the organisation of the region: arterial and radial public transport lines and particularly express beltways.

Global trends

This decentralization of jobs and services has greatly relieved the overloaded transportation system. On the other hand, there has been a significant increase in the inter-suburban mobility. Considering this, the delay in construction of the tangential rail lines in the suburbs would be regrettable, as the current network, mainly radial, is unable to meet the strong demand. But the investment programmes to come in the next ten years give priority to tangential public transportation, especially the project of "Tangentielle Nord" in the north of Paris.

There are many consequences for spatial decongestion on transportation habits. At first, the continuous expansion of urbanisation towards Paris' suburbs explains the proportional decrease of trip to and from Paris. Secondly, the private car has mostly benefited from the increased number of trips among the modes of transportation.

Over the last twenty years, the use of public transportation has decreased by 6% in the region. This is attributed to structural effects, as increased mobility in areas with limited public transport tends to bring the average down. So today tangential rail lines from suburb to suburb are questioned, because of the proposed level of services. It's clear that the future transport needs will concern suburb-to-suburb links. But will tangential rail lines answer to this problem? More flexible and less costly solutions as tramway are not preferable? Constant experience has shown that infrastructure like tangential rail line cannot provide a solution to serving areas of low population density, their potential traffic is therefore relatively small and thus they are unable to relieve road traffic. These are the questions that applications of our integrated urbanisation/transport model will try to answer.

The hypothesis of model, the data sources and difficulties

The process of data preparation is crucial in such a project. So we have particularly taken care in building the two databases : **the input database and the calibration database**. The input data requirements deal with: parcel data, business establishments, household data (census, lodging survey), land use plan, environmental constraints, political constraints, development costs. All these data have to be collected and assigned in a grid structure. For some variables such as the income date, we had to mix different sources to get the good information.

To build the database, we've largely used the GIS tool (ArcGis and ArcInfo). We have intersected the grid layer with about twenty other layers. Our traffic model shows that the effects of a new infrastructure as Tangentielle Nord will be distributed all over the region. So, we have decided to take into account the whole region as the study area. We selected 500 meters instead of 150 meters, which is recommended for the cell size. Finally, the grid is composed of 49 271 square cells. Our different data sources had different parcels and the data for households, jobs and land prices were not available for the same geographical units. Hence the allocation of jobs, households and other characteristics to cells required a considerable work using a GIS system.

For Paris Region, the general census data in 1991 and 1999 are available. We managed to assign all the 5 million households into the grid because in the census, the blocks in which households are localized have almost the same size than our cells. Since in the French census there is no information about income, we had to use the aggregated fiscal data to find the income distribution and assign it to the households.

For the jobs, we've used the census data too. Indeed, each worker is asked which city he works in and the activity sector. These data are more aggregated but more exact and above all exhaustive. The jobs were distributed on the cells according to available floor spaces and. In that case, the results should be interpreted at the level of municipalities (or city) and not cells.

For land use information, we've used the IAURIF numerical land use cover coming from aerial pictures (400 000 parcels classified into 83 different types). The notary database of real-estate transactions was used to find average land and improvement prices for any city. We've also used a centralized database of the land use plans known for each city.

We have also prepared a calibration database that contains a sample of true observations for which we have detailed information (including income and the previous and current residence cell location). These data are based on the region's global transportation survey for which about 11000 households were surveyed. This database is based on the differences between the situation of two given years : the beginning and the end of the calibration period.

Model Calibration

UrbanSim simulations will be performed in two stages: Calibration and Projection, which correspond to two distinct periods. It uses a variety of parameters that are multiplied by the variables in the utility functions or by the land price functions. The objective of the calibration stage is to estimate these parameters using the observed data as reference for a given period. At the projection stage, these parameters are used to simulate the future evolutions starting from the end of the calibration period. The calibration concerns location and development models (the discrete choice model estimation) whereas the hedonic land price and mobility models are estimated by linear regressions.

The calibration database should be fed to econometric software such as SAS or LIMDEP to perform the discrete choice models and the linear regression estimations.

For Paris Region, we will use the 1990 and 1999 data for calibration. Since the "Tangentielle Nord" project will be only operational in 2012, we'll continue the simulation up to 2020. The calibration period may seem short with regard to the projection period but the lack of numerical information before 1990 explains our choice.

FIGURE 4 Calibration procedure of UrbanSim

Tangentielle Nord Project

The northern tangential line is an important project of inter-suburban line. It will provide connections for urban poles in the outer suburbs, while revitalising the peripheries of the agglomeration. It will partially run on an existing line (the outer rail belt was initially constructed to transport goods).

The line runs from east to west of the Ile-de-France in the north of Paris, linking Sartrouville to Noisy-le-sec. It has a length of 70 km.

FIGURE 5 Tangentielle Nord location plan

The northern tangential line runs between densely populated areas and the dynamic outer ring which, although less populated, is rapidly developing.

The tangential line is aimed to encourage development in these sectors, and access to these sectors by public transport will be significantly improved. Not only will this facilitate access from the immediate periphery, but also from a greater high-traffic zone thanks to the existing radial network. The new line should provide new transport service in the radial network thanks to many connections, which will make it much easier for the working population and companies to respectively have access to jobs and labour in the northern and eastern suburbs. Our project aims to simulate the effects of the new line on localisation of households and jobs.

CONCLUSION AND PERSPECTIVES

This paper has presented the two building blocks of an integrated transportation and land use system. We have designed the architecture of the integrated system that to the best of our knowledge would be the first dynamic integrated transportation – land use model in France.

At this stage, we have designed the architecture of the integrated system. The necessary software elements have been developed. The input database of UrbanSim for the Paris Region is achieved and the first test simulations are in progress. We expect to get the first results during the next few months. Before starting the simulations at the cell level, we are performing the first estimations at the city level (1300 all over the area) to determine the main trends and the most significant variables. We notice that there are some essential differences between European cases especially French one and American cities, mainly concerning the land use market that is more regulated by public authorities. So, by the preliminary tests we'll try to adapt UrbanSim to our case. Moreover, the accessibility to public transit has much more influence in the location choices and in the prices market than the accessibility to the roads network. These specific aspects of Paris Region will be taken into account.

We plan to test several policies, which were originally studied only with our transportation planning model in order to study the impact of endogenous modelling of location decisions of economic agents. The project is concentrated on ex-post analysis of the construction of “Tangentielle Nord”. We hope to be able to use this application to improve the usage of conventional land use planning methods and to identify how a large scale model could provide useful guidelines. Much more has to be done in the next few years on this fast evolutionary topic.

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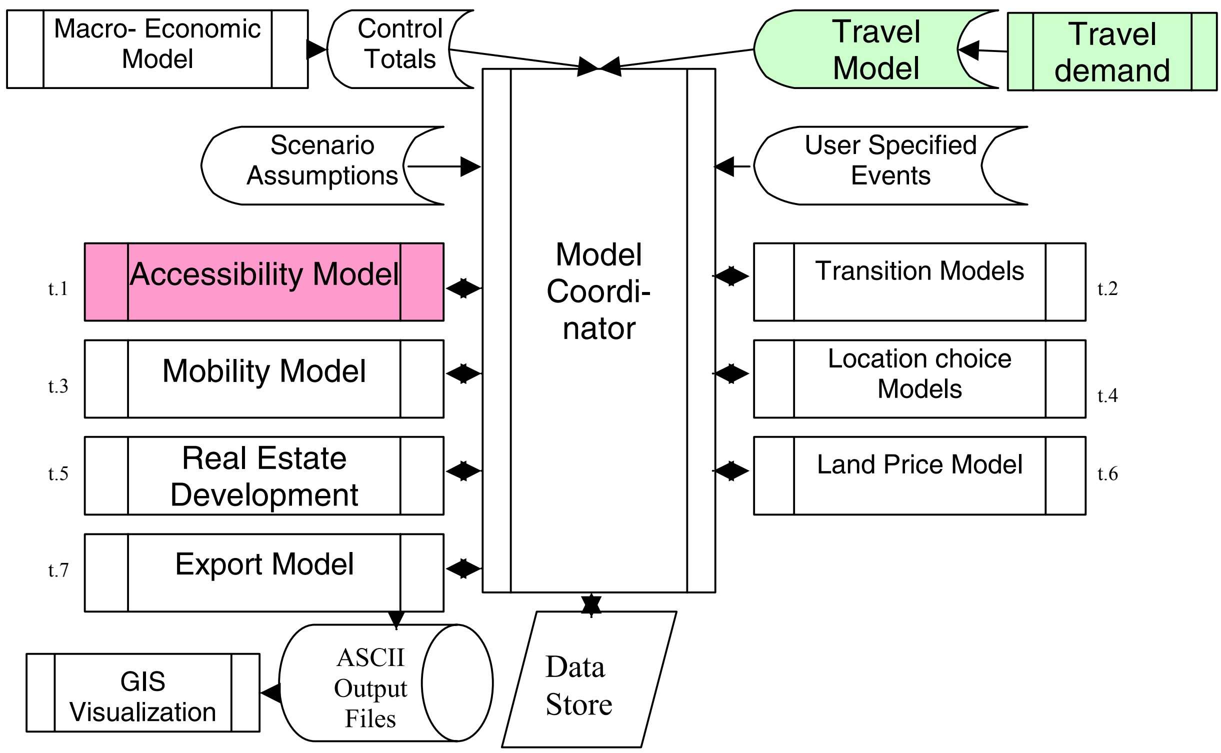

FIGURE 1 UrbanSim Architecture

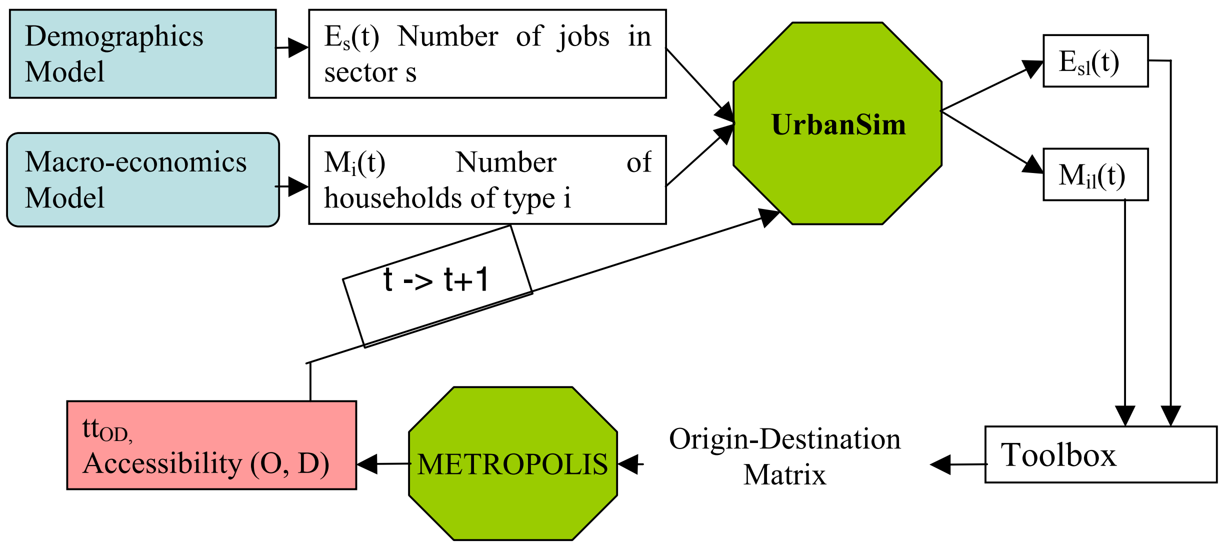

FIGURE 2 The cycle of integrated model

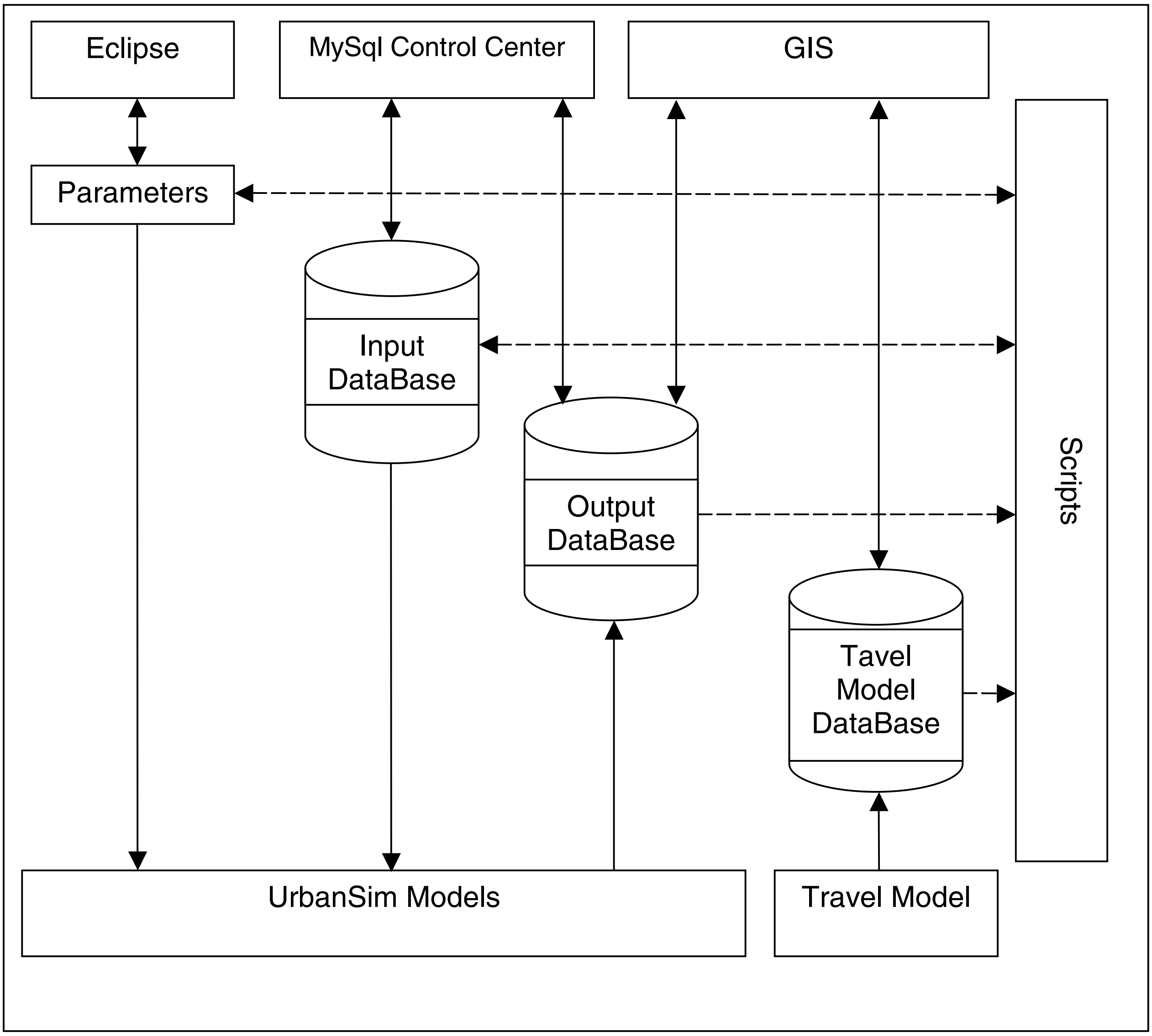

FIGURE 3 Software elements of integrated model

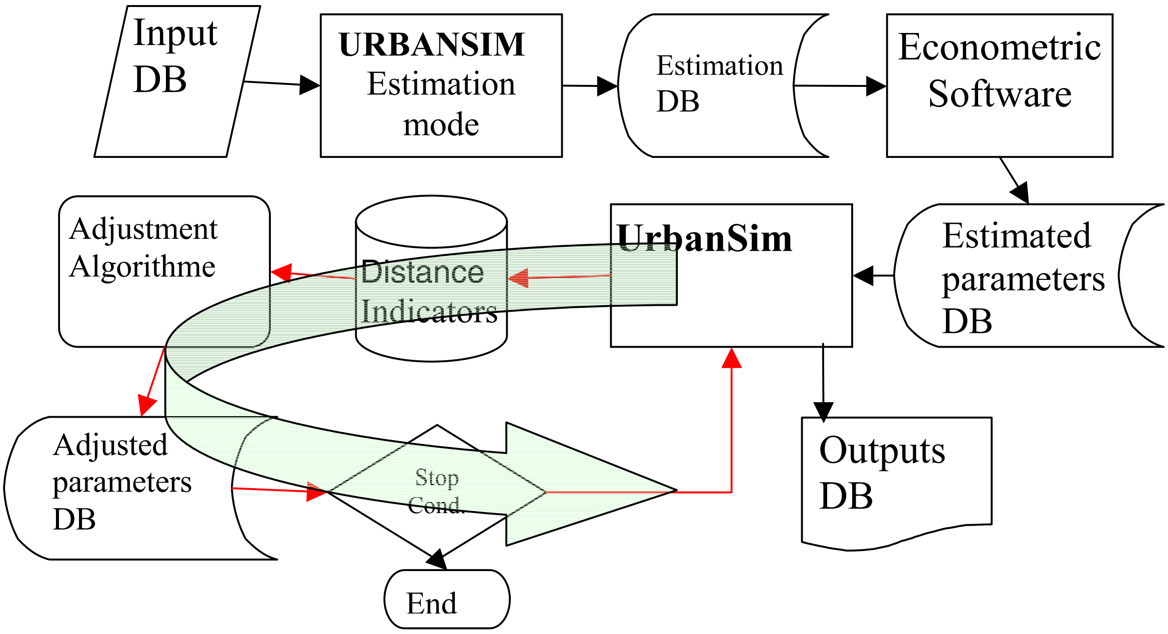

FIGURE 4 Calibration procedure of UrbanSim

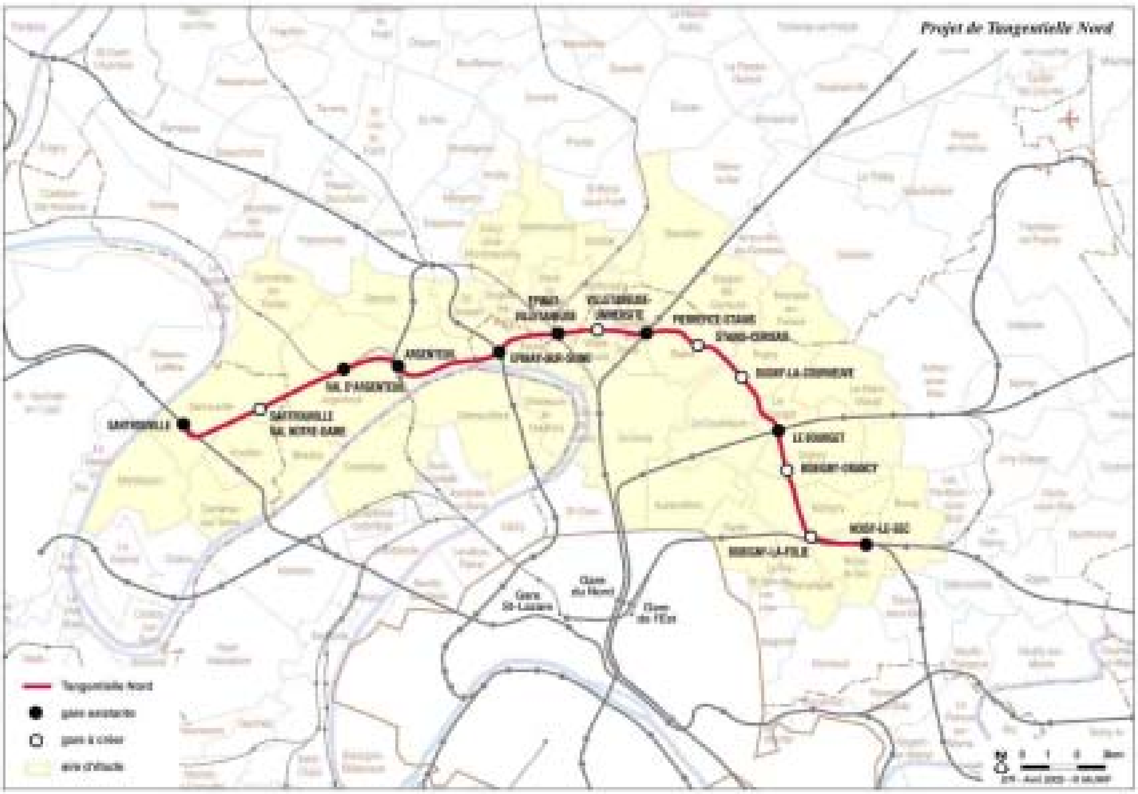

FIGURE 5 Tangentielle Nord location plan

TABLE 1 UrbanSim data tables

Name of tables	Type
Development Events	Scenario
Employment Events	Scenario
Development Constraints	Scenario
Land Use Events	Scenario
Development Constraint Events	Scenario
Transition Types	Scenario
Annual Employment Control Totals	Data
Annual Household Control Totals	Data
Grid Cells	Data
Travel Data	Data
Jobs	Data
Zones	Data
Household Characteristics	Data
Grid Info	Data
Households	Data
Race Names	Constants
Sqft For Non Home Based Jobs	Constants
Cities	Constants
Development Type Group Definitions	Constants
Development Types	Constants
Plan Types	Constants
UrbanSim Constants	Constants
Employment AdHoc Sector Group Definitions	Constants
Counties	Constants
Development Type Groups	Constants
Employment AdHoc Sector Groups	Constants
Residential Units For Home Based Jobs	Constants
Employment Sectors	Constants
Annual Relocation Rates For Households	Parameters
Annual Relocation Rates For Jobs	Parameters
Household Location Choice Coefficients	Parameters
Developer Model Coefficients	Parameters
Employment Location Choice Coefficients	Parameters
Residential Land Share Coefficients	Parameters
Land Price Coefficients	Parameters