AGENT-BASED MODELING OF URBAN LAND-USE DEVELOPMENT: MODELLING AND SIMULATING HOUSEHOLDS AND ECONOMIC ACTIVITIES LOCATION CHOICE IN BORDEAUX, FRANCE

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ABSTRACT
This article aims to respond to growing concerns about sustainable urbanization, which in recent years have generated a need for prospective assessment in the field of transport and land-use planning, by predicting future land-use development. We introduce a Land Use model (part LU of a Land Use Transport Interaction model) which aims to simulate households and firms location choice within an urban system. We use the agent-based approach to simulate location choices in order to account for land use changes and to estimate residential and economic activities location. This is a dynamic bottom-up approach with the households and the firms as their basic components. The MUST-B model considers the agents' location choices according to the utility theory and the equilibrium between real estate supply and demand. The model is used to simulate urban land-use development in the urban area of Bordeaux, France.

Keywords: Land use, agent-based modeling, location choice, accessibility, decision support system.

1. INTRODUCTION AND OBJECTIVES

Sustainable urbanization is a challenging issue in developing countries. The changes that occur in land-use due to urbanization enable a complex process caused by the interaction between natural and social systems (Valbuena, Verburg et al. 2008, Hosseinali, Alesheikh et al. 2013). Increases in population as well as the movement of people from rural to urban areas are the two major factors for this phenomenon. Major economic and social activities take place in the urban areas where complex systems (ex. Land use, transportation, utilities, etc.) interact with each other. The unplanned urbanization has been creating problems like land scarcity and pressure, pollution, traffic, and congestion. To understand and analyze the complexity of urban systems, models of land use and transport interaction serve as important tools for policy analysis and decision support.

Numerous studies show that the limits of daily travel are further extended (Orfeuil 2000). The population in urban areas has grown steadily, now estimated at around 75% in Europe and 80% in France. Many residents of metropolitan regions work within the central urban area, and choose to live in satellite communities commuting to work via automobile or public transport. The process of suburbanization is driven by effectiveness of means of transport, infrastructure, systems, facilities and vehicles. Urban sprawl is causing an explosion in commuting, home-work trips, resulting in increasing congestion of transport infrastructure, pollution at peak times, and dependence on cars (Newman and Kenworthy 1999). In this perspective, many authors ask questions about the fragility of populations living in peri-urban areas and whose transport budget is sensitive to changes in the cost of energy (Crozet and Joly 2004). The scarcity of space, energy and time makes it necessary to understand the residential relocations and the daily movements of households, the commuting conditions of travel and the urban planning. Controlling the phenomenon of urban growth clearly becomes a demand for sustainable development, urban planning and public policies.

Simulation is tremendous opportunity to analyze problems .It provides users with practical feedback when planning real-world systems (Zhang, Ban et al. 2011). It allows planners to study a problem at different levels of abstraction. In the last decade, several land use models have been developed and used to simulate and predict land use change in the future. Without using models that embrace the complexity of the urban system, it would be difficult to simulate and predict the future of urban growth (Hosseinali, Alesheikh et al. 2013). Theories on the interaction between urban land use and transport address the locational and mobility responses of private actors (households, firms and regional commuters) to changes in the urban land use and transport system at the urban-regional level (Wegener 2004). A general framework to model households and firms location choice and their interactions with other parts of the urban system can be framed in three interrelated stages, corresponding to urban development or land-use, activity, and transportation system performance.

There are many modeling tools in use according to different research objectives: the relevant LULI models can be divided into three categories. Firstly are empirical-statistical models. These models are based on data, statistical and econometric analysis to identify the factors of Land Use change (Bin and Tao 2010). Secondly are spatially explicit models, such as the cellular automata model (Ahmed and Ahmed 2012, Han, Yang et al. 2015). Thirdly, agent-based models have been developed to simulate LULI change by individual agents (Parker, Manson et al. 2003). ABMs use the actors of land-use change (individual or institutions) as objects of analysis and simulations, and pay explicit attention to interactions among these 'agents'. Specific advantages of agent-based models include their ability to model individual decision-making entities and their interactions. In this paper, we use the agent-based approach to study urban dynamics and to simulate the households and firms location choices. Our approach aims at integrating land-use factors into an agent-based model for modeling the part LU of a LUTI model: Land-Use changes as an interaction between households and firms location.

To achieve this goal, we will first explain the criteria for selection of a target location for households and firms. Then, we will show how the notion of territorial accessibility affects the real estate market of the Bordeaux region. We will also describe the characteristics and identify the primary driving factors of land use change patterns. Finally, we will simulate the Households and firms location choice in Bordeaux region under different scenarios.

2. BIBLIOGRAPHIC REVIEW

2.1. LUTI Models

The ideas behind residential location modelling have a long history. Residential location modelling dates back to the work of Alonso (Alonso 1960, Alonso 1964) who laid the foundations for the economic analysis by applying Von Thunen's key "bid rent" idea to residential location; and to Lowry (Lowry 1964) who used spatial interaction principles in his Model of Metropolis (Pagliara and Wilson 2010). The basic assumption of the Alonso model is that firms and households choose that location at which their bid rent, i.e. the land price they are willing to pay, equals the asking rent of the landlord, so that the land market is in equilibrium (Wegener 2004). According to Wegener all models rely on random utility or discrete choice theory to explain and forecast the behavior of actors such as households or firms (Wegener 2004). The random utility maximization-based framework assumes that the ultimate goal of an agent's (household or firm) behavior is to maximize its utility. Agents maximize their utilities by choosing a vector of goods and a residential location, described by a set of attributes. Segal (Segal 1977) identified five major characteristics used to evaluate the attractiveness of a residential location: the physical characteristics of the area, its socio-economic characteristics, the public services, the environmental qualities and the accessibility of the area.

LUTI-models combine a Land-Use model with a Transport model. This connection is based on the mutual influence of Land-Use and Transport (Wegener 2004). They have moved from special interaction models or statistical models through econometric models to micro-simulation, cellular automata and agent-based models. Researchers have built several residential mobility microsimulation models and applied them to the context of different countries and regions. Some of the most advanced LUTI models are IRPUD (Wegener 2011), DELTA (Simmonds 2001), MEPLAN (Echenique, Flowerdew et al. 1990), Urbansim (Waddell 2002), MUSSA (Martinez 1996) and MARS (Pfaffenbichler, Emberger et al. 2010). More recent developments have seen a move towards more detail with micro-simulation or agent-based models such as ILUTE (Miller and Salvini 2001). For a good overview of the models and their history, the reader is referred to Acheampong and Silva (Acheampong and Silva 2015), who discuss the existing operational LUTI modeling frameworks as well as the modeling methodologies that have been applied over the years.

The MUST-B Model, presented in this paper, is the part LU of a LUTI model. It introduces a land use model that allows the integration of urbanization and planning mechanisms in terms of the location of households and economic activities. It aims at interacting with a transport model that seeks to take account of the daily mobility. While some LUTI models have been built at an aggregate level, the MUST-B model has gone down the route of using more detailed models. The aim was to make the model easy to use while being easily understood by decision makers rather than black box by involving researchers and consultants in a multi-disciplinary approach in order to identify the interdependencies in the mechanisms that are reproduced by the simulation. Another feature of the MUST-B model is that it can assess environmental consequences of energy consumption and air pollution (e.g. greenhouse gas emission and air quality) related to the mobility and to the building. It aims to integrate the systemic articulation of the land and real estate markets which makes it possible to take into account all the interactions between the different urban actors. Also, MUST-B model integrates the social housing, which accounts for 25% of the national housing stock.

2.2. Agent-based modeling and simulation

The agent based models approach has recently emerged and gained popularity in the urban-related scientific community. It offers a way of replacing transition probabilities at one level with decision rules on entities at lower level. These models use the actors of land-use change (individual or institutions) as objects of analysis and simulations, and pay explicit attention to interactions among these ''agents" (Hosseinali, Alesheikh et al. 2013). Agent based modeling offers various types of agents, models of their behavior and characteristics, through a range of architectures and components libraries. ABM as a modeling technique allows for a natural description of a complex system in a flexible and robust manner so as to capture emergent phenomenon (Silva 2011, Acheampong and Silva 2015). While the use of behavioral rules is similar to other disaggregate simulation techniques, ABM approach allows the agents (e.g., household, firms) to learn, modify, and improve their interactions with their environment (Acheampong and Silva 2015). Several characteristics define agents: they are autonomous, they share an environment through agent communication and interaction, and they make decisions that tie their behavior to the environment so that they shape and are influenced by their environment. Agents make inductive and evolving choices that move them toward achieving goals (Parker, Manson et al. 2003, Wooldridge 2009). The agent-based simulation simulates the effect of changes in policy on each of these micro units. Differences before and after the changes can be analyzed at the micro-level; and aggregated to show the overall effect of the changes (Mitton, Sutherland et al. 2000).

3. DESCRIPTION OF MUST-B LAN USE MODEL

3.1. General Structure

The main purpose of the MUST-B model is to estimate variations in the location of population and jobs, and real estate prices in an urban system to changes that are mainly associated to the transport system (we also envisage to estimate the energy consumption and the level of greenhouse gases GHG emissions). At the end, our objective is to develop an integrated land use / transport model to simulate and evaluate the impact of exogenously given transport and multi-sectoral urban policies such as the implementation of new transport systems or new travel demand management policies and changes in public transport provision. This allows for any change occurring in the territorial system to lead to a new equilibrium solution representing the new state of the system. At the equilibrium of the two models (land use-transport) in interaction, one deduces the energy consumption and the GHG emissions linked to the four sectors: daily mobility, operation of building, urban services and economic activities. Figure 1 illustrates the conceptual structure of the MUST-B Model.

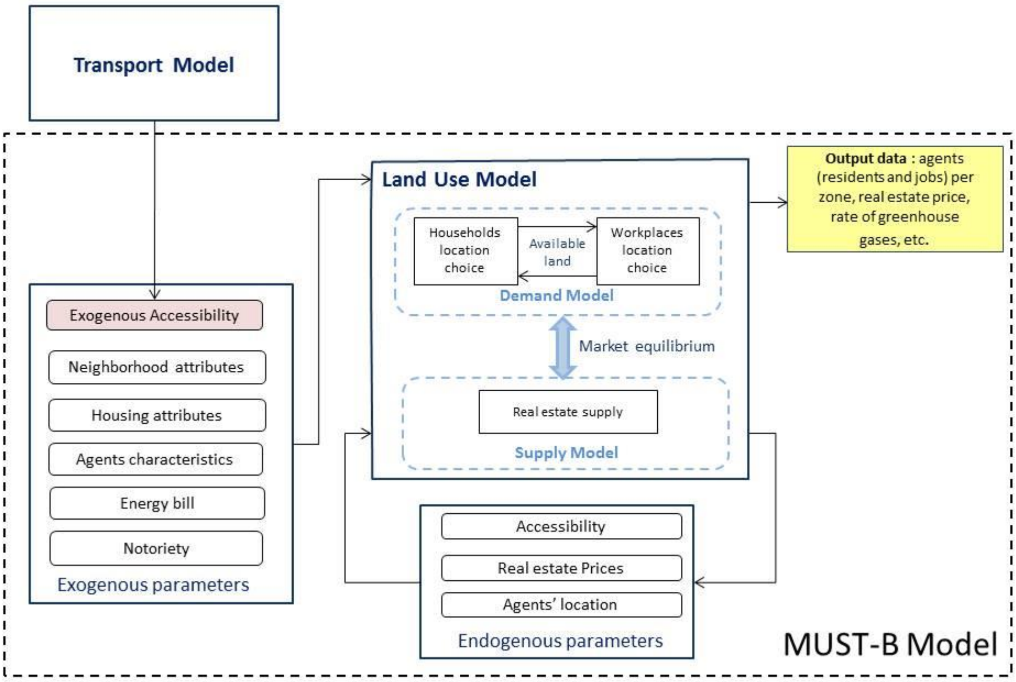

Figure 1: General structure of the MUST-B model

The two sub-models making up the main structure of the MUST-B model are as follows:

- A residential location model that, given a set of real estate prices, and a residential supply, simulates the location of households, disaggregated by income classes, in the study area. It calculates the number of households locating or leaving an area. This model depends on the accessibility to jobs, the capacity and the development model of each zone and the rent in each zone.
- A firm location model that is modeled similarly to the residential location model by differentiating activities according to their spatial footprint. It simulates the distribution of these economic activities disaggregated by an economic sector.

At this stage, we assume that some of the accessibility is exogenous. It is calculated at the beginning by the

transport model depending on the available transport supply (network capacity and public transport services), that generates a cost matrix between the zones (expressed in either journey times or generalized transport costs) that, in turn, influence the accessibility of each zone. A transport model that, given a travel pattern (Accessibility) for households and activities, simulates the simultaneous equilibrium between supply and demand in the transport system. Accessibilities are generated based on population, the number of jobs, travel time and travel cost.
The implicit prices model calculates the average real estate prices in each zone as a function of the supply and demand for locating in each zone as well as the structural and environmental characteristics of the area.
The residential location model starts from the hypothesis that households locate depending on different zonal characteristics, including the distance from workplaces, the notoriety or quality of the neighborhood (availability of public services, shopping centers, schools, etc.), or the costs involved including price, taxes, energy load, and travel costs obtained from the interaction between the transport and economic activities location sub-models. Another important variable involved in residential location are the real estate prices of each zone, obtained using the bid function which depends on household utilities. The activity location model works in a similar way to the residential location model, considering the utility of each zone as a function of different variables. Among these variables is the accessibility of the population to each zone, depending on the travel costs between areas derived from the transport model and the population of each zone derived from the residential location model. The simplified flow diagram of the sub-models can be seen in Figure 2. Initially, agents (households and firms) are distributed arbitrarily on the agglomeration respecting the capacity constraint of the areas. We randomly choose an agent *a* candidate to move located in the zone *i*, and a zone of destination *j*.

3.2. Characteristics of the bid function

The allocation of agents to the different zones is based on a bidding mechanism for the acquisition of household or a commercial establishment (firm). The bid function (Equation 1) is derived from the utility function and can be understood as profit in monetary terms. It represents the monetary value that a consumer allocates to the set of attributes of a property, constructed based on a structure of consumer preferences, as well as agent restrictions (such as income in the case of households).

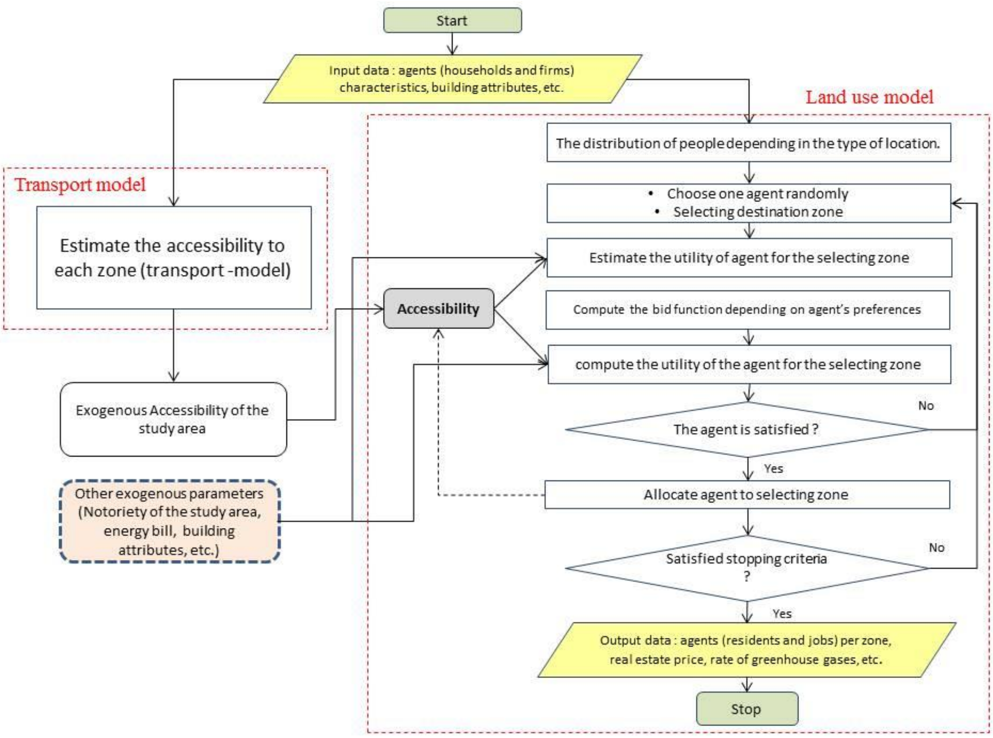

Figure 2: Simplified flowchart of the MUST-B model

At the iteration *n*, the bit that an agent (consumer) *a* makes to move into the area *j* depends on the price of the real estate in its original area *i* and the difference in utilities between zones *i* and *j* at the iteration *n-1*. The agent's willingness to pay can be calculated using the following expression:

$$\pi^{a}_{j,n} = P_{i,n-1} + \delta\left(U^{a}_{j,n-1} - U^{a}_{i,n-1}\right) \quad (1)$$

Where:

- P_i: the real estate price of the Zone *i*,

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- U_j^a: utility value associated with new location alternative *j* for the agent *a*,
- δ: Amplitude of the auction, determine the utility gain converted in an additive price of the initial price.

We assume that the agent *a* may choose to remain in its home area *i* if it is offered a discount on the price of the real estate. The expression of this new price is:

$$\pi_{i,n}^{a} = P_{i,n-1}(1-\beta) \quad (2)$$

3.3. Residential Location Model

Many researchers have considered various factors representing decision-making criteria of households to select target location (Matthews, Gilbert et al. 2007). Lowry rooted his very simple model in the journey to work and the availability of employment (Lowry 1964). Access to services – such as schools, facilities – is another interaction-based element. In this research, the residential location model is based on a hypothesis derived from random utility theory that households choose locations that maximize their utility. Households value different zones as a function of their location environment attributes and the time and goods associated with the activities. The proposed method consists of constructing a residential utility function that integrates household's behavior in their residential location choice and allows households to be allocated to residences using an auction procedure. The residential utility function reflects the satisfaction of the household associated to a given location and type of building.

Our model allows the inclusion of a large number of variables representing the most relevant attributes of households (socioeconomic characteristics), real estate (property types), and the locations (neighborhoods, activities). It depends on several parameters such as the accessibility and notoriety of the area, the surface of the housing, the price of real estate, etc. There is a trade-off of accessibility and environmental characteristics against rent. The utility is constrained by a household's socio-economic class. Within this calculation, the exogenous accessibility (derived from the transport model) is considered to be known and fixed.

The utility function of the household *h* residing in the zone *z* that ascribes utility values to the new home location alternatives has the following general, linear form:

$$U_{h,z} = \alpha_{1_h} AC_z + \alpha_{2_h} NO_z + \alpha_{3_h} SL_h - EB_z * SL_h - P_z * SL_h \quad (3)$$

Where:

- AC: accessibility of the selecting zone
- Z: index representing new zone of the new location alternatives,
- NO: notoriety of the zone (reflects the quality of neighborhood life and availability of public services such as shopping and schools),
- SL: surface area,
- EB: energy bill related to the housing per m² of the area under consideration,
- P: price per m² of the housing of the area under consideration,
- α_i: utility function parameter to be estimated according to the household's socio-economic class

The households will be allocated in zone where they maximize their utility.

If $U\left(\pi_{j,n}^{h}\right) > U\left(\pi_{i,n}^{h}\right)$ the household h chooses to locate in the zone *j*, otherwise it will remain in the zone *i*. In the case where the zone *j* is already saturated (the zone has reached its total capacity); we will move the household which has the lowest utility from the zone *j* to another destination.

3.4. Economic Activities Location Model

The economic activities location model can be used to determine the distribution of employment in the different zones of the study area. In urban research, economic activities are generally classified into four categories (Coppola, Ibeas et al. 2013): (1) basic sector activities dependent on exporting outside the system, (2) activities aimed at the internal demand, (3) representative activities such as those whose location depends on particularly attractive zonal characteristics for reasons of prestige or centrality, (4) activities with low spatial efficiency that need large areas of land to function correctly.

The proposed method is similar to that of households' location choice. It consists in constructing a job localization function that integrates the behaviors of firms in the choice of location of their workplaces. This localization depends on different factors such as the accessibility to population and workforce, the area's attractiveness, the firm characteristics and activities, the price of real estate, etc. The firm tries to acquire the local that it considers most useful for its activity according to its profit maximization function. So, as for households, we consider the choice that maximizes its utility.

The utility function of the firm *f* (characterized by its size and the sector of activity to which it is attached) located in zone z can be expressed as follows:

$$U_{f,z} = (\lambda_{1_f} AC_z + \lambda_{2_f} NO_z + \lambda_{3_f} RE_z - TT_z * SLe - P_z * SLe) \times S_f \quad (4)$$

Where:

- Accessibility (AC) of the working population to the zone,
- Notoriety (NO) of the area considered,
- Surface of the desired local (SL),
- Ratio of firms (RE) of the same activity in the area considered,
- Taxes in the area (TT),
- Real estate price (P) per m² ,
- S_f Size of the firm
- λ_i parameters to be estimated according to the activity of the firm

The firms will be allocated in zone where they maximize their utility.

If $U\left(\pi^{f}_{j,n}\right) > U\left(\pi^{f}_{i,n}\right)$ the firm f chooses to locate in the zone j, otherwise it will remain in the zone i. In the case where the zone *j* is already saturated (the zone has reached its total capacity); we will move the firm which has the lowest utility from the zone *j* to another destination, zone *k* for example (see Figure 3).

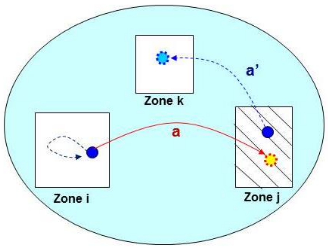

Figure 3: Space Assignment Mechanism

The relocation of an agent affects the composition of the area; neighborhood (in the case of residential use) or the possibility of agglomeration economies (in the case of firms). Since the model modifies these attributes and they can be assessed in a negative as well as a positive manner by the rest of the agents, consumers reevaluate their bid in response to the area's updated characteristics. According to each area characteristics there is the possibility of changing location, because the agent's willingness to pay is altered, either increasing or decreasing. For example, some retail firms would like to be located near the residents/clients who are their clients.

3.5. Accessibility Prediction Model

In the MUST-B Model, Households and firms are interacting via the accessibility variable. The accessibility of households considers the supply of transport (the transport system creates opportunities for interaction or mobility) and the supply of the location of firms (employment opportunities) on the one hand and the accessibility of firms take into account the supply of transport and the location of households (labor force). There is then, in the system, feedback between the two agents (Figure 4). The distribution of accessibility in space, over time co-determines location decisions and so results in changes in the land-use system.

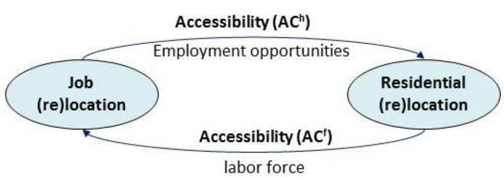

Figure 4: households/firms interaction

The accessibility of a zone comprises two components: one exogenous (land-use transport feedback cycle), which reflects the performance of the transport system and the other endogenous, which reflects the spatial distribution of the population and jobs during the simulation. At this stage, the accessibility associated to the performance of the transport system is calculated using a transport model and is injected into the land-use system as an exogenous parameter. The second part of the accessibility related to the spatial structure (distribution of jobs and population) is determined as follows

(1) The generalized cost of travelling between the zones *i* and *j* using the private vehicle (PV) mode is a combination of the time of travel, the distance travelled, and the actual monetary costs (fuel cost and parking fees). It can be calculated using the following equation:

$$C^{VP}_{(i,j)} = V_t * tt^{VP}_{(i,j)} + \left(CC + CK\right) * d^{VP}_{(i,j)} + C^{Park}_{j} \quad (5)$$

Where Vt = the time value, tt_{ij} = the time of travel between zones *i* and *j*, $d_{(i,j)}$ = the distance travelled, CC = fuel cost par km, CK = vehicle use costs and C_j^{Park} = the parking fee of the destination area.

(2) The generalized cost of travelling between the zones *i* and *j* using the public transportation (PT) mode is a combination of the time of travel, the number of transfers, and the actual monetary costs. It can be calculated using the following equation:

$$C^{PT}_{(i,j)} = V_t * tt^{PT}_{(i,j)} + Cost^{PT} + \eta * N^{Corres}_{(i,j)} \quad (6)$$

Where Vt = the time value, tt_{ij} = the time of travel between zones *i* and *j*, $N_{(i,j)}$ = the number of transfers, Cost = the travel cost and η = the parameter to be estimated.

The measure of the accessibility is based on a gravity model. It refers to the capacity of a place to reach certain opportunities. The endogenous part of the accessibility for the household measures the population size within the special reach of the employment opportunities. In general, the accessibility the accessibility of a zone can split into two parts. They are denominated as exogenous accessibility calculated using a transport model, and endogenous accessibility or potential reachable opportunities from an area.

The endogenous accessibility for a household of a determined zone to the employment opportunities in the reset of the zones using a private vehicle mode can be calculated using the following expression:

$$Acc^{PV}_{endog}(i) = \mu * \sum_j^n \frac{\text{pop(i)}*jobs(j)}{(C^{PV}_{(i,j)})^2} \quad (7)$$

Where *pop(i)* = the number of residents present in origin zone *i*, *Jobs(j)* = the number of jobs in destination zone *j*, $C^{PV}_{(i,j)}$) = a measure of travel cost by *PV* mode between the origin zone *i* and the destination zone *j* (expression 7), and μ= the parameter to be estimated.

Exogenous accessibility can be represented by

$$Acc_{exog}^{PV}(i) = \theta * \sum_i e^{-C_{(i,j)}^{PV}} \quad (8)$$

Where $C_{(i,j)}^{PV}$ = a measure of travel cost by PV mode between the origin *i* and the destination *j* (expression 8), and θ = the parameter to be estimated. Finally, the accessibility of a determined zone to the employment opportunities using a PV mode can be expressed as

$$Acc^{PV}(i) = Acc_{exog}(i) + Acc_{endog}(i) \quad (9)$$

The same process can be used to calculate the accessibility using public transport (PT) mode.
In order to calculate the accessibility of all modes of a determined zone, we must weigh the accessibility of each mode by its modal share. The determination of the modal share is based on the generation-distribution approach (gravity model) of the 4 steps transport model. The estimation of the parameters related to the accessibility indicators is based on the origin-destination survey.

3.6. An agent-based architecture for modeling land use and transport interaction

The agent-based simulation uses database for input, a Discrete Event-based simulation and RStudio to analyze and visualize the output results. The simulation starts with the experiment to simulate. Such experiment includes all agents' attributes and variables. In residential location choice sub-model, a household is modeled as a single agent, and in the economic activities location choice sub-model, a firm is also modeled as an agent. The repository contains all the individual static models. The GENERATOR connects to the input files to retrieve all the configuration information and all agents' static attributes from the experiment. The simulation is driven by an R script to produce a result set, which we processed to conduct statistical analysis and to display results. We use R to processes the results. The result files are used to visualize the simulation and to conduct analysis. The analysis can lead to a new cycle. This allows focusing on critical parameters (agent' preferences, environmental attributes, etc.) that determine the model output (real estate price, land use) (**Figure 5**). This simulation is run using VLE (Virtual Laboratory Environment). VLE software **(Quesnel, Duboz et al. 2009)** implements Discrete Event system Specification (DEVS) M&S and supports multi-modeling, simulation and analysis. It is based on an extension of DEVS, the Dynamic Structure Discrete Event formalism (DSDE) **(Barros 1997)**. The implementation of the DSDE abstract simulators gives to VLE the ability to simulate distributed models and to load and/or delete atomic and coupled models at runtime. It is also possible to perform statistical analysis of results thanks to a plug-in that allows communication between VLE and R **(Quesnel, Duboz et al. 2009)**.

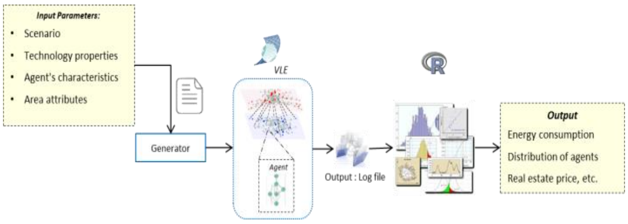

Figure 5: Agent based-modeling and simulation architecture for MUST-B model

4. APPLICATION OF THE MODEL TO THE METROPOLITAN AREA OF BORDEAUX

In order to model household and economic activities location as part of the MUST-B model, we use the agglomeration of Bordeaux as a case study. In this section, we will simulate a simple scenario to predict the urban development in a specific period and test our model functioning.

4.1. Study Area

The Urban Area of Bordeaux (UAB) consists of 191 communes of the counties of Gironde and Landes (called in France "département", a French legal subdivision) and covers an area of 3,901 km². This area contains the Bordeaux metropolis, considered as the central city of the Gironde County, and fifteen small towns located nearby. The area also includes several villages and industrial or touristic regions. Development has occurred mostly in lands around the city and the towns. The area of Bordeaux extends to the ocean and has 1.1 million residents, 523310 households, 467211 jobs and 34676 firms. The vast majority of the population lives in an area under urban influence, i.e., according to INSEE, the French National Institute for Statistics and Economic Research, a metropolitan area within the meaning of commuting from home to work activity.

4.2. Data Preparation

The area is administered by 255 different IRIS, the acronym of 'aggregated units for statistical information' with a target size of 2000 residents per basic unit. These units represent the fundamental unit for dissemination of infra-municipal data. They respect geographic and demographic criteria and have borders which are clearly identifiable and stable in the long term. The zoning used in this study has divided the metropolitan area into 42 zones according to geographic and transportation criteria (see Figure 6). The different sub models will be calibrated with data from 2012, which is taken to be the base year of this research. The data used in estimating the parameters of the different sub-models came from three main sources. The first source was provided by official statistics (INSEE 2012). It collects and publishes information about the activities, jobs and households, and carries out the periodic national census. The second source is the urban planning agency of the Bordeaux metropolis, which have appropriate information on urban planning and development projects and studies the general rules for land use in the territory of the study area. Finally, the third data source consists of a transport survey designed principally by the authors that provided information on the characteristics of the surveyed households and the mobility of each household member. These data are used to characterize demand (households and firms) and supply (housing stock, land, etc.). Some data have been estimated on the basis of demand and supply. For example, the building's energy bill based on the age of the building and the area's notoriety according to public services, Shops, schools, etc.

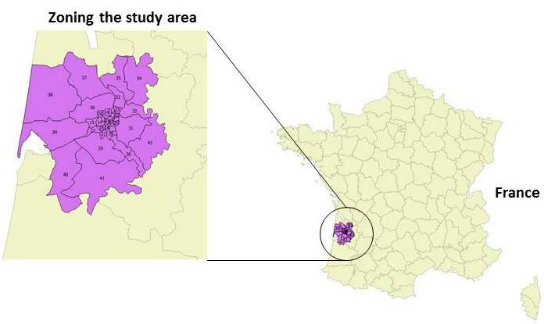

Figure 6: Zoning the study area

The location model for households was disaggregated into 10 subtypes of agents. The households were divided into, two income groups, those with high incomes (socio-professional category+) and those with medium and low incomes (SPC-) and five size groups. This distinction was made to try to obtain better-fitting parameters for the preferences shown by the different agents. The firms were disaggregated into 32 categories, 4 economic activities groups and 8 size categories.

4.3. Result and Discussion

The data required to run the MUST-B model are imported through a series of csv files that can be edited before each simulation cycle. In the present case, a part of the accessibility for activities and population in each zone is exogenous. The exogenous accessibility is based on a transportation model which is an external system related to the study area transport system. The measure of the other part of accessibility and attractiveness is modified at each iteration (each iteration represents a draw) depending on the results provided by residential and job (re)location sub-models. The behavior of these sub-models was implemented in VLE software and programmed using C++ code. An initial procedure (GENERATOR model) imports the exogenous accessibility indicators between the zones, the socio economic data and the neighborhood attributes. A second phase then calculates the real estate price indices as well as the location of households and firms by zone through the location models. On a computer view the agents do not exchange information, and from an economic and social point of view the endogeneity (notion of economic equilibrium) represents the interaction between the agents.

The results set out below are based on UAB data presented in the last section. However, the model is not validated and the results of the simulation of 10 million draws (which is the criteria to stop the simulation) are presented in order to illustrate the functioning of the model and to validate the implementation of the mechanisms.

Figure 7 illustrates the evolution of the real estate prices indicator during simulation. The real state price is modified at each iteration, depending on the results provided by residential and job location sub-models. After a certain number of iterations, the average price of real estate remains stable this means that the model is reached the state of equilibrium according to Wardrop's equilibrium principle in traffic assignment. We also verified through another scenario that the initial point does not affect the price indicator at equilibrium state (see Figure 6). The real estate price indicator is determined by the auction mechanism in an endogenous way.

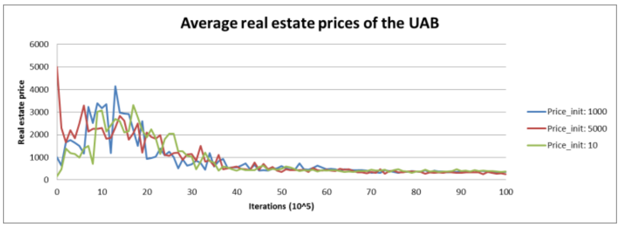

Figure 7: Real estate price indicator

The figure below shows the evolution of the real estate price of the 42 zones of the AUB.

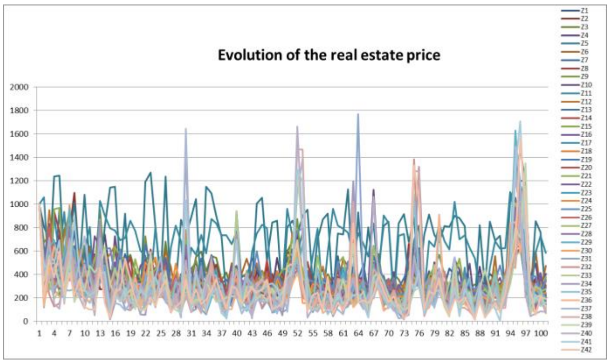

Figure 8: Evolution of the real estate price of the zones

At the beginning of the simulation, the population and jobs are located randomly taking account the capacity of each zone. Then, the MUST-B model is used to predict households location in study area based on the information available on demand, actual real estate supply, building attributes and the corresponding economic incentives. **Figure 9** shows the result of the simulation in terms of aggregated consumer utility obtained by zone. It represents the degree of satisfaction or happiness perceived by all households in a zone. In the **Figure 9**, we observe that the zone 5 (the central city of the urban area of Bordeaux) is very attractive and the households consume the entire supply. This attractiveness can be explained by better notoriety (public services, parks, schools, security, etc.) of this area and a good index of accessibility.

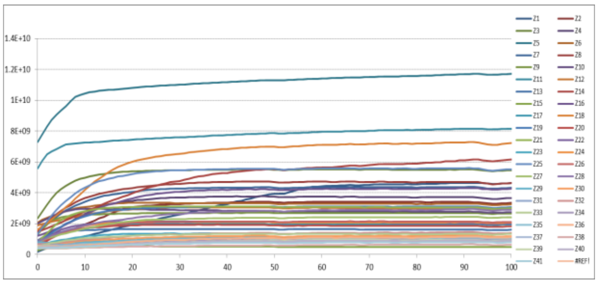

Figure 9: Cumulative utility at the scale of the zones

The Figure below shows the evolution during the simulation of the aggregate utility of households. We observe that the economic equilibrium is reached for the households after 60×10^5 draws.

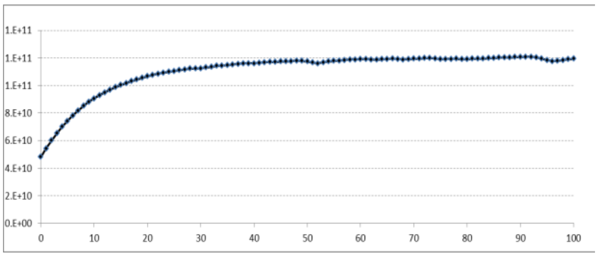

Figure 10: Cumulative utility of the AUB.

In this experiment we have presented the evolution of two indicators: the average price of real estate in the studied area and the location of households by zone. Other important indicators such as firms' (re)location, social mix, energy consumption, greenhouse gas emissions, etc. can be studied in order to analyse their influence on the pattern of land use development.

CONCLUSION

This article has presented a land use and transport interaction model that can perform estimations of changes in the location of population, economic activities, energy consumption, greenhouse gases and real estate prices as a result of the introduction of policies and projects relating mainly to transport. This model aims to provide better decision helping tools for urban and regional long term planning. MUST-B model enables us to construct future scenarios of urban land use in a methodical and practical way, using a mathematical model with solid economic basis. In this study, we developed a new agent-based model for simulating future urban land-use development in our study area, located in the New Aquitaine region of France. In details, MUST-B Model is developed using agent based modeling approach in which the agents are households and firms that seek to localize depending on the utility of the location and the financial constraints. It takes account of the functioning of land and real estate markets and it integrates several mechanisms such as real estate price estimation in an endogenous approach, integration of energy bills (housing and mobility) into the residential location choice model and Taking into account social housing. The different technics employed were previously validated in their respective domain and the models and simulation results proposed in this paper have confronted to expert in the domain. The next step is to make the MUST-B model operational by calibrating it to the urban area of Bordeaux and to validate it based on historical data. The predictive capacity of the MUST-B model will be assessed by confronting simulation results against historical observations that will be not used for calibration. In General, Available data are split between an "estimating" set (data 2012) will be used for model calibration and a "test" set (data 1990) will be used purely for validation.

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