Groupe de Recherche en
Économie Théorique et Appliquée

# MUST-B: a multi-agent LUTI model for systemic simulation of urban policies

***Seghir Zerguini***

*GREThA, CNRS, UMR 5113, University of Bordeaux*

*seghir.zerguini@u-bordeaux.fr*

&

***Nathalie Gaussier***

*GREThA, CNRS, UMR 5113, University of Bordeaux*

*nathalie.gaussier@u-bordeaux.fr*

***Cahiers du GREThA***
**n° 2019-13**
**october**

**GRETHA UMR CNRS 5113**
University of Bordeaux
Avenue Léon Duguit - 33608 PESSAC - FRANCE
Tel : +33 (0)5.56.84.25.75 - Fax : +33 (0)5.56.84.86.47 - www.gretha.fr

## MUST-B: a multi-agent LUTI model for systemic simulation of urban policies

*This article is part of the STRATEGIE research project co-financed by the Région Nouvelle Aquitaine. It presents the MUST-B model (Integrated Modeling of Land-Use – Transport: for application in the Bordeaux agglomeration) which is based on systemic land-use / transport modeling with regards to how the land and property markets operate, and the interdependent factors for selecting the locations of households and employment. MUST-B is an agent-oriented model which simulates household and job location choices. It is based on an auction mechanism which models competition between agents in the real estate market (existing property holdings, including residential, industrial and tertiary) and in the land property market (from buildable land reserves) over a given timeframe. This auction procedure is based on maximizing the utility provided to the agent by a given location: housing for a household and an area for business activity for employment premises. Utility is a function of several characteristics relating to the space and premises occupied, such as accessibility, surface area, energy quality of the building, notoriety, agglomeration effects and taxes, or property prices, the latter being endogenous. In this article, the mechanisms and functioning of the land property and real estate markets which prevail in MUST-B are presented. Methodological choices and behavioral guidelines for agents (households/workplaces), are also set out, and to illustrate the operational nature of the model, the databases required for implementing the MUST-B in the Bordeaux Urban Area are presented.*

**Key Words:** LUTI, Choice of location, Households, Employment, Accessibility, Real estate prices, Multi-agent, Systemic modeling.

## MUST-B : un modèle LUTI multi-agents pour la simulation systémique des politiques urbaines

*Cet article s'inscrit dans le cadre du projet de recherche STRATEGIE cofinancé par la Région Nouvelle Aquitaine. Il présente le modèle MUST-B (Modélisation intégrée de l'Usage du Sol – Transport : application à l'agglomération Bordelaise) qui est basé sur la modélisation systémique usage du sol / transport au regard du fonctionnement des marchés foncier et immobilier, et des logiques interdépendantes de localisation des ménages et des emplois. MUST-B est un modèle orienté agent qui simule les choix de localisation des ménages et des emplois. Il est fondé sur un mécanisme d'enchères qui permet de modéliser, à un horizon temporel donné, la concurrence entre les agents sur le marché de l'immobilier (parcs immobiliers existants, à la fois résidentiel, industriel et tertiaire) et sur le marché du foncier (à partir des réserves foncières constructibles). Cette procédure d'enchères est basée sur la maximisation de l'utilité que procure pour un agent une localisation donnée : un logement pour un ménage et un local d'activités pour un établissement d'emplois. L'utilité est fonction de plusieurs caractéristiques en lien avec l'espace et le local occupé comme l'accessibilité, la surface, la qualité énergétique du bâti, la notoriété, les effets d'agglomération et les taxes, ou le prix de l'immobilier, ce dernier étant endogène. Dans cet article sont présentés les mécanismes et les logiques de fonctionnement des marchés foncier et immobilier qui prévalent dans MUST-B. Sont exposés les choix méthodologiques et les règles de comportement des agents (ménages/établissements), et enfin pour illustrer le caractère opérationnel du modèle sont présentés les bases de données nécessaires à l'application de MUST-B sur l'aire urbaine de Bordeaux.*

**Mots-clés :** Modèle LUTI, Choix de localisation, Ménages, Emplois, Accessibilité, Prix de l'immobilier, Multi-agent, Modélisation systémique.

**JEL: R14, R31, R41, R52**

**Reference to this paper ZERGUINI Seghir, GAUSSIER Nathalie** (2019) MUST-B: a multi-agent LUTI model for systemic simulation of urban policies, *Cahiers du GREThA*, n°2019-13.

http://ideas.repec.org/p/grt/wpegrt/2019-13.html.

**GRETHA UMR CNRS 5113**
University of Bordeaux
Avenue Léon Duguit - 33608 PESSAC - FRANCE
Tel: +33 (0)5.56.84.25.75 - Fax: +33 (0)5.56.84.86.47 - www.gretha.fr

# 1 Introduction

Several works have demonstrated that we are constantly pushing the limits of our daily travel, leading to urban sprawl (Orfeuil, 2000). In France, for example, the population living in urban areas is constantly increasing, estimated by the Banque Mondiale to be 80% of the total population today, compared with only 62% in 1960. At equal cost, with increasingly efficient means of transport, infrastructure, systems and vehicles, it is possible to live further and further from the city center, in order to seek environmental amenities or to access property. Urban sprawl produces an explosion in commuting which results in increasing congestion of transport infrastructures, air pollution at peak hours and a dependency on cars (Newman and Kenworthy, 1998).

Within this perspective, many authors question the fragility of populations living in peri-urban areas and whose transport budgets may be very sensitive to changes in energy costs (Crozet et al., 2004). At the same time, scarcity is what is generally observed: scarcity of space, energy and time. This requires an understanding of residential locations and daily household movements from another perspective: that of travel conditions and planning urban space. Households are living in increasingly tight markets, with a constrained budget for housing, transportation and heating. As an example, the average property prices in Bordeaux have quadrupled between 1998 and today, pushing people further out towards the periphery. Controlling urban growth is clearly becoming a requirement for sustainable development and public policies.

In order to limit greenhouse gas (GHG) emissions and fulfil France's international commitments to fight global warming, the government has implemented a series of plans (Low-carbon strategy, multi-year energy programs, etc.) and laws such as the adoption of the Climate, Air and Territorial Energy Plan. Thus, the law on energy transition for green growth requires all regions with more than 20,000 inhabitants to adopt a Climate, Air and Territorial Energy Plan by 31st December 2018 at the latest, to be renewed every 6 years. The most important issues regarding energy transition are to be found in urban areas, which generate 60% of GHG emissions.

On the other hand, local authorities have no tools at their disposal which are capable of assessing the prospective effects of Climate, Air and Territorial Energy Plans in their regions. While the current diagnosis of GHG emissions is undertaken in a detailed and precise manner per sector (mobility, building, etc.), future forecasts remain based on single-sector approaches which ignore intersectoral interactions (Zerguini et al, 2012). For example, building a tramway line not only impacts GHG emissions linked to mobility (reduction of emissions through the mechanism wherein travel flows are transferred from cars to public transport) but also impacts GHG emissions linked to urban planning (through the mechanism wherein the urban area of the region is made more accessible by the tramway line).

The MUST-B model addresses this double issue of urban growth and sustainability. It aims to address the growing preoccupations of sustainable urban development, focusing specifically on prospective assessment in the field of transport and land use planning. Many studies have thus confronted the complexity of urban dynamics to propose models which integrate the interactions between transport and urbanization, known by the LUTI acronym, which stands for "Land Use – Transport Interaction". While the use of LUTI models has been compulsory in the United States for the past thirty years (the ISTEA Act, 1991 and TEA 21 Act, 1998), some local communities in France (Ile-de-France, Lyon, Lille, Grenoble, Besançon) have begun to explore urbanization scenarios in terms of investments and to government policies.

The MUST-B model is designed to be used to aid decision-making (helping to define and develop government policies) to guide the “trajectory” of an area towards improved “sustainability”. Its aim is to enable the prospective assessment of the impact of its Climate, Air and Territorial Energy Plan, particularly in the Bordeaux metropolitan are. This is conducted according to actions which can be implemented with regards the Energy-Climate policy. The MUST-B tool can provide an interesting insight to support institutional decision-makers in the Bordeaux area and rise to the challenge of sustainable urbanization.

This article first of all exposes the state of the art of LUTI modeling and the positioning of the MUST-B model in relation to existing LUTI models. It then presents the principles underpinning the development of the MUST-B model and its implementation for a given future time prospect. The third section describes the theoretical and methodological choices made to model the utility function and location mechanisms of households and workplaces, as well as the systemic interactions between households and workplaces. The final part, which presents the implementation of MUST-B in the Bordeaux Urban Area (AUB), highlights the main indicators of the complexity of the urban phenomenon produced by the model.

# 2 MUST-B: context and positioning

There is a wealth of literature on the subject of LUTI models (Wegener, 2004) dating back to the 1950s in the United States, which study the interaction between transport and urban development. It aims to better "open up" the black box of transport – urbanization interactions with the aim of proposing applications in the context of large foreign and French agglomerations. It raises many questions, particularly about the representation and articulation of the systems that make up these models. Wegener (2004) thus identifies about twenty models which he compares using an articulated reading grid according to nine characteristics: 1. Their unified or composite structure, developed from hierarchically ordered subsystems, 2. the complete or partial integration of the transport system, 3. the theoretical foundations - auction-based models, expected utility theory, equilibrium..., 4. modeling techniques according to their consideration of space and time, 5. simulated dynamics, 6. necessary data, 7. parameter and validation exercises of the model, 8. operationality and 9. model applicability.

In MUST-B, the mechanism for choosing the location - of households and workplaces - is based on the theory of maximization of the utility its location in a given place will procure for the consumer (households and workplaces). Here, we are interested in the balance between the real estate and land markets that emerges following simulation of intra-agent competition (competition between households on residential supply and between workplaces on business premises supply) and inter-agent competition (competition between households and workplaces on buildable land stock). More generally, MUST-B is founded on a formalized set of principles taking into account the behavior of a large number of urban agents / actors and their mutual interactions: households, businesses, planners, developers, government policies, regulations, etc. To account for the complexity of the urban phenomenon, a multi-agent simulation is used wherein most of the mechanisms that govern land use are endogenized, such as how property prices are defined, occupancy of the buildable land stock, and access to jobs and labor.

MUST-B proposes a novel approach in comparison to the numerous previous works on LUTI modeling for the following reasons:

- Its systemic articulation of the land and real estate markets (planner / developer / occupier – households and workplaces) enables us to consider all interactions between the different urban actors using a countdown mechanism, according to which the land price is deducted from the other costs of an operation and the sale price of real estate.
- The collaboration of multidisciplinary researchers (in the fields of the economy, urban planning, geography, transport, IT, etc.) enables us to consider the specificities of the different disciplinary fields in relation to the urban phenomenon.
- The diversity of the project team (researchers and consultants) enables us to develop a tool which is compatible with the requirements of local and operational authorities to conduct research and provide advice.
- Its multi-agent simulation enables us to better understand the complexity of the city system based on individual behaviors. Using computer power, multi-agent simulation enables us to model collective behaviors which are not otherwise easily accessible through intuition or analytical calculation (Lemoy et al., 2011).
- It compares theoretical approaches with operational actors (developers, corporations...), enabling us to validate the modeled mechanisms.
- It includes social housing, which represents a quarter of the national housing stock.

# 3 Methodology

## 3.1 Architecture and operation of the model

Households compete with each other in real estate, and with workplaces, to occupy buildable land stock.

MUST-B operates like a "four-stage" transport model in that, for a given time prospect (Bonnel, 2001), the balance results from the confrontation between supply (transport networks) and demand (flow matrix). Thus, MUST-B can be considered as a supply-and-demand model wherein spatial entities (land, housing, business premises) interact with social entities (households, institutions).

- Land occupation by households and workplaces in the different zones of an urban area at a given future time prospect is based on the following process (Figure 1):
- Exogenous demand in the future is defined by distinguishing between households (population) and workplaces (employment).
- At the beginning of the modeling process, agents are arbitrarily assigned to the respective current housing stock, respecting capacity constraints. For this, a procedure is developed in MUST-B which enables an automatic pre-assignment of agents in the zones.
- Households will start by occupying the current housing stock and, once this is saturated, they will occupy the buildable land stock dedicated to housing in accordance with the developer's profitability conditions. Deciding the location of workplaces follows the same process.
- In the case where the dedicated buildable land stock is saturated, households and/or workplaces will be located in buildable land stock designated for mixed housing/business premises until this is saturated in turn.

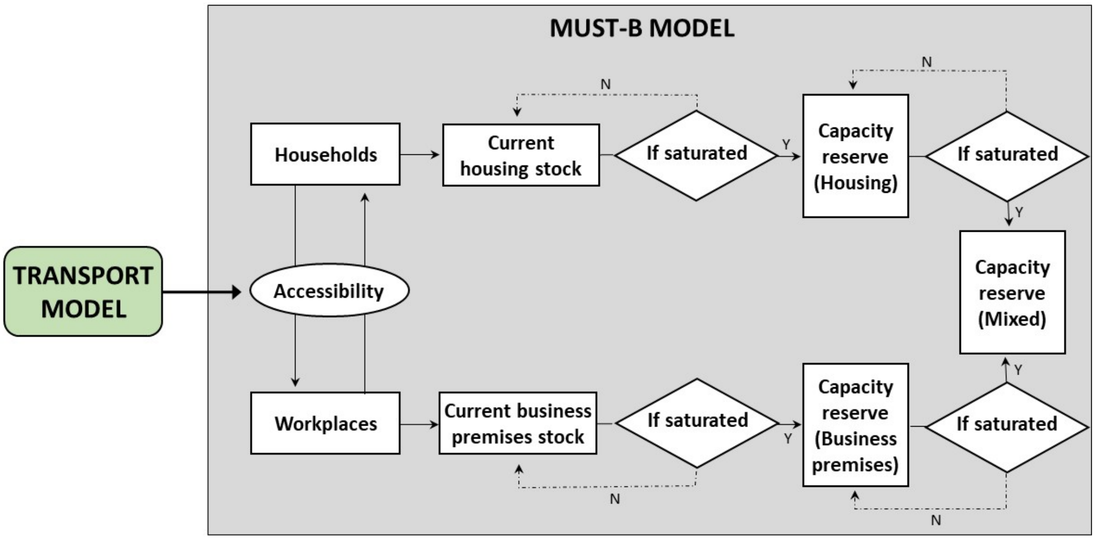


Figure 1: Operation of the MUST-B model for a future time prospect

The MUST-B model is thus able to account for urban sprawl or tightness: apart from the current exogenous stock, supply becomes endogenous, capped by the buildable land stock available, under pressure from demand from agents (households and workplaces) and financial profitability for the developer (countdown mechanism presented in §3.3).

## 3.2 Formalization and implementation of the MUST-B model

Agent-based modeling is defined as a modeling and simulation technique that works on the level of micro-units such as workplaces, households, etc. Each micro-unit contains several attributes and follows a set of behavioral rules. This technique simulates the decision-making processes of individuals based on the heterogeneous attributes of agents and their interactions with the environment and other agents. The agent-based modeling approach has recently emerged and has gained in popularity within the scientific community with regards to urban planning. These models use agent links (households or workplaces) - the use of land as objects of analysis and simulation and pay particular attention to the interactions between these "agents". Agents are defined by several characteristics: they are autonomous, they share an environment through communication and interaction, and they make decisions that link their behavior to the environment. Agents make inductive and dynamic choices that lead them to achieve well-being objectives.

The MUST-B model is implemented in the VLE -Virtual Laboratory Environment (Quesnel, Duboz et al., 2009). VLE is a platform for multi-modeling and simulation of dynamic systems based on discrete event system simulation (DEVS) (Zeigler, Praehofer et al., 2000). VLE enables us to specify complex systems in terms of reactive objects and agents, simulated the system dynamics and analyze the results of the simulation. The indexes provided also facilitate the development of customized programs. MUST-B is developed using the concept of object-oriented programming, in particular C++ language.

## *3.3 The notion of equilibrium in MUST-B*

MUST-B locates each agent randomly selected. The territory modeled is considered to be that of a closed city, with a given future time prospect, wherein the total number of agents (population, jobs) is fixed in advance. Thus, a large number of selections (several million) are conducted in a simulation in order to achieve a situation of equilibrium. The equilibrium is derived from the simulated dynamics of household and workplace location choices. Equilibrium is considered to be achieved when agents no longer improve the utility they can derive from a new location. This dynamic urban equilibrium, as opposed to the static equilibrium which can be calculated in urban models, is similar to the Wardrop equilibrium used in traffic flow allocation models. The Wardrop equilibrium is achieved in the allocation of traffic on a road network when no user can change itinerary without compromising their travel time.

In practice, in the MUST-B model, the aggregate utility of a given type of agent (household or workplace) converges towards a U* level after a number I* of iterations (Figure 2). I* corresponds to more than 4 million iterations for households while workplaces require a higher number of iterations.

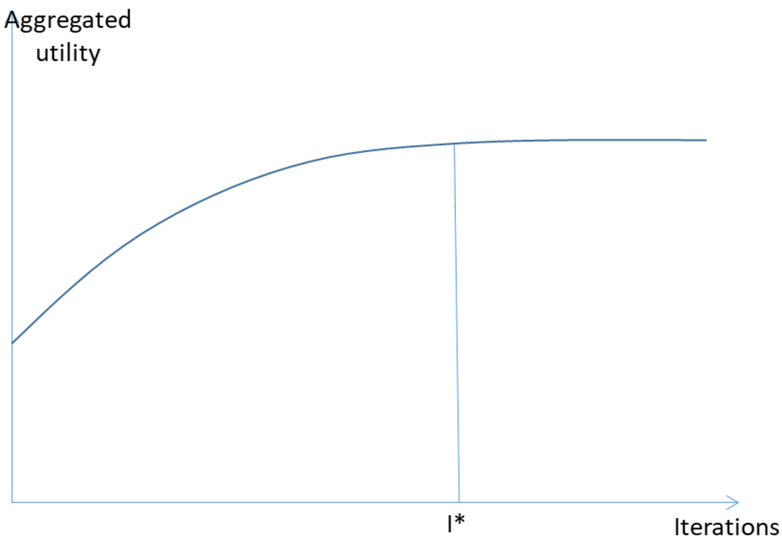


Figure 2: Evolution of aggregated utility over iterations

It can therefore be considered that, after a certain number of iterations I*, the aggregate utility of households will no longer increase, and that no household can increase its utility by being in a given area without at least decreasing that of another. As with Pareto efficiency, there is nothing to say that all households are satisfied with their location. The same applies for business premises.

## *3.4 Theoretical principles and modeling*

### *3.4.1 Utility functions*

The proposed approach consists of developing a residential utility function, which integrates household behaviors into their residential location choices. This enables households to be assigned to the different residential options according to an auction procedure. The residential utility function reflects the economic well-being that the household can derive from a given location and type of housing. It depends on several parameters relating to housing and space, such as the accessibility and reputation of the area, the surface area of the housing or the price of real estate...

The utility function of the household h residing in zone z can be expressed as follows:

$$U_{h,z} = \alpha_{1_h} AC_z + \alpha_{2_h} NO_z + \alpha_{3_h} SA_h - EB_z * SA_h - P_z^l * SA_h \qquad (1)$$

Wherein:

- *AC*: Accessibility of the zone under consideration (reflecting access to employment)
- *NO: notoriety of the area under consideration (reflecting the image and amenity of an area that can be qualified by various parameters such as the atmosphere, style, specificity and diversity of the businesses that are present)*
- *SA: surface area of the desired housing*
- *EB: energy bill per m² of the area in question*
- *P: price per m² of housing in the area under consideration (reflects the energy costs related to the use of the housing such as heating, air conditioning, lighting, etc.)*
- $\alpha_i$*: parameters to be estimated according to the household's socio-professional category (SPC)*

In order to take the heterogeneity of households within the same category (size x SPC) into account, a statistical distribution is introduced within each category. This distribution concerns the $\alpha_i$ parameters of the residential utility function. The statistical distribution used is the normal distribution of the mean of the value of $\alpha_i$ and the standard deviation is assumed to be 10% of the mean.

The proposed method for simulating location choices for workplaces is similar to that for households. It consists of developing a job location function which integrates the behavior of companies in the location choices of their workplaces and enables jobs to be assigned to the premises according to an auction procedure. This function reflects the utility that the company can derive from a given location and type of premises. This depends on several parameters, such as the accessibility and reputation (image) of the zone; the surface area of the premises, property prices, taxes, financial assistance, etc.  In the same way as for a household, the company will seek to acquire the premises which it considers to be the most useful for its business, taking the size of the workplace into account.

The utility function of workplace w (characterized by its size and its sector of activity) located in zone z can be expressed in this way:

$$U_{w,z} = \left(\lambda_{1w} AC_z + \lambda_{2w} NO_z + \lambda_{3_w} RW_z - TD_z * SA_{wa} - P_z^w * SA_{wa}\right) * S_w \qquad (2)$$

Wherein:

- *AC*: accessibility of the area under consideration (i.e. access to labor)
- *NO*: notoriety of the area under consideration (i.e. the image and specificity of an area)
- $SA_{ea}$: surface area of a job per type of business activity
- *RW*: ratio of workplaces operating the same business activity as the premises under consideration out of all of the premises present in the zone (i.e. agglomeration effects)
- *TD*: level of taxes and duties in the zone under consideration

- $P$: price per m² of business premises in the zone under consideration
- $S_w$: size of the workplace
- $\lambda_i$: parameters to be estimated according to the business activity of the premises

### 3.4.2 Location selection mechanism

The mechanism for choosing the location of households is the same as that for workplaces: it is based on maximizing the utility of a location for the agent (household/workplace).

The assignment of agents to the different areas that make up the agglomeration is based on an auction mechanism for the acquisition of housing / business premises. The principle is that each agent will locate themself in a given area, seeking to maximize their utility. The bid made by the agent (candidate wishing to move) is composed of the price of their current dzone and the "monetarized" gain of the utility provided by their potential move.

Concretely, at iteration[1] n of the simulation, the bid that agent a will make to move into zone j depends on the price of housing in his home zone i at iteration n-1, and on the difference in utilities between zones i and j at iteration n-1. This is expressed as follows:

$$\pi^a_{j,n} = P_{i,n-1} + \varepsilon\left(U^a_{j,n-1} - U^a_{i,n-1}\right) \qquad (3)$$

where $\varepsilon$, the amplitude of the auction, determines the utility gain transformed into a price added to the initial price in their current zone.

With the above mechanism (3), the simulated prices of the different zones will increase as they attract an ever-increasing number of agents. To simulate the inverse mechanism of price decline or stability, it is assumed that the agent can renounce moving if they obtain a reduction on the price of real estate in their home area i. The auction that the agent makes in order to remain in their home area is expressed as:

$$\pi^a_{i,n} = (1-\beta)P_{i,n-1} \qquad (4)$$

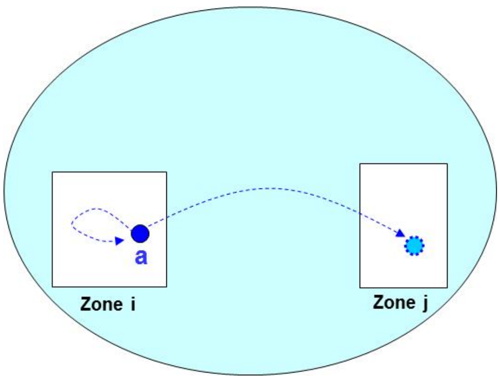


*Figure 3: Arbitrating the location of an agent*

[1] An iteration corresponds to the random selection of an agent subjected to the location selection process.

The agent *a* chooses to be located in the zone where they derive the most utility.

If $U\left(\pi_{j,n}^{a}\right) > U\left(\pi_{i,n}^{a}\right)$, the agent has chosen to be located in zone j, otherwise they will remain in zone i.

In the case where the utility of going to zone j is greater than that obtained in zone i, and zone j is already saturated (zone j has reached its total capacity) then agent a is relocated in any case to zone j and it is the agent which derives the least utility in zone j which is relocated to a randomly selected destination, zone k.

At the end of the location process for the randomly chosen agent assigned to a zone, the price of the area is updated and also calibrated with the auction made by the last agent. Thus, at each iteration, there is necessarily a zone which will be subjected to a price modification, upwards or downwards.

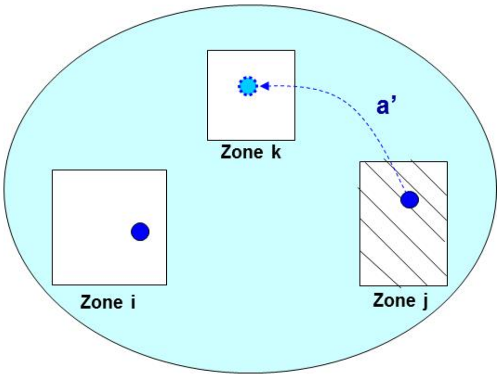


*Figure 4: In the event that zone j is saturated*

Equilibrium is attained when, for a given type of agent, the level of utility is the same wherever they are located. The agent cannot improve their utility by changing area.

### *3.4.3 Procedure for the endogenous offer (Developer)*

For a future time prospect, the MUST-B model locates homes and workplaces respectively in a zone, having knowledge of their current respective land stocks. Once each of these current land stocks are saturated, they will begin allocating to the buildable land stock (land which can be built on in accordance with regulations). Consumption of the buildable land stock is activated by the countdown mechanism: i.e. the price of land is deducted from all other costs of a real estate transaction. When the developer wishes to know the maximum price available to them to buy land and initiate a real estate transaction, they will deduct from the expected sales figure (depending on new housing prices and their knowledge of the local market), the costs of construction, financial costs, fees, taxes and margin (Vilmin, 2015). The only item that ultimately determines the decision to invest and the profitability of the project is the land, given that the margin conditions the bank's ability to obtain loans and guarantees. The difference between expected revenues and expenses therefore corresponds to the maximum land charge that the developer can incur. The endogenous capacity mechanism will therefore be activated with the confrontation between property prices and land charges.

*Decisional investment mechanism*

So, for one meter squared:

$\pi$: Price of the auction made by the agent at iteration n (in relation to the transferable surface)

$C_L$: Cost of land (in relation to the buildable surface area)

p: Weighting of the cost of land in the price of real estate ($p = C_L / \pi$)

$C_C$: Cost of construction

M: Developer's margin

$C_P$: Cost of production (land cost + construction cost + margin)

We obtain:

$$C_P = C_L + C_C + M \qquad (5)$$

$$C_P = p\pi + C_C + xC_P \qquad (6)$$

We can deduce that:

$$C_P = \frac{p\pi + C_C}{1 - x} \qquad (7)$$

The developer's profitability condition is expressed as follows:

$$\pi > C_R \qquad (8)$$

We finally obtain:

$$\pi > \frac{C_C}{1 - x - p} \qquad (9)$$

As illustrated in Figure 5, the mechanism for occupying the buildable land stock of a zone is conditioned by a double constraint: the saturation of the current land stock and the expected profitability for the developer to build in this zone (Equation 9).

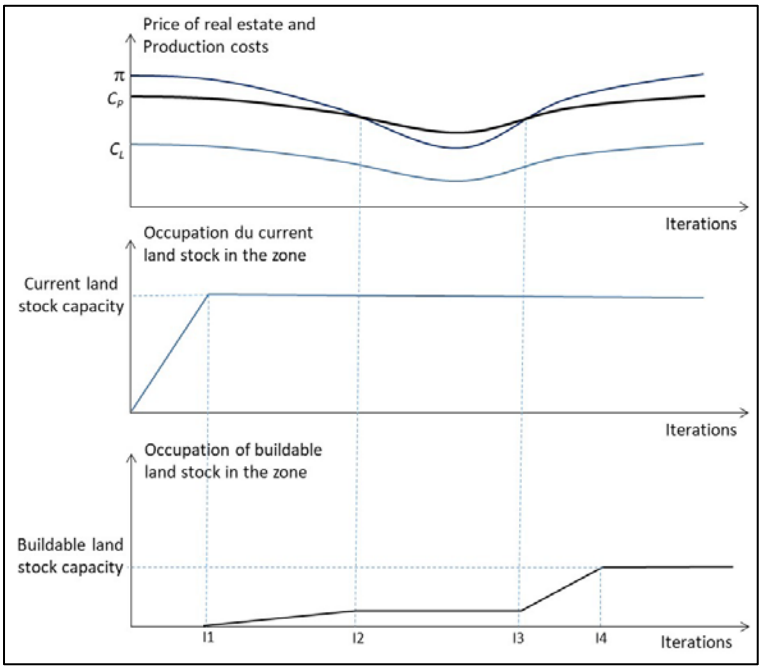


Figure 5: Occupation of buildable land stock

From Figure 5, we can identify 4 configurations:

1. Between the beginning of the simulation and iteration I1, the agents are located in the current zone.

2. Between iteration I1 and iteration I2, the agents are located in the buildable land stock because, on the one hand, the current land stock under consideration is saturated and, on the other hand, the price of the property enables the developer to gain a profit (auction is higher than cost price).

3. Between iteration I2 and iteration I3, the area is still considered saturated, but the buildable land stock is not mobilized because the developer's condition of profitability is not fulfilled within this interval.

4. Between iteration I3 and iteration I4, the agents are located in the buildable land stock as the profitability condition is fulfilled once again.

5. From iteration I4, the zone is considered definitively saturated (the capacities of the current zone and buildable land stock being full).

*<u>Process of spatial occupation of the buildable land stock</u>*

Thus:

- *IS*: the inhabitable surface area of the real estate sought by the agent (real estate demand)
- *BF*: Building footprint
- *GS*: Ground surface area of the land used
- $NF_{max}$: Maximal number of floors allowed in the zone

- $k_1$: add-on factor ($k_1$>1) of the occupied surface area taking external walls of the building into account
- $k_2$: add-on factor ($k_2$>1) taking into account networks (road, water, sanitation, street lighting, etc.) and urban planning easements (view, right of way, etc.)

The building footprint satisfying real estate demand IS is expressed as:

$$BF = k_1 * \frac{IS}{NF_{\max}} \qquad (10)$$

The ground surface area of land consumed by this real estate demand is equal to:

$$GS = k_2 * BF \qquad (11)$$

We finally obtain:

$$GS = \frac{k_1 * k_2}{NF_{\max}} * IS \qquad (12)$$

Each time an agent (household or workplace) is located in this zone, the ground surface area consumed by this demand is subtracted from the buildable land stock surface until the total consumption of the buildable land stock surface area of the zone in question is attained (see Figure 6).

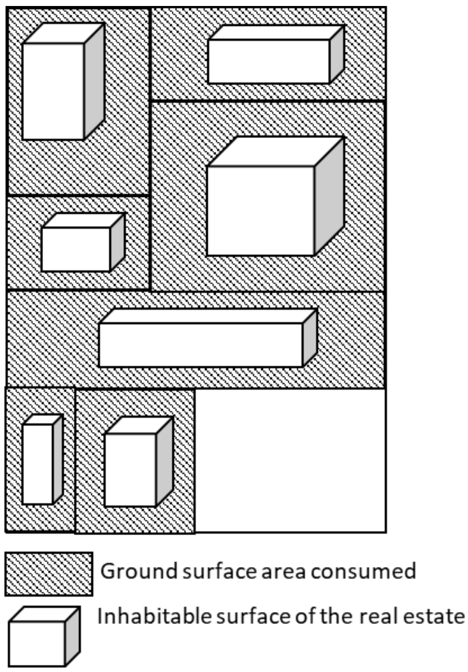


Figure 6: Process for occupation of buildable land stock

### *3.4.4 Mechanism of endogenous accessibility*

Households and premises interact via the accessibility variable (see Figure 1). Indeed, household accessibility must take into account not only transport supply but also the location of workplaces (employment opportunities) on the one hand, and on the other hand, the accessibility of workplaces must take into account transport supply and household location (labor force). There is then feedback between the two types of agents in the system (Figure 7).

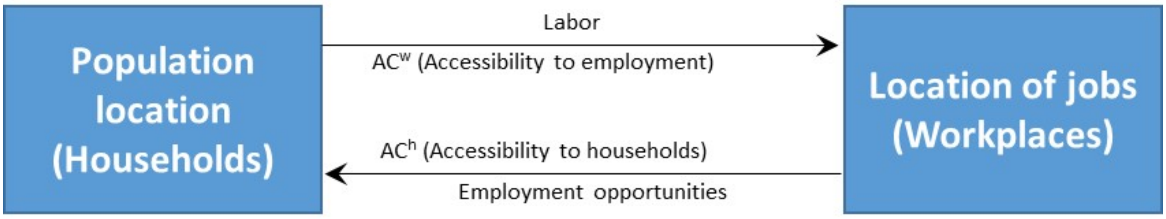


Figure 7: Interactions between households and workplaces

The accessibility of a zone consists of two components: an exogenous component that reflects the performance of the transport network (speed and capacity) serving the zone in question and an endogenous component that reflects the spatial distribution of the population and jobs which evolve during the simulation.

At this stage of development of MUST-B, two simplifying hypotheses are made on how to take accessibility into account:

- The accessibility of households is reduced solely to access to jobs, while there are other dimensions such as access to services, equipment, shops, schools, etc.... These elements, which are present in the utility function of households, do not contribute to the calculation of endogenous accessibility.
- It is assumed that accessibility linked to the performance of transport networks is completely exogenous, whereas part of this component could be endogenized by taking transport network congestion resulting from the attractiveness of certain zones at certain times into account during the simulation.

The determination of accessibility for both types of agents (households and workplaces) is based on the following approach:

- Determination of the matrix of generalized costs of interzone travel for PV (Private Vehicle) and PT (Public Transport) modes of travel
- Determination of accessibility vectors for PV and PT modes of transport
- Aggregation of all modes into a single accessibility vector

*Generalized cost of travel*

The generalized cost of travelling by private vehicle (PV) between zones i and j is expressed as follows:

$$C_{ij}^{PV} = V_t * tt_{ij}^{PV} + (CF + CK) * d_{ij}^{PV} + C_j^{Park} \qquad (13)$$

Wherein:

$V_t$: Value of time (€/h)

$tt_{ij}^{PV}$: Travel time via PV between zones i and j (h)

$d_{ij}^{PV}$: Distance covered in PV between zones i and j (km)

$CF$: Cost per kilometer of fuel (€/km)

$CK$ : Cost per kilometer of vehicle use excluding fuel (€/km)

$C_j^{Park}$: Cost of parking in zone j (€)

The generalized cost using public transport (PT) between zones i and j is expressed as:

$$C_{ij}^{PT} = V_t * tt_{ij}^{PT} + T^{PT} + \eta * C_{ij}^{MC} \qquad (14)$$

Wherein:

$tt_{ij}^{PT}$: Journey time on public transport between zones i and j (h)

$T^{PT}$: Tarif per trip on public transport

$N_{ij}^{MC}$ : Number of mode changes during the trip

$\eta$ : Parameter to be estimated

*AccessibilCity per mode of transport*

The accessibility provided for household *h* in zone i at iteration n, composed of an exogenous part (first term of the equation) and an endogenous part (second term of the equation), is expressed as:

$$AC_{i,n}^{h,PV} = \theta \sum_j e^{-C_{ij}^{PV}} + \mu \sum_j \sum_k \frac{s^k w_{j,n-1}^k}{\left(C_{ij}^{PV}\right)^2} \qquad (15)$$

$$AC_{i,n}^{h,PT} = \theta \sum_j e^{-C_{ij}^{PT}} + \mu \sum_j \sum_k \frac{s^k w_{j,n-1}^k}{\left(C_{ij}^{PT}\right)^2} \qquad (16)$$

The accessibility provided for workplaces *w* in zone i at iteration n, composed of an exogenous and an endogenous part, is expressed as:

$$AC_{i,n}^{w,PV} = \theta' \sum_j e^{-C_{ij}^{PV}} + \mu' \sum_j \sum_k \frac{s^l h_{j,n-1}^l}{\left(C_{ij}^{PV}\right)^2} \qquad (17)$$

$$AC_{i,n}^{w,PT} = \theta' \sum_j e^{-C_{ij}^{PT}} + \mu' \sum_j \sum_k \frac{s^l h_{j,n-1}^l}{\left(C_{ij}^{PT}\right)^2} \qquad (18)$$

Wherein:

$s^l$ : Size of household (number of people)

$h_{i,n-1}^l$ : Number of $t^l$ sized households in zone i at iteration n-1

$t^k$ : Size of the workplace (number of jobs)

$w_{j,n-1}^k$: Number of workplaces of $t^k$ size in zone j at iteration n-1

$\theta$, $\theta'$, $\mu$ and $\mu'$: Factors to estimate

*Aggregated accessibility*

In order to estimate the all-mode accessibility of a given zone, the accessibility of each mode is weighted by its modal share (MS) according to the following expressions:

$$AC_{i,n+1}^{h} = PM_{i,n}^{PV} * AC_{i,n}^{h,PV} + PM_{i,n}^{PT} * AC_{i,n}^{h,PT} \qquad (19)$$

$$AC_{i,n+1}^{w} = PM_{i,n}^{PV} * AC_{i,n}^{w,PV} + PM_{i,n}^{PT} * AC_{i,n}^{w,PT} \qquad (20)$$

Modal shares are estimated during the simulation using a sequential approach: generation, distribution and modal choice. The generation and distribution steps are based on a gravity model and the location of households and workplaces. The modal choice step is based on a logit model and the generalized costs of the 2 competing modes (PV and PT).

# 4 Implementing MUST-B in the Bordeaux Urban Area

In order to illustrate the functioning of MUST-B and check the availability and processing of the necessary data, it was applied to the Bordeaux Urban Area (AUB)

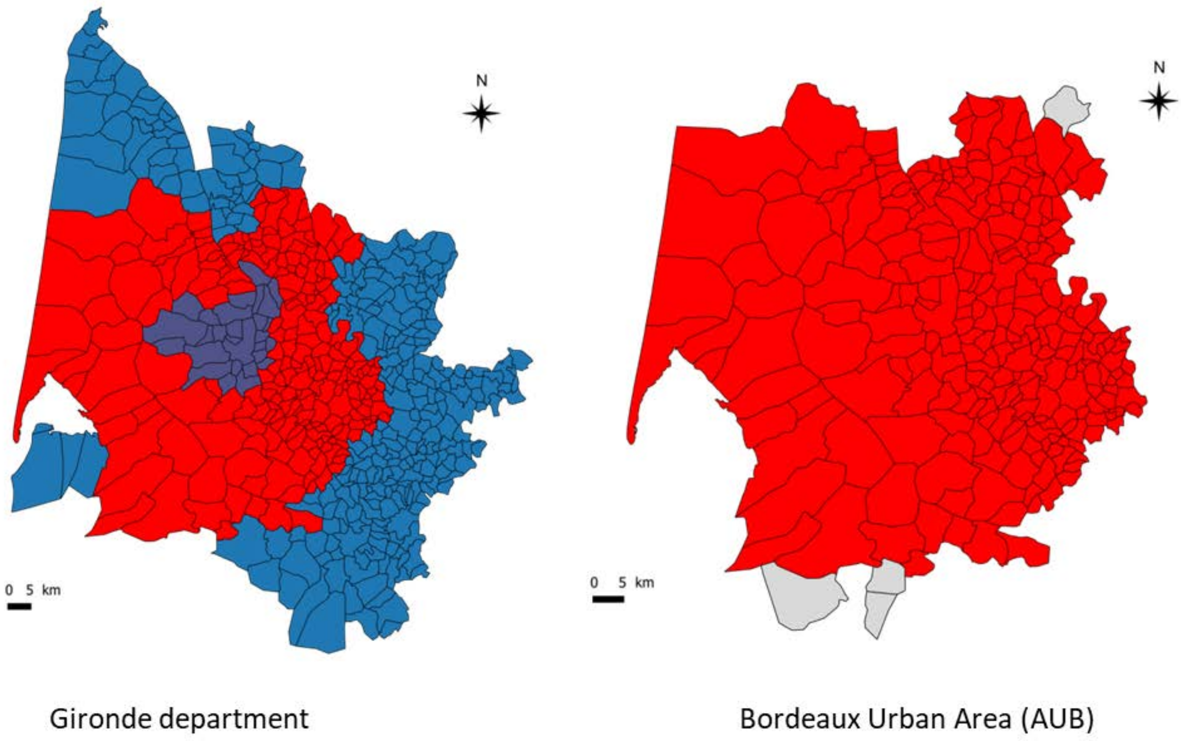


Figure 8: Implementation Territory

The AUB (Bordeaux Urban Area) region lies over a large part of French Department la Gironde and in 2012 (Figure 8) counted 1,158,431 inhabitants (523,310 households) and 467,211 jobs (34,676 workplaces).

## *4.1 Division of the territory into zones*

Using IRIS[2] geographical information, the AUB is divided into 42 zones according to a minimal threshold of population and jobs per zone and geographical constraints which constitute delineations (waterways, railways, motorways, ring roads…).

42 zones are derived, as illustrated in Figure 9, as follows:

- 14 zones for the Bordeaux municipality
- 2 zones for the Mérignac municipality
- 2 zones for the Pessac municipality
- Each municipality sharing a border with Bordeaux is deemed to be a zone
- The remaining zones are obtained by grouping several adjacent municipalities.

[2] IRIS is information regarding infra-communal divisions adopted by INSEE which demonstrates the partition of community regions into zones comprising populations of approximately 2 000 inhabitants.

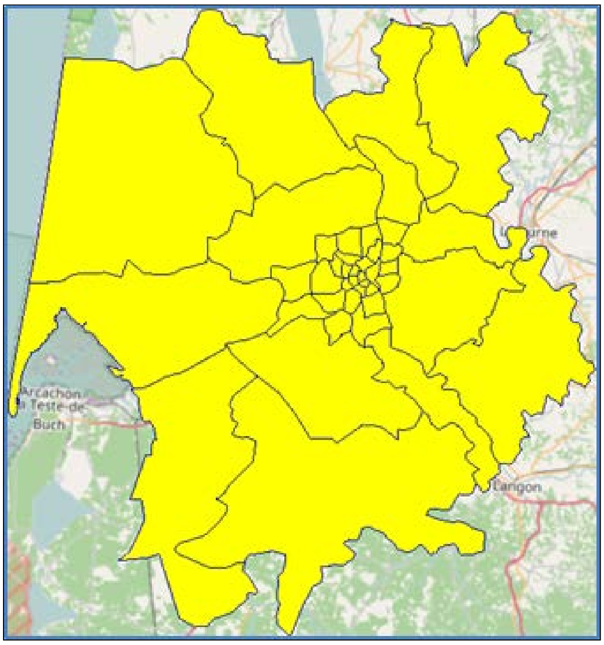


Figure 9: Division of AUB territory into zones

## 4.2 Population and employment

The population is considered in terms of households, the sizes of which vary between 1 to 5 + people. 2 types of households are also considered according to the socio-professional category (SPC): SPC- (modest low-income households) and SPC+ (high-income households).

Using INSEE (2012) data, Table 1 presents AUB households according to 10 categories (5 sizes X 2 SPC).

| 1 person | | 2 people | | 3 people | | 4 people | | 5 people & + | |
|---|---|---|---|---|---|---|---|---|---|
| SPC+ | SPC- | SPC+ | SPC- | SPC+ | SPC- | SPC+ | SPC- | SPC+ | SPC- |
| 95 856 | 95 257 | 88 704 | 81 275 | 43 309 | 33 415 | 36 784 | 24 817 | 13 693 | 10 201 |

Table 1: Number and categories of households in the AUB (source: INSEE 2012 data)

Jobs are considered in terms of workplaces by distinguishing 8 sizes: 3, 7, 15, 35, 75, 150, 350 and 750 employees. 4 types of business activities are also considered: Offices, Services, Factories and Agriculture/Warehouses.

Cross-referencing of the 8 sizes and 4 types of activities provides 32 categories of workplaces as presented in Table 2.

| Offices | | | | | | | | Services | | | | | | | | Factories | | | | | | | | Agriculture/Warehouses | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 |
| 3 | 7 | 15 | 35 | 75 | 150 | 350 | 750 | 3 | 7 | 15 | 35 | 75 | 150 | 350 | 750 | 3 | 7 | 15 | 35 | 75 | 150 | 350 | 750 | 3 | 7 | 15 | 35 | 75 | 150 | 350 | 750 |
| 7434 | 2145 | 1576 | 1065 | 455 | 206 | 104 | 47 | 8412 | 2531 | 1126 | 621 | 157 | 51 | 22 | 2 | 1051 | 502 | 348 | 214 | 73 | 35 | 17 | 12 | 4095 | 1121 | 590 | 418 | 163 | 54 | 13 | 3 |

Table 2: Categories and sizes of workplaces in the AUB (source: INSEE 2012 data)

## 4.3 Housing stock

Table 3 presents the private and social housing stock in the AUB, according to the number of rooms per unit. It is important to note that only main residences have been considered, i.e. the number of accommodation types is equal to the number of households.

| | 1 room | 2 rooms | 3 rooms | 4 rooms | 5 rooms & + |
|---|---|---|---|---|---|
| Private housing stock | 36 232 | 59 831 | 85 322 | 116 882 | 156 017 |
| Social housing stock | 4 241 | 9 460 | 17 824 | 18 921 | 17 222 |

Table 3: Main residences in the AUB (source: INSEE 2012 data)

AUB's stock of business premises is described in Table 4 according to number of jobs. For example, there are 3640 workplaces of size S3 on the AUB (15 jobs).

| S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 |
|---|---|---|---|---|---|---|---|
| *3* | *7* | *15* | *35* | *75* | *150* | *350* | *750* |
| 20 992 | 6 299 | 3 640 | 2 318 | 848 | 346 | 156 | 64 |

Table 4: Business premises in the AUB (source: reconstructed data)

The model does not take into account the notion of vacant space, whether housing or business premises. All land stocks are assumed to be occupied: this is indeed a hypothesis of the model, that assumes each household is a home and each workplace has a business activity space.

## 4.4 Other data

### 4.4.1 Household energy bill

The energy costs associated with the building used as a utility function of households is estimated according to unit consumption (€/yr.m²), which is determined according to the age of the building and the energy label (Energy Performance Diagnosis, EPD). The EPD indicates the energy efficiency of a home or building, by assessing its energy consumption and its impact in terms of GHG emissions.

The Energy Diagnosis comprises 7 categories of energy performances, presented in Figure 10.


| Median per classification | |
|---|---|
| A | 25 |
| B | 70 |
| C | 120 |
| D | 190 |
| E | 280 |
| F | 390 |
| G | 500 |

Figure 10: Classification of the energy performance of residential buildings (kWh/m².yr)

Table 5 presents the distribution by label according to the age of the building. This distribution is based on assumptions made by experts, which take into account the age of the building, thermal standards, urban renewal and the thermal insulation of the building stock. For example, it is assumed that 50% of buildings built before 1945 are very energy-intensive, while the other 50% is considered more efficient, having been renovated.

| | | |
|---|---|---|
| Before 1945 | B | 50% |
| | G | 50% |
| 1946-1990 | C | 70% |
| | F | 30% |
| 1991-2009 | B | 60% |
| | E | 40% |
| 2010-2012 | B | 70% |
| | D | 30% |

Table 5: Energy labelling according to the age of the building

Finally, we can deduce the unit consumption according to the year of construction of the building. This annual consumption per m² presented in Table 6 is expressed in kWh and in euros assuming an average energy price of €0.14 per kWh.

| | **kWh/m².year** | **€/m².year** |
|---|---|---|
| Before 1945 | 285 | 40.5 |
| 1946-1990 | 201 | 28.5 |
| 1991-2009 | 154 | 21.9 |
| 2010-2012 | 106 | 15.1 |

Table 6: Unit consumption according to the year of construction

The average annual energy bill (€/m²) can be determined for the zone under consideration according to the structure of the residential stock in each zone (age of the building and surface area of the property).

### 4.4.2 Notoriety

The notoriety used in the utility function for households conveys the image and standing of a given zone, which can be qualified according to various urban amenities such as green spaces, the ambiance, the style, and the specificity and diversity of businesses which are present in the zone under consideration. Notoriety is estimated from the INSEE Permanent Facilities Database which provides the level of equipment and services provided to the population in a given region.

The geographically positioned equipment of the Permanent Facilities Database is weighted according to the interest they may represent. As such, for example, a cinema room has a coefficient of 4, a bakery has a coefficient of 3, etc. From the weightings attributed to the equipment and their geographical locations, a notoriety value was derived for each zone of the AUB. In order to take into account the size of the zones, an index of notoriety was calculated by dividing the value by the surface area of the zone.

# 5 MUST-B: indicators of the complexity of the urban phenomenon

The simulation of a governmental policy can be undertaken using several indicators which are determined in the MUST-B model.

## 5.1 Indicators linked to urban planning

Occupation of the space following a simulation is characterized by defining the following for each zone:

- Number of accommodations / households / population
- number of workplaces / jobs
- social diversity and segregation
- functional diversity
- price of residential property
- price of land property for business activities
- price of land property

These indicators are output data calculated directly in the MUST-B model.

## 5.2 Sustainability indicators

Following a simulation, the effects of an urban policy on sustainable development are estimated according to a definition for each zone in terms of:

- energy consumption (home-work mobility, accommodation)
- GHG emissions (home-work mobility, accommodation)
- Artificialization of the land (built land / total surface of the zone ratio)

This last indicator can be directly calculated, whereas the two former indicators require prior calculations such as the number of kilometers in question or the surface areas of the accommodation occupied according to the degree of emission and energy consumption.

# 6 Conclusion

The aim of the MUST-B model is to simulate the choice of location of households and economic activities. It is based on an auction mechanism which enables us to model the competition between agents (households and workplaces) according to different timeframes, the competition between agents (households and workplaces) on the real estate market (existing property holdings: residential, tertiary and industrial) and on the land property market (reserves of buildable land stock).

The multidisciplinary approach to the design and development of MUST-B is a unique and defining characteristic wherein the collaboration of multidisciplinary researchers (from the fields of business, urban planning, geography, transport, computer science, …) meant that the specificities of the different disciplines could be considered in combination with the urban phenomenon and the multi-agent simulation enabled us to model the complexity of the city system from individual behaviors.

Today, MUST-B is an operational tool to support decision-making for urban development planning, integrating the effects of the different sectors of the city (mobility, accommodation, economic activities…) on the climate and atmospheric pollution. Indeed, MUST-B is designed to assist decision-making (helping to define and develop government policies) to guide the “trajectory” of a region towards increased “sustainability”.

Simulation using MUST-B therefore enables us to assess certain effects of urban policies and actions which communities can undertake, as well as assisting them in prioritizing these actions according to their financial resources and objectives, and to articulate them in coherent local policies in favor of ecological transition. MUST-B can thus significantly contribute in identifying the conditions and levers for action which help to locate a sustainable area.

**Acknowledgements**

The authors would like to thank all of the researchers involved in the MUST-B project for their remarks and observations throughout the discussions which took place: Anne Bretagnolle from Géographie-cités (Paris 1 University / Paris 7 University / CNRS), Sonia Guelton from Lab’Urba (Paris-Est University), Moez Kilani from LEM (University of Lille / CNRS), Nicolas Coulombel from LVMT (Paris-Est University), Laurent Guimas from Explain Consultancy and Ouassim Manout from ForCity.

We also thank Région Nouvelle Aquitaine for their co-financing of the STRATEGIE project, and the MSHA for the financial management of the project and use of their premises.

## References

BOUANAN, Y. ; ZERGUINI, S. ; GAUSSIER, N. (2018), Agent-Based Modeling of urban Land-Use Development: Modelling and Simulating Households and Economic activities location choice, International Journal of Service and Computing Oriented Manufacturing (IJSCOM), Vol. 3, No. 4.

BOUANAN, Y. ; ZERGUINI, S. ; GAUSSIER, N. (2017), Modeling households and firms location choice using agent-based models: application to the urban area of Bordeaux, Winter Simulation Conference, 3-6 décembre, Las Vegas, USA, 12 p.

BONNEL P., (2001), Prévision de la demande de transport, Rapport HDR, Université Lumière Lyon 2, 409p.

CAMBIEN A., (2011), La modélisation urbaine: une approche historique, in: Modéliser la ville – Formes urbaines et politiques de transports, Economica, Paris, p. 19-49.

CROZET Y., JOLY I., (2004), Budgets temps de transport: les sociétés tertiaires confrontées à la gestion paradoxale du "bien le plus rare", les Cahiers Scientifiques du Transport, n°45, p. 27-48.

LEMOY R., RAUX C., JENSEN P., (2011), ILOT: un modèle multi-agents de structuration sociale de la ville, in: Modéliser la ville – Formes urbaines et politiques de transports, Economica, Paris, p. 333-364.

NEWMAN P.W.G., KENWORTHY J.R., (1998), Overcoming Automobile Dependence, Island Press, Washington D.C.

OLLIVIER G., GENIAUX G., NAPOLEONE C., PAOLI J-P., (2012), Mesurer la notoriété touristique communale: contribution méthodologique à l'aide de l'analyse textuelle de guides touristiques, Cybergeo: European Journal of Geography, http://cybergeo.revues.org/25187; DOI: 10.4000/cybergeo.25187 (page consultée le 10/06/16).

ORFEUIL J.P. (2000), La mobilité locale: toujours plus loin et plus vite, in : BONNET M. ET DESJEUX D., Les territoires de la mobilité, Paris, PUF.

QUESNEL G., DUBOZ R., RAMAT É., (2009), The Virtual Laboratory Environment–An operational framework for multi-modeling, simulation and analysis of complex dynamical systems. SIMULATION MODELING PRACTICE AND THEORY 17(4): 641-653.

WEGENER M. (2004), Overview of land use transport models, in: Handbook of transport geography and spatial systems, Emerald Group Publishing Limited, p. 127-146.

VILMIN T. (2015), L'aménagement urbain. Acteurs et système, Editions Parenthèses, Marseille, 141 p.

ZEIGLER B. P., PRAEHOFER H., KIM T. G., (2000), Theory of modeling and simulation: integrating discrete event and continuous complex dynamic systems, ACADEMIC PRESS.

ZERGUINI, S.; GAUSSIER, N. (2019), "MUST-B an Agent-based Model of Urban Land-use Development: Simulating Households' and Firms' Location Choices in Urban Area of Bordeaux", 45th Annual Conference - Eastern Economic Association, Feb. 28 – Mar. 3, 2019, New York, USA.

ZERGUINI, S.; GAUSSIER, N. (2019), "Dépenses énergétiques contraintes et localisation résidentielle: Le cas de l'aire urbaine de Bordeaux", 2emes Rencontres Francophones Transport Mobilité – RFTM 2019, 11-13 juin 2019, Montreal, Canada.

ZERGUINI S., GAUSSIER N., (2016), De nouveaux enjeux pour les modèles LUTI: L'exemple du modèle MUST-B et son application sur l'agglomération bordelaise, in: 53ème colloque ASRDLF, 7-9 juillet, Gatineau, Canada, 23 p.

ZERGUINI S., LATERRASSE J., LE NECHET F., AULAGNIER S., HEYDER M., PETER M., (2012), PROSPEG: modèle de Prévision de l'Occupation du Sol pour la Prospective Energétique et les émissions des GES à l'échelle de l'agglomération, in: 11ème séminaire francophone est-ouest de socio-économie des transports, 23-27 mai, Karlsruhe, 15 p.

# *Cahiers du GREThA*
# *Working papers of GREThA*

---

**GREThA UMR CNRS 5113**

Université de Bordeaux

Avenue Léon Duguit
33608 PESSAC - FRANCE
Tel : +33 (0)5.56.84.25.75
Fax : +33 (0)5.56.84.86.47

**http://gretha.u-bordeaux.fr/**

---

## Cahiers du GREThA (derniers numéros – last issues)

*2019-03 : USECHE Diego, MIGUELEZ Ernest, LISSONI : Highly skilled and well connected: Migrant inventors in Cross-Border M&As*

*2019-04: BROUILLAT Eric, SAINT JEAN Maïder : Dura lex sed lex: Why implementation gaps in environmental policy matter?*

*2019-05: CARAYOL Nicolas, LAHATTE Agenor, LLOPIS Oscar : The Right Job and the Job Right: Novelty, Impact and Journal Stratification in Science*

*2019-06: BONIN Hubert : Luxury relying on banking and finance (19th-21st centuries)*

*2019-07: MAUBLANC François, ROUILLON Sébastien : Contests with an uncertain number of prizes*

*2019-08: RANDRIAMIANDRISOA Jossie, BALLET Jérôme : Solidarités à l'égard des ménages défavorisés à Madagascar. Le cas des ménages dirigés par des femmes*

*2019-09: SAINT-JEAN Maïder, ARFAOUI Nabila, BROUILLAT Eric, VIRAPIN David : Mapping technological knowledge patterns: evidence from ocean energy technologies*

*2019-10: ROUILLON Sébastien : A physico-economic model of space debris management*

*2019-11: GONDARD-DELCROIX Claire, RANDRIAMANAMPISOA Holimalala, A. LAZAMANANA Pierre, ANDRIANJAKATINA Aina: Diversity of social protection forms in Madagascar. A multi-scalar and multi-actor approach*

*2019-12: FRIGANT Vincent: L'industrie 4.0, vers une dé-globalisation des chaines de valeur ? Effets attendus de la robotique industrielle avancée et de la fabrication additive sur le système de coordination*

---

*La coordination scientifique des Cahiers du GREThA est assurée par Ernest MIGUELEZ.*
*La mise en page et la diffusion sont assurées par Julie VISSAGUET*