ALMA MATER STUDIORUM - UNIVERSITÀ DI BOLOGNA

SCUOLA DI INGEGNERIA E ARCHITETTURA

DICAM

Dipartimento di Ingegneria Civile, Chimica, Ambientale e dei Materiali

CORSO DI LAUREA IN INGEGNERIA CIVILE

TESI DI LAUREA

In
Pianificazione dei trasporti M

Micro-simulation models at neighbourhood scale: the interplay of agents, buildings, activities and transport.

CANDIDATA
Viola Poidomani

RELATORE:
Chiar.mo Prof. Luca Mantecchini

CORRELATORI
Chiar.mo Prof. Fabien Leurent
Chiar.ma Prof.ssa Nadia Postorino
Natalia Kotenokova

Anno Accademico 2012/13

Sessione I

A Adriano e Irene,
pour la merveille
de leurs regards émerveillés.

INDEX

ABSTRACT

Urban systems consist of several interlinked sub-systems - social, economic, institutional and environmental – each representing a complex system of its own and affecting all the others at various structural and functional levels.

An urban system is represented by a number of “human” agents, such as individuals and households, and “non-human” agents, such as buildings, establishments, transports, vehicles and infrastructures. These two categories of agents interact among them and simultaneously produce impact on the system they interact with.

Try to understand the type of interactions, their spatial and temporal localisation to allow a very detailed simulation trough models, turn out to be a great effort and is the topic this research deals with.

An analysis of urban system complexity is here presented and a state of the art review about the field of urban models is provided.

Finally, six international models - MATSim, MobiSim, ANTONIN, TRANSIMS, UrbanSim, ILUTE - are illustrated and then compared.

Key words: Urban system interactions, Micro-simulation, Neighbourhood scale, Population, Activities.

SOMMARIO

I sistemi urbani sono costituiti da un insieme di sotto-sistemi – sociale, economico, istituzionale e ambientale – tra loro interconnessi. Ognuno di questi è caratterizzato da una propria complessità e influenza gli altri a diversi livelli, strutturali e funzionali.
Nel sistema urbano inoltre si possono distinguere gli agenti "umani", come gli individui e le famiglie, e quelli "non-umani", come gli edifici, le imprese, i sistemi di trasporto, i veicoli e le infrastrutture. Queste due categorie interagiscono continuamente tra di loro, generando degli impatti nel sistema in cui intervengono.

Il presente lavoro si propone di cercare di comprendere la tipologia di queste interazioni e la loro localizzazione spaziale e temporale nel sistema urbano, tematica all'oggi molto attuale nell'ambito degli studi dei modelli di micro simulazione, per poter condurre una simulazione dettagliata attraverso l'impiego di modelli.

A tale scopo, nella prima parte dello studio viene inizialmente presentata la complessità del sistema urbano; in un secondo momento si offre un panorama dello stato dell'arte dei modelli di simulazione, sia per quanto riguarda i trasporti sia per gli edifici.
Nella seconda parte vengono invece illustrate le caratteristiche di sei modelli internazionali - MATSim, MobiSim, ANTONIN, TRANSIMS, UrbanSim, ILUTE - che saranno infine confrontati tra loro.

Parole chiave: Interazioni nel sistema urbano, Micro-simulazione, Quartiere, Popolazione, Attività.

BRIEF DICTIONARY

English / Français / Italiano

Household / Menage / Famiglia

Building / Bâtiment / Edificio

Enterprise, Firm, Company / Entreprise / Azienda

Agent / Agent / Agente

Displacement, Trip, Journey / Deplacement / Spostamento

Equipment, Infrastructure / Reseaux de transport, Infrastructure / infrastruttura

Standard / Critère / Criterio

Housing, Dwelling / Logement / Abitazione

Establishment / Etablissement / Impresa

Purpose, Motif, Reason / Motif / Motivo

Vehicle fleet / Parc vehicule / Parco veicolare

Housing fleet / Parc logement / Parco immobiliare

Supply / Offer / Offerta

Demand / Demand / Domanda

Activity / Activité / Attività

INTRODUCTION

The present study is drafted in the eco-design framework. Nowadays, eco-conceiving "objects" is more and more becoming a need and it actually represents a new approach to the fields of development and transport.

Some examples for the sector of development are the eco-neighbourhood, sustainable neighbourhood, cities without carbon, sustainable development, sustainable infrastructures management and sustainable green spaces management.

On the other hand, in the field of transport, there are the soft modes of transport, eco-respectful modes, eco-mobility, sustainable mobility and electrical mobility.

A definition of "Eco-design" comes from the law ISO 2002: "integrating environment in all development phases (and as early as possible) of a product (as well as other criteria: quality / cost / time, safety, health, etc.)".

Generalizing the definition, the eco-design consists of taking into consideration the environmental aspects during the conception phase.

The system of reference of this research for the eco-design is the urban one. The responsibility to conceive or plan an urban system belongs to the urban planner or city planner that is a professional who works in the field of urban planning/land use planning for the purpose of optimizing the effectiveness of a community's land use and infrastructure. They formulate plans for the development and management of urban and suburban areas, typically analyzing land use compatibility as well as economic, environmental and social trends. In developing their plan for a community (whether commercial, residential, agricultural, natural or recreational), urban planners must also consider a wide array of issues such as sustainability, air pollution, traffic congestion, crime, land values, legislation and zoning codes. Therefore, an urban planner could be considered as a green collar profession.

The importance of the urban planner is increasing throughout the 21st century, as we begin to face issues of increased population growth, climate change and unsustainable development. The planner role consists in develop places "where people can live and work well, with minimal environment impact, by utilizing local water, food and energy resources" and he tries to create "a transverse relation between logic used in different sectors to produce a space in which people want to live, rather than simply a developed space with all necessities".

When experimenting with urban systems, a first difficulty is to define precisely which are the objects under study, or in other words, to identify clearly the content and limits of each level of organization.

Indeed, the complexity of urban systems comes from the further objects that form it. The main objects that at the same time constitute and influence the urban system are:

1. Infrastructures and amenities;
2. Transport: private and public;
3. Protocols: traffic management, service organization, planning and programming, vehicle control, vehicle guidance;
4. Agents: individual, household, population;
5. Agents habit: eco-citizen, eco-journeys, modes, time, localization;
6. Buildings, housing, enterprise, establishment;
7. Activities and displacements;
8. Impacts: pollutants, noise, energy consumption, resources consumption;
9. Land use;
10. Territory: area of action, interaction with external area;
11. Freight.

Among the objects above quoted, strong interactions clearly exists. Furthermore, most of them evolve in time and the planner could modify and work on them to achieve the purpose to arrange an area where the agents can find advantageous life and activities conditions.

It is now clear that the urban system is an open system and its objects interactions are very complex processes that unfold into the area and they cannot be dealt with separately. For this reason, the difficulty for the planner is to well understand "his barriers to action".

The planner cannot avoid the existence of synergies between environmental, social, and economic objectives.

This leads to an integrated approach in conceiving urban systems without forgetting the environmental dimension of the urban system.

Definitively, the planner has to deal with topics such as:

1. *How the urban system will develop?*
2. *In which way it is possible to renovate for example a neighbourhood?*
3. *Which measures could be taken?*
4. *Do some measures have to be stopped or modified?*

To better understand the way the planner can operate some examples are produced:

- The insertion of a pay zone for private vehicle could be translated into accessibility loss but at the same time an incentive to use public transport such as an enhancement of fuel price or a fuel tax;

- The introduction of pricing policies is a way to reduce emission of pollutants too. There are numerous pricing options available such as peak/off-peak differentials, discounted prices for certain areas or part of the network, premium price for higher quality services, congestion charges, discounted energy and water price for certain time slot, etc;
- Non-residential car parking spaces can be separated into on street locations and off street locations;
- Parking pricing differentiated for location, type of parking, length of stay, use (residential/office/shops);
- Influence car use and congestion trough the introduction of workplace parking levies, stricter planning controls, constraining parking supply, increasing the cost of parking via influencing off street parking, increasing park and ride provision;
- Incentivize greater use of double yellow lines and red routes to eliminate parking and improve traffic flow;
- Provide attractive, promotional fares at off peak times such as the early morning, inter-peak, evening and week end to reduce passenger crowding and pre pay rebates for season ticket holders;
- Make services easier to operate and more reliable concerning public transport;
- Provide a ticketing system simple to customers and operators to understand and use, cost effective and flexible, comprehensive and integrated in the way that facilitate interchange and maximize users' choice;
- Increase density of coverage and frequencies for public transport;
- Provide information and marketing, travel awareness campaigns;
- Increase the use of rail and water fir shifting freight traffic off the road;
- Review of parking/loading regulations;
- Provide real time information;
- Incentivize a sustainable use of energy, a reducing carbon emissions, as well as attractive urban design and access to green space;
- Improving facilities for walking and cycling will provide a sustainable alternative, particularly for short journeys;
- Embedding integration at all levels such as regional, sub regional, area and site level;
- Integrate development with transport;

- Provide news links to housing developments by public transport;
- Provide a better layout of bus stops and links to trains and underground;
- Provide wider pavements and better crossing facilities;
- Introduce bus priority, road closure, width restrictions, parking charges or levies;
- Choice of materials not affecting and renewable for renewal and reducing the amount of materials used (dematerialisation);
- Measures to reduce consumption of natural resources;
- All buildings should provide their inhabitants with a clear sense of location, weather and time. Natural methods of heating and cooling can be more resource-efficient than mechanical systems.
- Complement and support the relationships between the institutions;

These are some of the soft and hard measures that the planner could adopt.

The difficulty of the planner in acting in urban system highlight the need to watch urban system under a different point of view meant as taking into consideration the interactions among the actors of the system.

To achieve and solve these sets of problems, here, a review of existent methods of simulation is provided and a new approach is introduced.

The first chapter deals with an introduction to the study system in which are defined the notion of eco-neighbourhood, land-use, scales and interactions and a description of the objects that “act” in the urban system is provided. The entirety of the urban system complexity is illustrated trough a flow diagram.

Switch to the second chapter, it supplies a panorama of the further existent simulation approach for transport and buildings.

The third and fourth chapters represent the core of the research. The first focuses on the procedure implemented to identify which objects are taken into consideration in the study models. The method to realize the table that collects the characteristics of the models is illustrated. The second one polarizes on the description of the chosen models such as MATSim, MobiSim, TRANSIMS, UrbanSim, ILUTE, ANTONIN.

The document ends with a fifth chapter dedicated to the comparison of the study models trough a comparison table and provide a guideline to lead an “ideal representation” of the urban system complexity.

Bibliography

LEURENT Fabien, 2005/2006. *Enjeux, échelles et fonctions de l'aménagement.* ENPC, LVMT, Paris, France.

Mayor of London and Transport for London, 2006. *Transport 2025, transport challenges for a growing city.*

BERKE Philip R., 2002. *Does sustainable development offer a new direction for planning? Challenges for the Twenty-First Century*. Journal of Planning Literature, Vol. 17, No. 1, August.

SEYMOAR Nola-Kate, MULLARD Zoe, WINSTANLEY Marena, 2009. *City to city learning.* Plus Network, partners for long term sustainability, Vancouver, Canada.

CHAPTER 1:
The study system

1.1. Introduction

Urban ecological systems are characterized by complex interactions among social, economic, institutional, and environmental variables. These interactions generate complex human-dominated landscapes, which significantly influence the functioning of local and global earth ecosystems and the services they provide to humans and other life on earth. Urban development fragments, isolates, and degrades natural habitats; simplifies and homogenizes species composition; disrupts hydrological systems; and modifies energy flow and nutrient cycling. Urban areas also appropriate a large share of earth's carrying capacity from other regions in terms of resource input and waste sinks. Change in ecological conditions that result from human actions in urban areas ultimately affect human health and well-being. Urban development affects the spatial heterogeneity of the landscape (i.e., pattern of variation in land cover) and spread of disturbance (i.e., invasive species).

In this chapter, the complexity of urban systems is expounded. First of all, the context of the analysis is defined; secondly, the use and the interactions that characterised the system are illustrated together with the different scales of analysis. Moreover, a list and description of the urban actors, meant as the objects that exist and interact in it, is provided. Finally, the proposal of the paper is illustrated. The chapter is supplied with a diagram to better understand the overall urban system and its complexity.

1.2. Context and study area

The territory, that represents the largest frame of action, is made up of various "organs" characterised by morphology (organs configuration) and metabolism (organs interaction).

At the same time, each territory is a "unique exemplar" but it is possible to find regularities in shapes, organs type, organs interaction and systems.

Different types of urban systems are localized in the territory and they could be viewed under a physical approach that describes the space through a materials composition point of view, and a geographical approach that is a functional perspective.

It should be noted that a territory is also characterized by a bio-diversity that is the degree of variation of life forms within a given species, ecosystem and biome, and by a geo-diversity that identifies the various urban functions (housing, production, services, leisure, etc.) matched to the considered spatial unit.

In greater detail, neighbourhood is a smaller scale approach in urban system.

Try to give a definition to the notion neighbourhood it is worth to refer to different ones such as:

1. Georges Perez in Espèces d'espace, Paris 1974, Minuit Edition: "Le quartier est une portion de ville dans laquelle on se déplace à pied, ou pour dire la même chose sous la forme d'une lapalissade, une partie de la ville dans laquelle on n'a pas besoin de se rendre, puisqu'on y est."
   "The neighbourhood is a portion of the city where it is possible to make displacements on foot or the part of the city where it is not necessary to go because people are already there."
2. From the "Les cahiers de l'observatoire de la ville n.2, 2007, Les quartiers durables: nouvel enjeu de la ville de demain?": "Fraction du territoire d'une ville, dotée d'une physionomie propre et caractérisée par des traits distinctifs lui conférant une certaine unité et une individualité ; (…) le plus souvent, le quartier est indépendant de toute limite administrative."
   "Part of the city territory, provided with own aspects and characterised by distinguishing features that make it singular; (…) the neighbourhood is often independent from the administrative boundaries."

It is now clear that researchers have not agreed in a common definition for neighbourhood since it is a system that could be considered under various points of view. Here below a not full-scale list of distinction factors meant as boundary criteria is provided:

1. Statistic: the neighbourhood notion is defined as a group of more adjacent areas within a city, town, suburb or rural area. The size of the neighbourhood is really variable and it follows population standards;
2. Population: neighbourhoods are often social communities with considerable face-to-face interaction among members. They could be split up in function of the nationalitiy, religion, economic characteristics of its inhabitants such as the Chinese neighbourhood, Muslim neighbourhood, Latin neighbourhood, Jewish neighbourhood, African neighbourhood, Bourgeois neighbourhood, etc;
3. Architectural and Historical: neighbourhood are generally characterised by a recurring architectural motif and buildings and the structure of the district dates back to

historical period and sometimes it revokes historical events such as Haussman neighbourhood, Middle Age neighbourhood, Modern neighbourhood, Ancient neighbourhood, Baroque neighbourhood, etc;

4. Functional: neighbourhood identification could also be tied to the main activity located in it such as business district, military neighbourhood, university neighbourhood, leisure neighbourhood, residential neighbourhood, etc;
5. Symbolic: a distinctive element such as a monument, a building, etc, that usually represents an attractive pole could be the symbol that recalls a district such as Science neighbourhood, Operà neighbourhood, Stadium neighbourhood, etc;
6. Topographical and geographical: neighbourhood could be recognised according to its land characteristics such as Left/right riverside neighbourhood, low-rise/high neighbourhood, etc.
7. Impacts: neighbourhoods generally provoke different kind of impacts and these could represent a marking of the district such as eco-neighbourhood, industrial district, etc.

Given that this paper is contextualized in the eco-conceiving topic, it should best specify the notion of eco-neighbourhood also because it is the main system of this research since the present study is drafted in the eco-design framework.

An eco-district or eco-neighbourhood is a neologism associating the terms "district" and "eco" as an abbreviation of ecological. It designates an urban planning aiming to integrate objectives of "sustainable development" and reduce the ecological footprint of the project. This notion insists on the consideration of the whole environmental issues by attributing them ambitious levels of requirements.

The notion eco-district is used nearby the term sustainable neighbourhood. In the strict sense, an eco-district project is addressed to the environmental dimension of the work or rather to the energetic efficiency and to the environmental impacts reduction both in terms of architectural standards and dismantling standards.

The basis of an eco-district project is described by the following parameters:

1. Take into consideration the world-wide issues:
    - ➢ Climate change and greenhouse gas emission (project design, buildings, management and displacements);
    - ➢ Resources preservation (sustainable management of space, bio-diversity, water, materials and natural resources);
    - ➢ Challenge against poverty and exclusion;

2. Take into consideration the local issues (answer to citizens' expectation in terms of life quality, density, life quality, accessibility to services and equipment, housing and private spaces quality, public spaces quality, noise reduction);
3. Make cities, town and suburb long term durable (district integration within the city, functional mix and reduction of the journeys need, solidarity and mix policy, education and training);
4. Standards to conceive an eco-district (new way to think and act, politic strategy, new governance, indicators to evaluate the success).

Further example of eco-district have been realized in Europe, such as: Vauben (Freabourg, Germany), Solar City (Linz, Austria), BedZED (London, England), Hammarby Sjostad (Stockholm, Sweden), Eco-Viikki (Helsinki, Finland), Loretto, Mhulen and Franzosische Viertel (Tubinga, Germany)

Making a closer examiation of the system, within a neighbourhood or more specifically the eco-neighbourhood, there are various "objects" that interact within each other.

Here is the list of the main objects:

12. Infrastructures and amenities;
13. Transport: private and public;
14. Protocols: traffic management, service organization, planning and programming, vehicle control, vehicle guidance;
15. Agents: individual, household, population;
16. Agents habit: eco-citizen, eco-journeys, modes, time, localization;
17. Buildings, housing, enterprise, establishment;
18. Activities and displacements;
19. Impacts: pollutants, noise, energy consumption, resources consumption;
20. Land use;
21. Territory: area of action, interaction with external area;
22. Freight.

A detailed description of the objects is after-specified.

As it is expressed in the introduction, the eco-designer has the purpose to arrange an area where the agents can find advantageous life and activities conditions. Their interactions are very complex processes that unfold into the area and they cannot be dealt with separately.

1.3. Uses, interactions and scales

The operation of an urban system consists of the interactions among the objects that make it up.

Interactions that arise in an urban system are at-large among the social system (quality of life, social interaction, job, cultural and leisure time opportunities), the economic system (level of richness, diversification of the job market, efficiency of services and infrastructures, income and energy costs, investment opportunities) and the physical-environmental system (settlement morphology, climatic conditions, residential quality, parks and gardens, production technologies, energy consumption and disposal, communication technologies, road and transport networks).

Among these three systems, the main components of their interactions are:

- The component displacements/transport: meant as the structure of the displacements of persons and goods by modes and reasons;
- The component localization/land occupation: represented by the residential and economic activities localization;
- The component accessibility: it is the access to different activities and urban services.

To better get a sense of interactions, an example of transportation-land use interaction is provided: automobile-oriented development may induce demand for more roads and parking (which in turn induces more automobile-oriented development), while compact urban environments may induce more walking and demand for transit. Both land use and transportation have significant environmental effects, in particular on emissions, resource consumption, and conversion of rural to suburban or urban land.

Recognising the above mentioned components facilitates the comprehension of the whole urban system operation.

Only positive interactions between the three subsystems represent the pre-conditions that are essential for the life and development of the city. On the contrary, the undesired effects of diseconomies of scale produce negative externalities of urban degradation, social marginalization and pollution.

It is evident that the city, as a dissipative structure (Prigogine and Stengers, 1975) exists since it activates a complex system of interactions with its hinterland: the dependencies regarding energy, green areas, labour force and, on the opposite side, the impact of pollution, wastes, tourism and leisure time, are known factors of this dependency.

The city is in fact an articulated and interconnected system where areas that are spatially differentiated carry out different and complementary functions. The identities of neighbourhoods, the socio-economic characters of the inhabitants, the economic/productive tradition and the spatial structure and location of the sites and the networks make the interactions between the three subsystems produce different and unpredictable results.

Thus, city is a system that necessarily implies different space-time scales. For instance, the scale of analysis could vary from a building, a neighbourhood, though a district of several hundred buildings to an entire city of tens of thousand. As above mentioned, defining the geographical bounders of a neighbourhood is a great issue, on the other hand, a building is a well-defined scale and it lets to assess management costs, water and energy consumption, etc. A more extended scale is under emissions and impacts point of view. They normally let approach to the system trough a global scale such as environment, health, social, economic scales.

A further level is the time scale that refers to the system evolution such as residential mobility, change in the type of use of a building, enhancement of the transport supply, progressively ageing population, etc. Therefore, cities are multi-dimensional systems and try to find a unique dimension among different objects may allow better get and describe their interactions and understand its complexity.

This is the approach proposed in the study, in particular it is assumed a micro-scale so as to describe in really detail and break into different parts the system in order to allow a later construction of a model.

1.4. Objects of the urban system

For the purpose of the study it is worth to define and illustrate the main objects of the urban system:

- *Agents:* agents could be both individual and collective entities such as organizations or groups. Here, it is assumed that *"Individual"* and *"Household"* represents it.

  An individual is a single person with his/her own characteristics. A household is defined as a group of people living together within a single dwelling unit, without these persons necessarily being blood-related. A household can be constituted by a single person.

The fundamental feature of an agent is the capability of the component to make independent decisions. This requires agents to be active rather than purely passive.

An agent is identifiable, a discrete individual with a set of characteristics and rules governing its behaviours and decision-making capability. Agents are self-contained.

Furthermore, an agent is situated, living in an environment with which it interacts along with other agents. It resides in networks and in lattice-like neighbourhoods. It is goal-directed, having goals to achieve with respect to its behaviours. This allows an agent to compare the outcome of its behaviour relative to its goals.

Moreover, it is autonomous and self-directed. It can function independently in its environment and in its dealing with other agents, at least over a limited range of situations that are of interest.

In addition, an agent is flexible, having the ability to learn and adapt its behaviours based on experience. This requires some form of memory. It may have rules that modify its rules of behaviour.

- *Activity:* household and individual travel patterns are generated from the desire to pursue activities in time and space. However, their desires are limited by personal/physical constraints and by the institutional, economic and cultural context. Since not all the activities can be done in the same location, agents have to travel which produces traffic. And to plan an efficient day, many decisions have to be made by each agent.

For the paper purpose, the object activity is assumed split up into *"Activity"* and *"Activities program"*.

The word activity refers to actions such as "being at home", "being at school", "working", "shopping", etc. An activity "is a continuous interaction with the physical environment, a service or person, within the same socio-spatial environment, which is important to the respondent. It includes any pure waiting (idle) times before or during the activity (KW Axhausen)". An activity program "contains the pattern of activities individual or household wishes to perform along with the location of each activity".

As a rule, also movements undertaken for their own sake are considered as activities, for example: walking the dog, strolling, through the park, cycling through the countryside.

Agents operate within their budgets of time, resources (in particular money) and of social capital. Furthermore, they schedule their activity in co-ordination with the members of their household or of their social network, so as to optimize their satisfaction balancing short and long-term considerations.

Scheduling encompasses the choice of time, duration, location and access mode for the activity selected. Thus, every activity is characterized by:

- Location: building such as housing, establishment, public building, etc. and open space such as park, etc.;
- Type of activity: what the person is doing;
- Purpose: what the person hopes to achieve in a moral sense or say about himself/herself such as helping someone, fulfilling a promise, taking care of himself/herself, etc.;
- Project: the greater context of the activity, the framework under which it is undertaken such as preparing dinner, obtaining a degree, working toward promotion, building a house, etc.;
- Duration and frequency;
- Effort accepted to be able to undertaken the activity, in particular the detour required to get to the activity location;
- Expenditure for/income from the activity participation and the associated additional travel;
- Urgency of the activity in terms of the possibility of (further) delay;
- Impacts originated from the activities such as noise, pollutants, energy consumption, natural resources consumption, production of waste, etc.

As a consequence of the need to take part in activities, displacements arise.

- *Buildings:* they represent an intermediary site between their occupants and the surrounding. The purpose of a building is to be a proper space for the estimated activities (housing, business activity, etc.) and, at the same time, where the activities are integrated.

  It is possible to distinguish:

  - Interior environment: so called because it represents the environment for the occupants. It is a built environment that has to meet quality requirements such as functional space, human health protection, hygrothermal comfort, visual, acoustic and olfactory, quality of life;
  - External environment: from outside the building, the surroundings and the region (spatial scales that could differ from the zones to the analysis of

environmental problems), till the global scale. It is a matter of minimizing impacts at those further scales such as climate, fauna and flora, resources, health and landscape protection;

- Interior and external relations that have to meet certain requirements such as movements of goods and people, protection, aesthetic envelop quality, regard for natural flows such as solar gain and stormwater, connection to water, transport and energy supply and management of waste.

Over these different spatial scales are layered a temporal scale. A building is planned for further years as a rule and it aims to provide the conservation of performances.

On the other hand, the issue of sustainable development led to take into consideration long-term aspects such as climate protection, biodiversity, genetic heritage and long-term waste.

- *Infrastructures:* it can be generally defined as the set of interconnected structural and fixed elements that provide framework supporting an entire structure of development. The term typically refers to the technical structures that support a society, such as roads, bridges, water supply, sewers, electrical grids, telecommunications, and so forth, and can be defined as "the physical components of interrelated systems providing commodities and services essential to enable, sustain, or enhance societal living conditions." Viewed functionally, infrastructure facilitates the production of goods and services, and also the distribution of finished products to markets, as well as basic social services such as schools and hospitals. To make it simple, infrastructure is anything that is needed everyday, an everyday item.

  Concerning transport, in this study the infrastructures only refer to road and rail transport.

  The infrastructure supply is made up of further elements such as:

  - Roads and related signals to regulate circulation and flow;
  - Rail infrastructures and related building such as station;
  - Parking fleet and related rules to use it such as private parking, pay parking, free parking, hourly payment, etc.;
  - Non-motorized infrastructures for pedestrian and cyclist;
  - Parks, green areas.

  It is clear that infrastructures are generally specific for a mode of transport and they are conceived to permit circulation of certain type of vehicles.

They are characterized by further aspects such as:

- Capacity that is generally defined as the amount of space available for transport and the number of passengers, volume (for liquids or containerized traffic), or mass (for freight) that can be transported per unit of time and space;
- Accessibility that refers to people's ability to reach goods, services and activities, which is the ultimate goal of most transport activity. It can be defined as the potential for interaction and exchange (Hansen 1959; Engwicht 1993);
- Connectivity meant as the degree to which a road or path system is connected, and therefore the directness of travel between destinations.

The modes of transport that characterized the infrastructure belong to the transport supply, shown below.

Also infrastructures produce impacts both in the construction and demolition phase as it is possible to calculate trough the LCA (Life Cycle Assessment) methodology. Nevertheless, many technologies exist to reduce the environmental impacts of infrastructures. The use of advanced planning, intelligent construction, and efficient maintenance techniques should be incorporated into every design project.

Concerning buildings, infrastructures are in terms of building energy demand such as water and energy supply network, electricity grid, drainage system, domestic waste and garbage disposal.

As for transport infrastructures, "building" infrastructures are one of the further elements considered in the LCA methodology to evaluate different impacts indicators such as resource depletion, energy and water consumption, global warming, waste generation, toxicity, etc.

- *Transport:* it represents the transport supply meant as the transportation options, mobility options, transport diversity or transport choice and refers to the quantity and quality of transport modes and services available in a particular system. Different modes serve different users and purposes. It is possible to distinguish two main groups: "*Individual/private transport*" and "*Public transport*". They both represent the transportation modes among which agents make choice when project displacements. The choice of mode of transport depends on the transport cost link to each transport. As a rule, the transport cost should encompass the characteristics of the infrastructure networks, vehicle and energy used, as well as labor, insurance, tax, and general charges borne by transport carriers. The transport costs can vary considerably according to the itinerary, time, distance direction, mode, energy, taxation, operating costs, commodity, etc.

- *Vehicles:* they are all the possible modes of transport and they just consist in the type of vehicle from the bicycle and the private automobile to the bus or train with the latest sustainable types of vehicles. They are represented by the vehicle fleet. They will be listed in chapter 3.

- *Impacts:* as a consequence of the land use and interactions among all the objects emissions arise and then converted into impacts trough indicators. It is clear that each object produces impact on the other or it is exposed impacts caused by other objects. In the emissions are grouped all the types of pollutants and noise and related dispersion and impacts could be classified into:
  - *Social impacts:*
    - people's way of life – that is, how they live, work, play and interact with one another on a day-to-day basis;
    - their culture – that is, their shared beliefs, customs, values and language or dialect;
    - their community – its cohesion, stability, character, services and facilities;
    - their political systems – the extent to which people are able to participate in decisions that affect their lives, the level of democratisation that is taking place, and the resources provided for this purpose;
    - their environment – the quality of the air and water people use; the availability and quality of the food they eat; the level of hazard or risk, dust and noise they are exposed to; the adequacy of sanitation, their physical safety, and their access to and control over resources;
    - their health and wellbeing – health is a state of complete physical, mental, social and spiritual wellbeing and not merely the absence of disease or infirmity;

- their personal and property rights – particularly whether people are economically affected, or experience personal disadvantage which may include a violation of their civil liberties;
- their fears and aspirations – their perceptions about their safety, their fears about the future of their community, and their aspirations for their future and the future of their children.

➢ *Land impacts:*

- climate change;
- environmental degradation;
- environmental health;
- land degradation;
- land use;
- land pollution;
- desertification;
- water pollution;
- air pollution;
- exploitation of natural resources;
- ozone depletion;
- waste;
- air quality;
- habitat fragmentation;
- soil contamination.

➢ *Economical impacts:*

- investment;
- operation;
- maintenance;
- dismantling;
- sustainability;
- heritage value.

To better understand the complexity of the urban system, a diagram of its objects and interactions is provided at the end of this chapter.

1.5. The proposal

After an explanation of the context and its elements, it is worth to illustrate the proposal of the research: in this paper an urban system models classification is proposed. The aim of the procedure is to classify the simulation models according to their main characteristics. In this particular case, the models under examination are: MATSim, MobiSim, TRANSIMS, ILUTE, UrbanSim, ANTONIN.

The procedure consists in defining a list of criteria, gathered together in a table, and verifying how many of those are present in the different studied models. The list of criteria is based on the objects of the study system previously described. They are obviously split up into further sub-categories and characterised with more detail.

After the classification, the more fitting models for the simulation of agents' activities and related environmental impacts are chosen to outline a system of models to assess the performance of the neighbourhood and to address a guideline for the city planner.

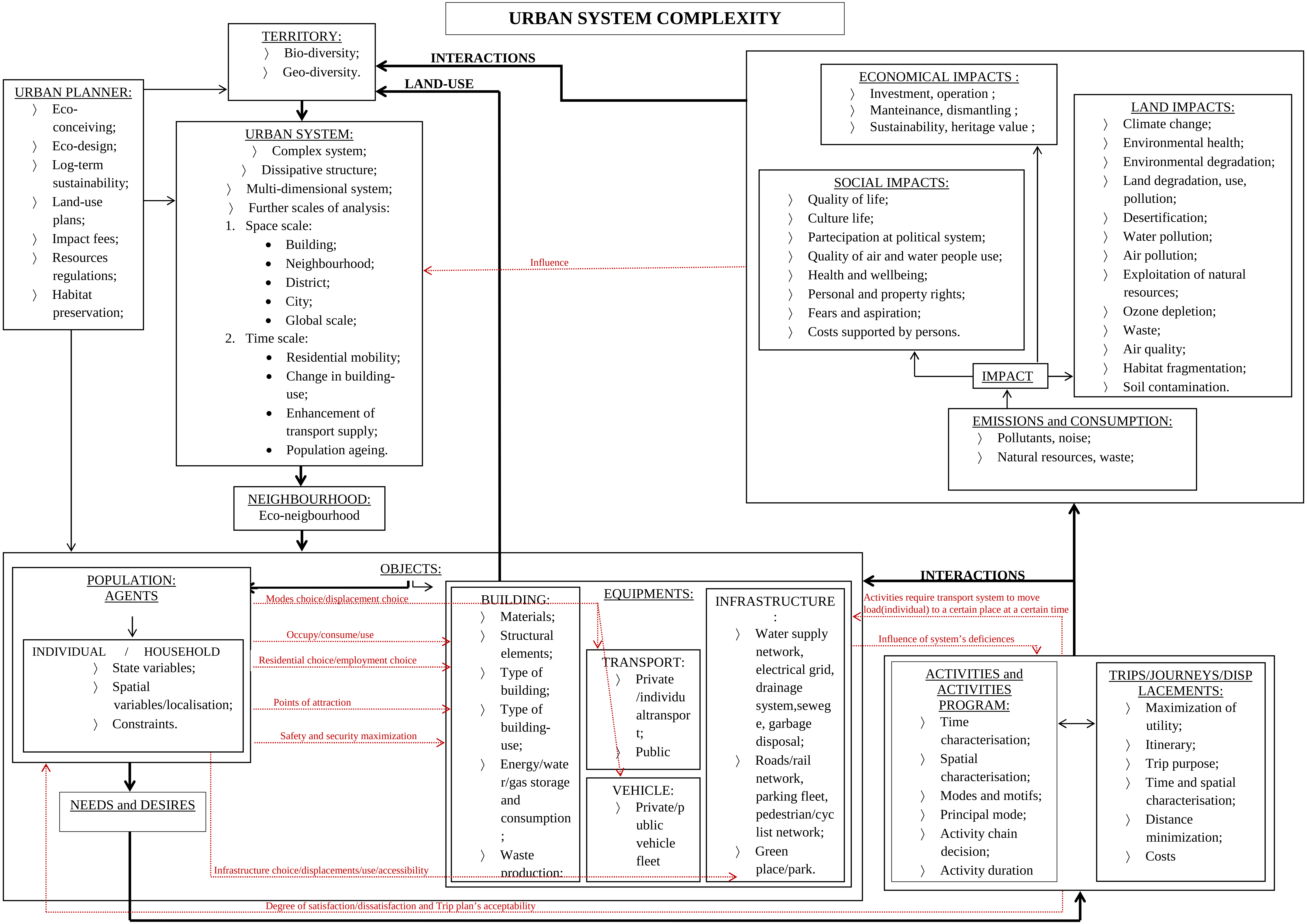
In particular, the goal is to individuate a model that supports the need to create a buildings-transport integrated model.

This analysis can help in the interpretation of the characteristics of models under the following different point of view:

1. *Which agent is involved in which activity at any given instant on a typical day;*
2. *Which program of activities and trips are performed by each user along the day, by place, activity purpose and travel mode;*
3. *Which transport vehicles are available to the user and their environmental impacts when used.*
4. *Where the activities are carried out, in which place (building, public place, etc.);*
5. *Which impact arises from activities.*

To conclude, it can be said that the main aim of this procedure is to work on how the interactions among the objects, above mentioned, those that form the system eco-district, are taken into consideration in the different models and so which models are well suited the complexity of urban system.

It is now provided the diagram of the urban system complexity to help in the visualization of the whole context of analysis.


URBAN SYSTEM COMPLEXITY
TERRITORY:
〉 Bio-diversity;
〉 Geo-diversity.
INTERACTIONS
LAND-USE
URBAN PLANNER:
〉 Eco-conceiving;
〉 Eco-design;
〉 Log-term sustainability;
〉 Land-use plans;
〉 Impact fees;
〉 Resources regulations;
〉 Habitat preservation;
URBAN SYSTEM:
〉 Complex system;
〉 Dissipative structure;
〉 Multi-dimensional system;
〉 Further scales of analysis:
1. Space scale:
• Building;
• Neighbourhood;
• District;
• City;
• Global scale;
2. Time scale:
• Residential mobility;
• Change in building-use;
• Enhancement of transport supply;
• Population ageing.
Influence
ECONOMICAL IMPACTS :
〉 Investment, operation ;
〉 Manteinance, dismantling ;
〉 Sustainability, heritage value ;
SOCIAL IMPACTS:
〉 Quality of life;
〉 Culture life;
〉 Partecipation at political system;
〉 Quality of air and water people use;
〉 Health and wellbeing;
〉 Personal and property rights;
〉 Fears and aspiration;
〉 Costs supported by persons.
LAND IMPACTS:
〉 Climate change;
〉 Environmental health;
〉 Environmental degradation;
〉 Land degradation, use, pollution;
〉 Desertification;
〉 Water pollution;
〉 Air pollution;
〉 Exploitation of natural resources;
〉 Ozone depletion;
〉 Waste;
〉 Air quality;
〉 Habitat fragmentation;
〉 Soil contamination.
IMPACT
EMISSIONS and CONSUMPTION:
〉 Pollutants, noise;
〉 Natural resources, waste;
NEIGHBOURHOOD:
Eco-neigbourhood
OBJECTS:
POPULATION: AGENTS
INDIVIDUAL / HOUSEHOLD
〉 State variables;
〉 Spatial variables/localisation;
〉 Constraints.
NEEDS and DESIRES
Modes choice/displacement choice
Occupy/consume/use
Residential choice/employment choice
Points of attraction
Safety and security maximization
Infrastructure choice/displacements/use/accessibility
Degree of satisfaction/dissatisfaction and Trip plan's acceptability
BUILDING:
〉 Materials;
〉 Structural elements;
〉 Type of building;
〉 Type of building-use;
〉 Energy/water/gas storage and consumption;
〉 Waste production;
EQUIPMENTS:
TRANSPORT:
〉 Private /individualtransport;
〉 Public
VEHICLE:
〉 Private/public vehicle fleet
INFRASTRUCTURE :
〉 Water supply network, electrical grid, drainage system,sewege, garbage disposal;
〉 Roads/rail network, parking fleet, pedestrian/cyclist network;
〉 Green place/park.
INTERACTIONS
Activities require transport system to move load(individual) to a certain place at a certain time
Influence of system's deficiences
ACTIVITIES and ACTIVITIES PROGRAM:
〉 Time characterisation;
〉 Spatial characterisation;
〉 Modes and motifs;
〉 Principal mode;
〉 Activity chain decision;
〉 Activity duration
TRIPS/JOURNEYS/DISPLACEMENTS:
〉 Maximization of utility;
〉 Itinerary;
〉 Trip purpose;
〉 Time and spatial characterisation;
〉 Distance minimization;
〉 Costs

Bibliography

REY Emmanuel. *Quartieri sostenibili: Sfide e opportunità per lo sviluppo urbano. EPFL / ENAC / IA / LAST* Laboratory of Architecture and Sustainable Technologies / last.epfl.ch. Confederazione Svizzera, Ufficio Federale dell'energia UFE, Ufficio Federale dello sviluppo Territoriale ARE.

CHAKER Walid, 2010. *Modélisation conceptuelle des ensembles batis et des infrsatructures urbaines : approches et échelles.* ParisTech, France.

ANTONI Jean-Pierre, 2011. *Modéliser la ville. Formes urbaines et politiques de transport.* Collection « Méthodes et Approches » dirigée par Gérard Brun. Economica.

PEUPORTIER Bruno, 2008. *Eco-conception des bâtiments et des quartiers.* Collection sciences de la terre et de l'environnement. Mines ParisTech, le presses.

Modélisation urbaine : de la représentation au projet. Commissariat général au développement durable. Septembre 2012.

SANDERS Lena, 2005. *Simulation des systèmes urbains.* Equipe P.A.R.I.S., UMR Géographie-cités, CNRS-Université Paris 1-Université Paris 7-ENS Lyon.

LEURENT Fabien, 2012. *Modélisation urbaine : panorama et discussion.* Ecole des Ponts ParisTech, Bureau du GIS MU.

LEURENT Fabien, 2010. *Principes d'éco-conception en transport et en aménagement.* Ecole des Ponts ParisTech.

LITMAN Todd, 2012. *Evaluating accessibility for transportation planning. Measuring people's ability to reach desired goods and activities.* Victoria Transport Policy Institute, www.vtpi.org

COPPOLA Pierluigi. *Un sistema di modelli per la simulazione delle interazioni trasporti territorio.*

SAHEB Yamina, 2007. *Analyse critique des quartiers durables.* La Fabrique de la cité.

Le cahiers de l'observatoire de la ville, n.2, 2007. *Les quartiers durables: nouvel enjeu de la ville de demain?* Observatoire de la ville.

CHAPTER 2:

Panorama of urban system models: Transports and Buildings

2.1.Introduction

This chapter provides an introduction to urban simulation, which it is interpreted broadly to mean operational models that attempt to represent dynamic processes and interactions of urban system. The intent is to provide a reasonable understanding of the context and objectives for urban simulation modelling within urban areas.

Urban systems can be conceptualized as systems where emerging properties are produced mainly at two levels of observation through the interactions between “agents” occurring at a lower level: the morphological and social structures of a city are emerging from the multiple interactive decisions of the residents or groups of citizens, while the spatial organization, hierarchical and socio-economic differentiation at the scale of a system of cities are created by the adaptive strategies and mainly competitive relations between the cities considered as “agents” at this level of analysis. Thus, urban systems are complex systems with a complex nature of humans interacting with the transportation and land system.

When experimenting with urban systems, a first difficulty is to define precisely which are the objects under study, or in other words, to identify clearly the content and limits of each level of organisation. Indeed, urban objects are essentially relational (for instance when compared to rural settlements which mainly exploit ecological local resources, towns and cities are developing by capturing and maintaining positions within networks). At every level of organisation, there are so many relations and interactions, within and among the different levels, that it is a complicate task to isolate them, theoretically and practically, for measurement purposes.

The chapter is mainly spilt up into a first review of transport models and in the sequel the review of energy simulation models for buildings. The proposal of this chapter is to provide a “panorama” so as to help in the comprehension of the models described in chapter 4.

2.2.Background review of urban system models: Transports

Urban systems are becoming ever larger and increasingly complex as urban economies, social and political structures and norms, and transportation and other infrastructure systems and technologies evolve. Mathematical and theoretical models have long been used to attempt to reduce complexity and encode a clear and concise understanding of some aspects of urban structure and transportation, as exemplified by the classic work on the Monocentric Model of the city (Alonso, 1964; Mills, 1967; Muth, 1969). While the value of theoretical models is facilitating a broad understanding of some underlying principles of urban development and transportation, much of this work remains too simplified in its assumptions and too abstract to be of direct value to agencies needing to inform decisions about specific policies and investments in particular urban settings. To begin to address more operational needs in planning and policy decisions, computerized models representing urban travel and land use began to be developed and used from at least the 1960's in the United States, with the advent of the Urban Transportation Planning System for travel demand forecasting (Weiner, 1997), and the subsequent work on spatial interaction models for predicting locations of households and jobs across urban landscapes (Putman, 1983), which emerged out of earlier work on the Lowry gravity model (Goldner, 1971). A separate branch of applied urban modelling developed along the lines of the Input-Output model of the macroeconomy developed to describe the structure of economic flows between economic sectors (Leontief, 1966), adding a spatial component and transportation costs to represent economic and transport flows between zones in a region (de la Barra, 1989; Marcial Echenique & Partners Ltd., 1995). The objectives for much of the work on land use and transportation modelling in the United States from the 1960's through the 1980's were focused on the planning problem of determining transportation capacity needs, mostly focusing on roadway capacity, to accommodate expected demand generated by predicted land use patterns represented by the spatial distribution of households and jobs within a metropolitan area at some future planning horizon. Over the 1970's and 1980's, increasing pressure from environmental groups, proponents of transit, and others, led to a substantial shift in policy objectives, reflected in the passage of the Clean Air Act Amendments (CAAA) of 1991 and the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1990. By 1990, a significant degree of attention had emerged on the effects of transportation improvements on land use changes, the potential for long-term induced demand from highway expansion that might significantly undermine the expanded capacity through additional travel, and increasing environmental consequences in the form of emissions and loss of open space due to stimulation of low-density development at and beyond the urban fringe. The passage of the CAAA and ISTEA legislation set that the computerized transportation and land use modelling and planning processes did not adequately account for these complex feedbacks between transportation improvements, land use, and air quality. Simultaneously, the policy environment began to shift towards a more multi-modal approach to transportation, including non-motorized and transit modes, other demand side policies began to emerge as alternative ways to match capacity to needs, including a range of transportation system management techniques (ramp metering, traffic light signalization, and so forth), travel demand management (ride-sharing, staggered work hours, parking pricing policies, congestion pricing, etc.), and land use policies (jobs-housing balance, urban growth boundaries, transferable development rights, concurrency requirements or adequate public facilities ordinances). The range of policies and strategies under potential consideration by metropolitan areas to address transportation needs has essentially exploded over the past two decades, from a fairly narrow focus on highway capacity expansion to a multi-modal transportation capacity and demand management and land use policies. The objectives for operational urban land use and transportation models have consequently grown. Besides the growing need to test the effects and effectiveness of an ever-more diverse range of land use and transportation policies, and their interactions, pressures on operational modelling have grown from a very different perspective. From the earliest efforts to develop operational urban models, critics have raised serious concerns about the viability of such models.

In summary, the context and objectives for urban modelling have grown far more complex over the past two decades, and combine to shape the needs for urban model development in ways that are sensitive to a range of land use and transportation policies and their interactions, that build on clear and defensible foundations in behavioral theory, and that facilitate participation in the testing of alternative policy strategies and their evaluation.

2.2.1.Model Requirements

As general guideline the model system must:

- Be sensitive to the effects of transportation pricing policies on both travel behavior and land use.
- Be able to address the impacts of proposed land use and transportation policies on housing affordability.
- Be sensitive to policies that are designed to promote densification, infill and redevelopment., and to the effects of land use policies such as comprehensive land

use plans, zoning, and the Urban Growth Boundary on real estate development and the location of households and firms.

- Be able to assess policy effects over periods ranging from less than 5 years to 30 years.
- Be designed to support a participatory policy process that includes activities where scenarios are generated and publicly discussed.

- Public access to the model assumptions, theory, structure, and results is required, and the models must be explainable to a non-technical audience.
- Be based on an activity-based framework in order to adequately represent the complexity and constraints of travel behavior, and the influence of land use and transportation policies on travel behavior.
- Allow comparison of different transit modes, for example rail vs. bus. The new model system must be capable of adequately representing non-motorized travel behavior. The model must allow comparison of different auto modes of travel, for example high occupancy vehicles with 2 or 3+ person vs. single occupancy vehicles. Recognize the impact of land use patterns on demand for transportation. Allow analysis of demand induced by transportation system improvements.
- Be able to assess the impacts of environmental regulations that affect the development of environmentally sensitive lands, wetlands, floodplains, seismic areas, steep slopes, and other sensitive lands.
- Recognize the effects of multi-modal transportation system and policy changes on real estate development and the location patterns of households and firms.
- Be sensitive to the effects of urban design elements such as mixed land use, density, street pattern, transit service and pedestrian amenities on household and firm location and travel behavior.
- Be able to analyze the residential movement and location choices made by households, and the influence on these choices of relevant housing and location characteristics. The model system must be able to model the choice of household members to participate in the labor market, and to choose a work location. The model system must be able to model the vehicle ownership choices of households.
- Be able to analyze the interactions between household choices related to residential mobility and location, labor market participation and workplace, vehicle ownership, and daily activity and travel scheduling.

- Be able to represent demographic processes such as the change in household size and structure, and the ageing of the population.
- Incorporate a component to model the process of real estate development, including infill and redevelopment, and the effects of various policies on this process.
- Be able to support the analysis including real estate development, household and business location, to assist in station area planning.
- Incorporate a macroeconomic component to model economic growth in the region and its relationship to internal and external economic drivers. Analyze the factors and policies influencing the location choices and real estate demands of different firms in different industries.
- Address freight and commodity transport within and through the region.
- Address modal choices and tradeoffs of moving goods by truck, rail, barge or air.
- Be able to produce multi-modal travel assignments for roadway, transit and possibly non-motorized systems.
- Contain information pertinent to policies such as workplace incentives, telecommuting, and a greater breakdown of carpool sizes.
- Provide output relevant to policies instituted as part of Intelligent Transportation Systems (ITS) such as incident management systems or public information distribution.
- Be developed in a way that supports open and unrestricted access to the software by Regional Council staff, consultants, and constituents, in order to maintain and modify the models to meet emerging needs over time. The model system should support distributed access and use by Regional Council member governments, and should use consistent data for Regional Council and member agency applications.
- Be manageable from the perspective of its data requirements.
- Provide tools to facilitate visualization of model results and comparison of scenarios in ways that are useful to non-technical audiences.
- Allow Multi-Modal Cost-Benefit Analysis, to enable model users to make more informed transportation investment decisions.
- Address uncertainty in the models and produce ranges of values for outputs rather than specific results to avoid suggesting artificial accuracy

2.2.2. Preliminary model design choices

Having reviewed the context, the stage is set for examining the design choices in more detail. There are several major design choices that must be considered for an urban simulation system, and the combination of these choices narrows the choice of modelling approach. The considered design choices are the level of behavioral aggregation, the level of determinism, their temporal representation, and the resolution of agents, space, and time.

- *Behavioral Resolution*. The system can work on an aggregate scale of average behaviors or on the disaggregate level of behavior of individual agents. The simulation system can be deterministic or stochastic. Deterministic systems are based on predetermined rates of change and static functions, and the same inputs will always produce the same results. Deterministic models are typically used along with aggregate scale of behavior, since the average behaviors can often be approximated with a fixed rate of change. But, agent based simulations can also easily be deterministic, for example queuing models, or choice models that force the agents to choose the most likely result.
- *Resolution of Agents, Space, and Time*. The size of the units of analysis, or resolution, of the system is another major design decision. Simulation systems range from macroscopic to microscopic in resolution. Macroscopic systems have the largest units of analysis, typically aggregate values for geographic zones, household distributions, or groups of vehicles. These models are in wide use, mostly because they have relatively low computational needs. They run relatively fast and use relatively little memory. Macroscopic models also require much less data than finer resolutions, and the data is more readily available through census data or other such large databases. Macroscopic models are typically static and deterministic. Microscopic models have a small unit of analysis, for example a single individual, household, vehicle, trip or activity. Microscopic models are being actively developed because their requirements for considerable computational power are increasingly being satisfied by personal computers, making these models more feasible, and they support clearer behavioral specifications than macroscopic models. Microscopic models are typically stochastic, disaggregate models that require enormous amounts of data. The data needs of microscopic models are still a limitation since detailed data on individuals

are expensive to collect. Methods to synthesize households from census data exist (Beckman, Baggerly and McKay, 1995) and such methods facilitate the creation of synthetic households for use in micro-simulation. Mesoscopic models are a mixture of macroscopic and microscopic models. They may use small decision makers but large time steps, or small time steps for large units of analysis. They therefore allow the use of aggregate data for certain aspects of the model but make use of greater detail where it is available.

- *Level of Determinism*. Stochastic models are based on probability distributions. They are most typically used with agent-based simulations in the form of probabilistic choice models. They allow the agent to randomly choose an alternative, which means an agent can end up with an unlikely choice. These models will generally not give the same result if run twice, but the results can be made repeatable by fixing the random seed that controls the random distribution. Such a feature does not make the model deterministic, since it is always probabilistic what happens if the initial condition is changed slightly.
- *Temporal Representation*. Models can also be cross-sectional or dynamic in their representation of time. Cross-sectional (sometimes referred to as static or equilibrium) models are not time dependent, and model conditions are fixed at a hypothetical condition generally identified as a long-term equilibrium. Equilibrium models assume that the system begins in equilibrium and adjusts completely to some exogenous shock, that is, it reaches a new equilibrium. The assumption of equilibrium usually allows the explicit derivation of the solution describing the system, although the underlying functions may be time-dependent. Dynamic models make no assumption about equilibrium, but concentrate on adjustment processes over real calendar time. The solution describing such a model is therefore often impossible to derive analytically and the system must typically be simulated to find the result.
- *System Interaction*. There are complex interactions between components within the urban system that must be represented in any complete urban simulation system, such as the endogenous relationships between land use, transportation, and the environment. Urban simulation systems must therefore either explicitly model the interactions between land use, transportation, and the environment, or interface with separate transportation or environmental models. This interaction, or interface, between systems is made especially complex because of the different

time scales of urban development, transportation, and environmental changes. In particular, there is a large contrast between urban development and transportation. Simulations of urban development work on time scales from a year down to a month, while transportation simulation systems are on the scale of days down to seconds. Environmental models can be on both scales, for example, the effect on wildlife habitat works on the urban development time scale, i.e. years or months, while models of pollution will be on the transportation model scale.

2.2.3.Modelling Approach

The modelling approach is a major design decision, though it will be heavily constrained by the preceding design choices. Several different urban modelling approaches have been developed and applied to either planning or research objectives over the past several decades. Three of these methods were used in the earliest operational urban models, dating from the 1960's and 1970's: spatial interaction, spatial input-output, and linear programming. Microsimulation was developed in the 1960's, but not applied to urban modeling until the 1980's. Since the 1980's, the development of discrete choice modeling and the emergence of cellular automata and multi-agent simulation techniques have created a proliferation of modeling approaches. Furthermore, the supporting role of Geographic Information Systems is discussed.

- *Spatial Interaction.* Models based on the spatial interaction approach include some of the earliest efforts to model systematic spatial patterns of urban land use. The approach draws on the model of gravity in physics, which indicates that gravitational pull increases in proportion to the mass of two objects in space, and decreases with the square of the distance separating them. Applied to urban settlements and travel, the gravity model implies that travel between two zones increases with the amount of activity in the origin and destination zone, and decreases with the square of the travel impedance between them. The basic model has been extended to model trip destination choices, residential location choices, and employment location choices (Putman, 1983). This type of model tends to be limited in the degree of spatial detail used, and does not represent many behavioral factors influencing location choices, nor does it represent the role of real estate markets and prices.

- *Spatial Input-Output.* The spatial input-output framework extended the input-output model developed to represent the structure of the U.S. economy (Leontief, 1966) to address spatial patterns of location of economic activity within regions, and the movement of goods and people between zones. Zones are treated in a sense as economies that engage in production, consumption, import, and export within the zone and with all other zones in the model. These economic exchanges between zones are denominated in monetary units, and driven by demand for exports. Monetary flows are converted to flows of goods and services by type of vehicle, and of commuting and shopping trips by mode.

  The approach includes explicit real estate and labor markets, as well as travel demand modelling, and is structured to generate a static equilibrium solution to changes in one or more inputs. Zone sizes in operational applications tend to be large relative to zone sizes used in typical urban travel modelling.
- *Linear Programming.* Linear programming models of land use are rare. Linear programming optimizes a global objective function, such as consumer surplus or utility, across the entire model system. The approach is therefore more suited to exploration of alternative land use configurations that might optimize transportation flow, than to reflect realistic behavioral responses to changes in the transportation system or in land use policies.
- *Microsimulation.* Microsimulation as an approach essentially implies a model that is applied at the level of the individual. Developed in the late 1950's and early 1960's, the method was initially applied to study the effects of social and economic policies. It has more recently been applied to the formulation of urban models.

  Microsimulation models used for socio-economic (non-spatial) policies such as taxes are used with a sample of households, and compute the effects of the tax policy alternatives on the sample of households to study distributional, or equity, effects. Urban, spatially-explicit models, have used combinations of discrete-choice models and transition rates, to predict changes in the state of individuals or households, such as entering or leaving the labor force, and their choices such as residence location. Once considered too data-intensive, these methods have been growing in popularity because they allow modelling at an individual level, where behavioral theory is clearer, and due to increased interest in detailed characteristics of households for equity analysis and other reasons, can make individual-level analysis more efficient than cross classification of households using multiple characteristics.

- *Discrete Choice.* Discrete choice modelling techniques are widely used in travel demand modelling, mostly in the analysis of mode choice. Discrete choice models have been used in some form for much of the last 100 years. However, it was Daniel McFadden's Nobel-prize winning Random Utility Theory work and his derivation of the generalized extreme value class of models (which includes multinomial and nested logit models) that gave these models a firm foundation within econometrics, and they have since become standard methods in developing models that attempt to predict individual choices among a finite set of alternatives (McFadden, 1973; McFadden, 1984; McFadden, 1981). Discrete choice models are generic in the sense that they do not impose overly-restrictive assumptions on the choice process, and have been shown capable of addressing large and complex choice sets effectively (Ben-Akiva and Lerman, 1985). Discrete choice techniques can be readily used in conjunction with other simulation approaches, such as microsimulation.
- *Rule-Based.* Several land use models have been developed in recent years using GIS and a rule-based set of procedures to allocate population, employment, and/or land use. Such rule-based applications may have a useful role in making models more accessible, but there is a risk that model users would interpret the models as having a more behavioral basis than their rules actually contain. There are also rule-based methods that are emerging from the field of artificial intelligence, using observed data to generate clarification trees of behavioral rules that are used in microsimulation, such as the Albatross activity-based travel model (Arentze, Hofman and van Mourik, 2000).
- *Cellular Automata.* Cellular automata (CA) models have emerged within the broad field of complex systems as a means of representing the emergent properties of simple behavioral rules applied to cells within a grid (Wolfram, 1984). The approach has now been widely applied to urban land cover or land use change (Benati, 1997; Clarke and Gaydos, 1998; Couclelis, 1997; White and Engelen, 1993). To date, applications have been principally for research purposes rather than operational planning or policy, though efforts are underway to make these models useful for planning purposes. The approach is particularly useful for representing the interactions between a location and its immediate environment,

but tends to reflect a fairly abstract representation of agents, decisions, and behavior, since the models focus on simulating the change in state of individual cells. In addition, challenges remain in reconciling the emergent behavior of cells acting on localized rules with more systemic or macro-scale behavior, in validating these models using observed data, and in computational requirements. Potentially the most ambitious use of the CA approach to date is the TRANSIMS traffic microsimulation system.

- *Multi-Agent Simulation.* Multi-agent simulation (MAS) models are related to CA in that both draw on complex systems theory, but differs from CA in that its emphasis is on emergent system behavior arising from interactions between agents.

  The MAS approach is gaining substantial research interest across the social sciences, since it opens new avenues to analyze social behavior from an interactive perspective.

- *Supporting Role of Geographic Information Systems.* The growing use of Geographic Information Systems (GIS) to automate land records and collect environmental data have led to substantial interest in using the technology in urban modelling. Most of the applications of GIS are of two forms: integrating the input data for use in urban models, or visualizing results of the simulation in a map-based display. While both of these roles are valuable, they do not exhaust the potential applications of GIS technology. A number of efforts have emerged to operationalize models within a GIS software environment. An example of this for travel demand modelling is the TransCAD system (Caliper, 2002).

2.3.Background review of urban system models: Buildings

Getting on to buildings simulation, in this specific paper, only energy simulation models for buildings are considered.

Energy performance simulation programs are powerful tools to study energy performance and thermal comfort during the building's life-cycle. Today, numerous such tools are available and they differ in many ways such as in their thermodynamic models, their graphical user interfaces, their purpose of use, their life-cycle applicability, and their ability to exchange data with other software applications.

Most of the thermal simulation programs consist of a so-called engine, which enables detailed thermal simulations based on simple text-based input and output files. These engines contain mathematical and thermodynamic algorithms that are used to calculate the energy performance. Most important for the practical use of these tools is a graphical user interface that eases the generation of input and the analysis of output, and exposes the functionality of the engine to the user. However, easy-to-use interfaces do not make energy analysis available to everyone, the knowledge of limitations of the programs and an understanding of thermal processes are crucial to the generation and understanding of realistic and reliable simulation results. In addition, the graphical user interfaces differ in their purpose and mostly do not use the complete functionality of the related engine. Usually, these tools are developed to be used during the design phase of the building life-cycle. Recent developments lead to a broader use over all phases of a building’s life. Data exchange, primarily from CAD applications, but also in conjunction with other design tools such as HVAC (Heating, Ventilation and Air Conditioning) modeling tools, can provide a userfriendly and practical way of integrating these tools in the design process of a building.

Two types of software tools are being used today: design tools, which are focusing in sizing HVAC equipment and simulation tools, which predict the energy performance of the building annually. Design tools base their calculations on the worst case scenario to enable the selection of the HVAC equipment size. Typically, the HVAC equipment is sized based on summer and winter design days that define the extreme conditions for the building in question. They are usually based on static calculations.

Annual simulation tools predict the annual energy performance of a building and its HVAC system. They usually include a sizing functionality, but can predict differences in energy consumption for different design alternatives. They typically include dynamic calculations based on various thermodynamic equations.

2.3.1.Basic principles of energy simulation

Energy simulation tools predict the energy performance of a given building and thermal comfort for its occupants. In general, they support the understanding of how a given building operates according to certain criteria and enable comparisons of different design alternatives. Limitations apply to almost every available tool of this kind today, thus it is necessary to understand certain basic principles of energy simulation.

First of all, any simulation result can only be as accurate as the input data for the simulation. The input mainly consists of the building geometry, internal loads, HVAC systems and components, weather data, operating strategies and schedules, and simulation specific parameters. Every energy simulation is based on thermodynamic equations, principles and assumptions. Since thermal processes in a building are complex and not totally understood today, energy simulation programs approximate their predictions with qualified equations and methods.

Therefore, results can be arbitrarily incorrect, if certain assumptions are not satisfied in the simulation or matched in real life.

Furthermore, most energy simulation tools comprise of an engine and a graphical user interface. Different calculation methods to determine space loads are being used within the engine. All available simulation tools are uniform time increment models. While these time increments are somewhat flexible (or user-definable), they are not based on events or changes.

In general, energy simulations could be applied in every stage of the building lifecycle, since the used concepts are equally valid independently of the stage of a building's life. However, so-called design tools are mainly focusing on the design of a building from a heating and air conditioning perspective including its passive performance, such as shading. Many of the underlying assumptions and features are primarily related to the design stage and limit capabilities for other stages of the life-cycle. In particular design tools are used to size HVAC equipment for worst case conditions and do not consider the overall annual performance. In contrast, simulation tools use more generic concepts, thus they can be used during any life-cycle phase. The latter produce more data (typically over a period of one year) that can be compared to actual building performance and, thus, they are also useful for commissioning and operations purposes.

Today, energy performance simulation tools are mainly based on one-dimensional heat transfer between thermal zones. This assumption simplifies the geometric input dramatically and allows shorter simulation run times. While 2 or 3 dimensional heat transfer would increase the accuracy of simulation results, geometry input and simulation run time is likely to be more complex.

2.3.2.Input to energy simulation

The building geometry constitutes the basic input for energy simulation. It is crucial to understand that there are differences between a building model that was created by an architect and a building model needed for energy simulation.

The latter, often referred to as thermal building model or thermal view of the building model, is basically a simplified view of the architectural building. One of the differences is that architectural spaces can typically be aggregated into thermal spaces or in case of large open offices the architectural space can be divided into multiple thermal spaces. This conjunction or division of architectural spaces is based on the thermal perspective where spaces with the same or very similar thermal characteristics and control patterns are combined into one.

For energy simulations spaces need to be defined by space boundaries, which are not necessarily the same as walls in an architectural model.

For example, single long walls may need to be divided into multiple space boundaries in case multiple neighboring spaces are attached to this particular wall. These space boundaries define the interface between a thermal space and its surrounding boundaries for energy equations, thus only that part of a wall that represents an actual boundary needs to be assigned to the space (Bazjanac 2002). Based on this space boundary concept the intersecting portion of the two walls is ignored in the thermal simulation model, because of the mentioned one-dimensional heat transfer assumption. This intersection can only be described if two dimensional heat transfer is available.

Freestanding walls or columns can be mostly ignored in thermal models. Since there is no difference in temperature between the exterior surfaces that all belong to the same thermal space there will be no heat transfer. However, in simulation cases where the thermal mass of these walls and columns may have an effect on simulation results, one can represent these with appropriate thermal mass objects that do not have a specific geometric representation, but contain the exposed surface area. But generally, engines do not take freestanding walls or columns as part of the daylighting calculation into account. Thus modeling the columns or freestanding walls as internal walls does not improve the simulation results when compared to simple thermal mass objects. Slabs and walls that do not relate to a particular building space and are external can be ignored from a heat transfer perspective, but need to be converted into shading objects if they shade the building. Shading devices are an important part of any energy model, since they can dramatically reduce solar loads in a space.

Today, curved surfaces cannot be represented as such in any thermal simulation engine that is based on one-dimensional heat transfer. Usually objects with curved surfaces are approximated through a number of plane surfaces.

While in the early design phases both the architectural and the thermal model can sometimes be almost identical, the differences increase while design progresses. The automated simplification process to derive the input geometry for thermal simulation from an architectural model is still a challenge today. In practice, CAD models must be validated to ensure a sufficient geometric representation.

Internal and external loads are necessary to provide enough information for an energy balance in a space. The external loads are strongly influenced by weather and climate, thus collected and statistically assembled weather data are used in energy performance simulation. Weather data files are being created for design purposes for an increasing number of cities and regions around the world. These weather files do not reflect a specific year, but provide statistical reference for the typical weather parameters of a specific location. During commissioning and operation weather information can sometimes be measured directly at the building in question or at weather stations that are locally close. Internal loads such as loads from people, lights and equipment in a space depend greatly on the actual usage of a space and the behavior of the occupants. It is obvious that assumptions have to be made about the quantity of internal loads in a given space for energy simulation in design.

HVAC systems and their components are a major part of the input information for thermal simulation models. These systems can be modeled to reflect the actual system if the energy simulation tool (graphical user interface and the engine) provides enough flexibility. To define a realistic representation of the real HVAC system within a predefined structure can sometimes be challenging. Therefore, newer engines such as EnergyPlus support component-based HVAC modeling without the restriction of hardcoded predefined HVAC systems employed by older tools, such as DOE-2. Another important aspect is the possibility to model new HVAC technologies and concepts such as under-floor heating and cooling within the energy simulation tool. Besides the HVAC system configuration and HVAC component parameters, control strategies are necessary as input for energy simulations. These strategies define the simulated behavior of the HVAC components to act as a system and serve the building as intended. These control strategies in current simulation tools are simplistic when compared to actual control implementations.

Last but not least, every energy simulation tool needs specific simulation parameters, for example numeric convergence tolerances, that are needed for the underlying simulation model of the engine. These parameters influence the numerical behavior of the simulation engine. Also, the definition of parameters such as the simulated time frame and the time step (if applicable) has to be provided.

2.3.3.Assumptions in energy simulation

As mentioned earlier, the input, especially weather data and internal loads, for energy simulation is already based on assumptions, as are the thermodynamic concepts.

For that matter, any simulation is based on assumptions, so that complex interrelations can be simplified and managed. Users need to be aware of these assumptions and be able to decide whether they are reasonable for their specific simulation or not. For example, the majority of energy simulation tools are based on the assumption that every space in a building is well-mixed. In other words, the temperature within a space is spatially uniform. This assumption applies for a majority of one story high spaces; but becomes less acceptable as the space height increases. Atria, for instance, extend over several floors; therefore, the temperature distribution in atria varies according to the height of the space.

Many energy simulation programs use simplified approaches for infiltration and natural ventilation that are pressure independent. While the traditional approach to slightly pressurize a building is sufficient for conventional HVAC systems, it is not adequate for buildings which are primarily naturally ventilated.

2.3.4.Basic tool architecture

Most building simulation tools consist of two different components, the engine and the graphical user interface. While the simulation engine is usually developed by one or more academic and/or research institutions, the user interfaces are mostly implemented by private software vendors.

The simulation engine uses an input file (or files) of a defined format that contains a representation of the previously described input. Based on this input the engine performs a simulation and writes its output into one or more output files. While the output files contain results from the simulation, they also contain information about the simulation run itself, such as warning messages or additional information to evaluate the input. Graphical user interfaces usually wrap around this process and enable the user an easier generation of input files, initiate the simulation with the engine and process the output files to illustrate results in a more graphical manner.

2.3.5.General purpose of energy simulation

A major benefit of energy simulation in design today is the comparison of architectural design alternatives: alternatives to the original building design are validated for both thermal comfort and energy usage. For this type of application, the validity of the discussed assumptions is less crucial. Different design alternatives are based on almost exactly the same assumptions and the common belief is that relative differences in the simulation results are reliable. However, if building usage patterns are depended on the type of design alternative, the comparison of design alternatives may provide less accurate comparison results.

The prediction of absolute energy values of an energy simulation, given the assumptions, is rarely accurate. Usually, various validation tests, such as the BESTEST (Building Energy Simulation Test) that was developed and conducted by the International Energy Agency (IEA), are performed to validate building energy simulation tools relative to each other (IEA 2007). Validation tests comparing actual measurements from test buildings can also be conducted. The differences in absolute values are mainly due to assumptions made regarding input information and the dynamic occupant usage of buildings. To obtain absolute predicted values that more closely match the actual values of the building, energy performance simulation models need to be calibrated with actual measurements. One of the biggest challenges for this comparison is the dynamic human behavior. Typically, internal loads resulting from humans are represented with schedules in energy simulation models; the actual usage of the building, however, changes on a daily basis. It is uncommon today to keep track of occupancy for every thermal zone, and to match the simulation input of occupancy with the actual occupancy. The input of static occupancy schedules in energy simulation cannot properly represent the actual building usage. Statistically derived stochastic distributions may provide a methodology to simulate the actual behavior of people in buildings more accurately, but none of the energy simulation tools provide such a functionality.

Bibliography

NGUYEN Quoc Tuan, BOUJU Alain, ESTRAILLIER Pascal, 2012. *Multi-agent architecture with space-time components for the simulation of urban transportation systems*. Paper, L3I laboratory - University of La Rochelle, Avenue Michel Crépeau, La Rochelle, France.

HUET Sylvie, 2013. *Individual based models of social systems: data driven hybrid micro-models of rural development and collective dynamics of filtering or rejecting messages.* Thesis, Université Blaise Pascal – Clermont II, France.

CASCETTA Elio, 2010. *Modelli per i sistemi di trasporto. Teoria e applicazioni.* UTET Università.

ALONSO William, 1964. *Location and land use.* Cambridge: Harvard University Press.

WETTER M., 2011. *A view on future building system modelling and simulation.* ErnestOrlando Lawrence Berkeley National Laboratory.

CLARKE, J.A., 2001. *Energy simulation in buildings Design.* Butterworth-Heinemann. Glasgow, Scotland.

CHAPTER 3:
The procedure

3.1.Introduction

This chapter provides the description of the procedure followed in the study to observe and compare the models analyzed. In particular, the process to create a support tool to allow a detailed analysis of the models characteristics is illustrated. The tool under consideration is a table here below shown.

As already seen in the previous chapters, the operation of an urban system is characterised by strong and complex interactions located in a frame of urban, environmental and political constraints that cannot be ignored. That's why, take into consideration and understand the existent interactions is more and more necessary and essential and it represents a nowadays challenge for simulation. Much more, the modelling challenge is to establish the existence and the nature of these relations.

For instance, transport models do not take into consideration the impact that transport system causes on the locations system.

The huge diversity and presence of interactions in an urban system justifies the purpose of the present study to prepare a tool to help in individuating the detail of the study models and as a consequence, to supply a support for modelling the operation of a whole urban system.

Furthermore, to better explain the need to integrate interactions of sub-systems in the urban system when modelling, just see statistics on urban system. By way of example, it is reported the energy consumption. The greater energy consumption in an urban system comes from private vehicle and the building heating system. Mentioning the analysis of Lewis (2000), concerning the case of the city of London, he gives the London energy breakdown as buildings 72% (housing 35%, commercial 26%, industry 11%) and transport as 28% (cars 14%, goods vehicles 8%, air/rail/bus 6%). (Information available on : www.developpement-durable.gouv.fr).

It stands to reason that all the objects that act on the urban system produce a great quantity of emission and as a consequence lots of impacts on the urban system. The emitted pollutants come from different sources so as for the energy consumption but they are all part of the urban system and localised in it. For these reason, it is evident that take into consideration each object singularly is nonsense because of their interactions on the same context.

3.2.Construction of the table

3.2.1.Conceiving the table

Examining in depth the procedure, a construction of a table of criteria is realised. The table is conceived with the aim to highlight which elements are present in the study models.

To analyse a model in the way meant in this study, signifies to understand the degree of detail of its input and output data. Thus, it is necessary to choose the criteria that best suited to the objects of the system and to specify them with a high degree of detail so as to appreciate the simulation capacity of the study models.

Models with a high degree of detail are obviously investigated. This force to polarize on the microsimulation approach typically expressed through stochastic, disaggregate models. It means that small units of analysis are considered and their specification and interaction are closer to real situations thanks to the detailed data which they are based on. Since it is not required in this research an analysis based on numerical dataset because it deals with a “prototype system”, the choice of criteria follows the structure of urban census that, in the bargain, represents the only way to obtain very detailed database. The information collected in urban census is generally of interest to the local authorities, the State departments but also enterprises, sociologists, town planners, etc. Such information helps to define:

- on the national level, the social policies and infrastructures to be implemented ;
- on the local level, the urban policies for transport, housing, cultural and sports facilities, school infrastructures and the installation of facilities for young people and senior citizens. For private stakeholders, the census is used for projects for the location of enterprises, shops and services.

3.2.2.The criteria of the table

Models require a huge quantity of input data to permit an exhaustive representation of reality. Since the aim is to highlight the degree of detail of the dataset considered in the models, it is necessary to choose very fine grain criteria. To achieve this target it has been decided to follow the structure of the EGT and SIRENE census and consult the INSEE website.

The “Enquête Globale des Transports (EGT)” is a household transport survey that is organised every 5 to 10 years in the Ile-de-France region (Greater Paris). The survey describes travel behaviour by over 10,000 households and some 25,000 people making over 80,000 trips that consist of one or more travel modes.

The other support called INSEE is the “Institut nationale de la Statistique et des études économiques” and is a Directorate General of the Ministry of the Economy, Finance, and Industry. The official statistical system collects the data needed to compile quantitative results. In this capacity, it undertakes censuses and surveys, manages databases, and also draws on administrative sources. INSEE organizes the population census and tracks demographic changes. It produces the main indicators for the national economy, such as the national accounts, the consumer price index, and other short-term economic indicators.

It periodically conducts statistical surveys of households on topics including employment, living conditions, housing, and health.

It gathers information from enterprises on their characteristics. It participates in the improvement of collection methods. Using the data collected, INSEE prepares studies on the national economy, in particular the production system: economic conditions, analysis of major economic and financial balances, analysis of the situation and behavior of enterprises, and analysis of economic activity sectors. It produces studies on French society, covering demographic behaviors (births, deaths, migrations), education and training, employment and unemployment, income and poverty, and living conditions.

These studies often include a spatial dimension, such as the geographic distribution of people and economic activities, and exchanges between territorial units. INSEE prepares very-short-term forecasts on the French economy. It develops and applies macroeconomic and demographic models to contribute insights on medium- and long-term changes in the French economy and society.

INSEE also manages the SIRENE business register. It is the enterprises and establishments inventory which the INSEE is based on to create the SIRENE database and it is the other support taken into consideration to choose the criteria. The register records the full title of all companies and their establishments, whatever their legal category and whatever their sector of activity (industry, traders, craftspeople, the professions, farmers, local authorities, banks, insurance, associations, etc.), located in France and in the overseas departments.

The register lists all individual entrepreneurs or corporate bodies that are listed in the business register, in the trade directory, employ salaried workers, have tax obligations, receive public funding.

It’s worth to remark that here the main investigated aspect is not the numerical value of each population, activity, displacement, territory and impact feature but the way and detail to collect data that's why surveys are take just as a landmark and finally the models capacity to take into consideration such a fine grain level of information and dataset is investigated.

3.2.3.The papers of the table

Going now ahead in the table structure, it is made up of six main "objects papers":

1. Agent;
2. Activity;
3. Displacement;
4. Territory;
5. Interaction;
6. Impact.

Each of them includes the huge quantity of sub systems that interact within themselves in the urban system and they are described through further characteristics, the criteria, chosen according to the surveys above mentioned.

After having chosen the six groups, the next step consists in the specification of the whole components explicating the criteria for each object.

Polarizing now on the papers, a comprehensive description is provided. The criteria will not been listed in their whole by reason of their multitude but pictures of table are shown. For each object a table figure is provided; the figures are not entire by reason of the copious number of the listed characteristics. The whole table is visible in the annex.

1. *Agent.* Starting from the agents, they are spilt up into *"Individual"* and *"Household"*. To understand why population is usually represented by agents just think that since humans want to be mobile, and transportation of people and goods is a necessary part of economy, and since transportation itself has negative effects on humans (traffic congestion, safety issues, etc.) and the environment, the process of planning an effective transport system infrastructure involves finding a compromise between this positive and negative aspects. Since building and mantaining transport infrastructure is an expensive long term investment which influences typically a large metropolitan area containing millions of inhabitants, transport planning technologies should be capable of predicting long term impacts. Even more, infrastructural changes in the system also change the individual needs of each resident. Therefore, planning technologies should also reflect changes in the behaviour of each individual in the area. Even though planning is, at least partially, done to meet the needs of the

travellers, people are selfish and are not concerned about the system itself. The travellers use the transport system for their own benefit, to move themselves or to move goods for economic purposes, without much regards to other travellers using the system. The system offers only limited resources (road capacity, space, etc.), so the users end up competing for those resources. Individual travellers do not worry about the functioning of the system as a whole; they only care about the part they use. In fact they cannot generally perceive any more of it than what they experience. As such, they are not generally aware of the impact their own decisions have on the rest have on the rest of the system or the other travellers. It is up to the planners, and thus, planning technology, to consider the entire system, how the collective impact of the individual decisions made by its users affect the system as a whole, and how those users will react to the system.

As we can understand, individuals are obviously the most basic unit of population, as well as the level at which many decisions occur.

Going back to the structure of the table, agents are here characterized by further variables with the purpose to replicate, as closely as possible, the properties of the targeted population.

- *Individual*: they are characterised by state variables that include: personal characteristics, professional status, family context, transport accessibility, level of education, occupation, principal occupation, professional status per person, vehicle use status, and individual updating (aging, mortality, births).

  Moreover, no less important than the state variables are the spatial variables such as residential situation and place of work. Localising agents during their daily activity and timing evolution is one of the hardest challenge for simulation models.

Agents	Characterization			
Population simulation				
Individual	Personal characteristics	Age		

		Excluded age classes		
		Gender		
		Disabled persons (reduced mobility)		
		Persons with health issue		
		Level of educatio/schooling		
		Web purchase		
		Web admnistrative formalities		
	Occupation and professional situation characteristics	Social-professional status, current or passed		
		Social-professional status (level of detail)		
		Principal occupation		
		Primary work location		
		Type of workplace		
		Availability of parking at workplace		
		Availability of bike-parking at workplace		
		Income		
	Family circumstances	Family circumstances		
		Dependent child		
		Temporal evolution		
	Residential situation	Resident/non-resident		
		Permanent resident		
		Other		
		Occupancy status		
		Housing		
	Access to transport	Public transport subscription	Yes	
			Non	
			Type of subscriptions	Weekly
				Monthly
				Annual
			Number of transit journeys	Limited
				Unlimited
			Concerned transport network	
			Zones	
		Other subscriptions		
		Cost per persons (supported by persons)		
		Shared-transport subscriptions	Car-sharing	
			Bike-sharing	
			Car-pooling	
			Type of subscription	Weekly
				Monthly
				Annual
				Daily

		Driving license (cat.B)		
		Driving course		
		Accompained driving		
		Driving license for mopeds (cat.A)		
		Car availabiltiy		
		Individual exclusively use vehicle (the entreprise makes vehicle available)		
		Rent of parking, insurances costs, maintenance costs supported by persons		
		Rent of parking supported by the entreprise		

- *Household:* is the second explicitly entity represented. A household is defined as a group of people living together within a single dwelling unit, without these persons necessarily being blood-related. A household can be constituted by a single person. As for the individuals, households are described by several attributes.

  In the table there are the state variables: personal characteristics, economic characteristics, housing accessibility, transport accessibility, level of education, occupation, principal occupation, professional status per person, vehicle-use status, and household updating (aging, mortality, births, divorces, new household development, residential mobility) and spatial variables such as residential situation and place of work.

Household	Personal characteristics	Age of the head of the household
		Socio-professional status of the head of the household
		Members of the household
		Reletionships with the other members of the household
		Temporal evolution
	Economic characteristics	Number of working persons (actives)
		Total income of the household
		Socio-economic characteristics
		Rent or amounts of reimbursement excluding charges
		Rental subsidity
		Amount of charges
		Rent of parking supported by the household
		Vehicle maintenance costs supported by the household
		Vehicle insurance costs supported by the household
	Access to housing	Household dwelling

		Occupancy status
		Nomber of dwellings available for the household
		Parking places owned by the household
		Telephone availability in the housing
		Wi-fi availability in the housing
	Access to transport	Light weight vehicle available for the household (the entreprise makes it available)
		Number of driving license (cat.B)
		Number of vehicles
		Number of bikes
		Number of electric bikes
		2/3 wheel vehicle available for the household
		Vehicle status
Individual and household updating	Individual	Births
		Deaths
		Ageing
	Household	Changement of the workplace
		Divorces
		Creation of new households
		Modification on primary households
		Residential mobility

- *Activity:* household and individual travel patterns are generated from the need or desire to pursue activities in time and space. However, their desires are limited by personal/physical constraints and by the institutional, economic and cultural context. Since not all the activities can be done in the same location, agents have to travel which produces traffic. Moreover, to plan an efficient day, many decisions have to be made by each agent.

  The object activity is presented split up into *"Activity"* and *"Activities program"*.

  - *Activity* is described by: motifs, spatial characterization (geographic localisation, type of place of work, type of shopping place, cultural place, leisure and sport place), time characterization and modes (group composition decision).
  - *Activities program*: the word activity refers to actions such as "being at home", "being at school", "working", "shopping", etc. An activity program contains the pattern of activities individual or household wishes to perform along with the location of each activity. For these reason, in the table the activities

program is specified by: agents, principal mode, activity duration, activity chain decision, activities starting time choice decision.

Activity	Characterization	
Activity	Motives (EGT)	Domicile (go out, go back)
		Second home, occasional dwelling, hotel, other
		Working at the work place
		Working at an other place
		Have prosessional meeting
		Nannies, crèche, etc.
		Go to preschool, primary school
		Go to High school
		Go to Lycee
		Go to College
		Go to University
		Go to the shopping centre
		Go to the hypermarket, supermarket, shopping arcade
		Go to the small and medium-sized trade
		Go to the covered market and open air market
		Receive health care
		Submission of an application and looking for a job
		Look for a job
		Take part in leisure cultural, sporting and associational activities
		Take a walk, take driving lessons
		Go to the restaurant

		Visit family and friends
		Accompany someone
		Look for someone
		Bring somebody to transport modes
		Pick somebody up from transport modes
		Make a professional tour
		Sport
		Leisure
		Culture
		Other
	Place	Zone
		Place (job, purchase, culture, hobby,sport)
		Geographical localization
	Time	Activity day (working day, Week-end, etc.)
		Frequency
		Time slot
		Duration of the activity
	Practical modalities	Groupage (alone/group)/capacity for each given activity
		Context/modalities
		Private constraints
		Schedule flexibility
		Priority
Activities program/plan	Agents	
	Principal motive beyond domicile	
	Day	Working day, week-end, holiday, etc.
	Starting time	
	Average duration	
	Elementary activities	

	Standard deviation of the average activity duration	
	Order	
	Timetable of the program	

- *Displacement:* it is recognized that travel is a derived demand and the need to travel arises from the more fundamental need to participate in activities as above mentioned. Displacement is a person motivated trip between an origin and destination through an itinerary and for a certain period. Generally, it is the result of a sequence of choices made by the agent.

  It is worth to recall the users' decision characteristics to better understand the choice of the criteria. The agents' decisions are usually affected by four theoretical components:

  - a person's decision is based on a utility function assigning a numerical value to each option;
  - the person defines an exhaustive set of alternatives strategies among which just one will be selected;
  - the person can build a probability distribution of all possible events and outcome for each alternate option;
  - the persons selects the alternative that has the maximum utility;

  Utilities depend on characteristics of the alternatives and the decision maker. The utility function consists of deterministic part and a stochastic part which is assumed to follow a pre specified distribution. The deterministic part is explained by the decision maker preferences and characteristics of the alternative.

  The characteristics chosen to describe displacements follow the general four-step procedure that reflects an assumption about the order in which decisions involving different choice dimensions are made, and therefore about how these decisions influence each other.

  The table "Displacements" paper is structured in the following way:

  - *Displacements* that are represented by : social effects such as mimetism, ecologic sensibility, surrounding influence, habits; trip purpose; time that refers to duration, departure time, arrival time, frequency, punctuality, reliability; itinerary (computation algorithm); modes that represents the choice of transportation mode.
  - *Networks* meant as services supply and modes alternatives supply;

- *Individual transport supply*;
- *Collective transport supply*;

Displacement	**Caracterization**				
Displacement/trip/journey	Social effects	Mimétisme, entourage impact (ecological sensibility), habits			
	Trip purpose/motives	Activity at origin: place and motive			
		Activity at destination: place and motive			
		Size of departing group			
		People with disability			
	Time	Duration			
		Departure time			
		Arrival time			
		Frequency			
		Punctuality			
		Reliability			
	Itinerary (computational algoriythm)				
	Modes	Sequence of patterns	Departure time		
			Arrival time		
			Path		
			Mode		
			Unit	Persons	
				Freight	
		Contraintes	Displacement genarelized cost		
			Mode genarelized costs		
			People's equipment		
			Ecological sensibility		
			Comfort		

			Distance		
			Distance on foot		
			Accessibility		
			Aspects linked to time		
			Aspects linked to space		
			Equipment quality		
			Quiet and security		
			Crowded place		
			Parking availability		
		Principal mode of displacement	Individual transport	Light weight vehicle	Brand and model
					Type of vehicle
					Turism vehicle: different size (break, berline, commercial) or commercial vehicle < 800kg
					Commercial vehicle: 800-1000kg
					Commercial vehicle > 1000kg de charge utile mais <3.5tonne de PTAC
					Camping-car
					Car without permission
					Vehicle's energy
					No-plomb
					Super
					Diesel
					Hybrid
					Electric

					Year of placing into circulation of the vahicle
					Puissance fiscale
					Average yearly mileage
					Check mileage
					Status
					Consumption
				2/3 wheels motorized	Brand and model
					2 wheels
					Moto
					Scooter
					Other
					3 wheels
					Type of engine
					2 stroke engine
					4 stroke engine
					2/3 wheels energy type
					Electric
					Fuel
					Year of placing into circulation of the vahicle
					Engine size/cubic capacity
					<50cm3
					50-125cm3
					>125cm3
					Average yearly mileage
					Check mileage
			Public transport (Ile de France)	Type of vehicle	
				Train de banlieue SNCF	
				RER	
				Orly Val	

				Metro	
				Tramway	
				TVM	
				Bus RATP Paris	
				Bus RATP banlieue	
				Bus OPTILE	
				Noctilien	
				Bateau bus / vogueo	
				TAD	
				Transport Employeur	
				Ramassage Scolaire	
				Thandicapé	
				Autres TPC	
				Taxi	
				Avion	
				TGV	
				Grandes Lignes SNCF autre que TGV	
				TER	
				VP Conducteur	
				VP Cond Covoit	
				VU1 Cond	
				VU2 Cond	
				Cond 2RM Non Immat	
				Cond 2RM	
				VP Pass	
				VP Pass Covoit	
				VU1 Pass	
				VU2 Pass	
				Pass 2RM NI	
				Pass 2RM	
				Bike-sharing	
				Autre VLS	
				VAE	
				Fauteuil / voiturette	
				Roller, skate, trot	
				Autre	
				Type of energy	
				Enleaded	

				petrol	
				Super	
				Diesel	
				Hybrid	
				Electric bike	
				Methane	
				Capacity	
			Soft modes transport	Type of vehicle	
				MAP	
				Bike	
				Roller, skate, trot	
				Bike-sharing	
				On foot	
				Electric bike	

- *Territory:* it, though varying greatly throughout Europe, plays everywhere the same roles as the physical base for productive activities, the life support system for people and natural resources, and the place where the impacts of most policies can be seen or felt. It is the locations of activities and therefore origins and destinations of trips.

  For these reasons, territories have a strong influence on the objects above mentioned and once again, it represents the context where activities and choices take place and by which agents interact.

  The paper "Territory" of the table is divided in the further following subgroups:

  - *Territory* that is described by its physic characteristic such as morphology, topography, weather conditions, density, land occupation, poles, accessibility, mesh;
  - *Infrastructures:* type, circulation policy, accessibility;
  - *Service supply*;
  - *Public space;*
  - *Parking fleet;*
  - *Building:* category, activity, physic characteristics, services, both agents and materials in/out flux;
  - *Building and urban shape update*;
  - *Establishment:* identification, type of activity, physic characteristics, both agents and materials in/out flux;
  - *Firms:* identification, legal category, APE code, firm status, physic characteristics, firms and establishment update;
  - *Housing:* physic characteristics, nearby services;

Territory	Characterization		
Territory	Mesh	Whole size	
		Mesh (spatial unit)	City
			Distirct
			Neighbourhood
			Building
			Zone
			Cell
	Morphology et topography		
	Climate		
	Land use (objects)	Building	
		Green space	
		Public space	
		Infrastructures	
		Public transport network	
	Density	Building	
		Housing	
		Employment	
		Bio-diversity	
		Equipment and service	
	Point of attraction	Type of service	Personal services
			Trade
			Education
			Health
			Sport, leisure and culture
			Transport
		Distance	Proximity range
			Mid-range
			Higher range
		Type of point of attraction	Park
			Classified building
			Point of attraction for employee
			Industries
	Accessibility (transport network)	Spatial	
		Temporal	
Infrastructure	Type	Section	
		Crossroads/station	
	Circulation regime	Reserved lane	
		Tidal flow lane	
		Bus/taxi/bike/rail reserved lane	
	Access conditions	Private access way	
		Sidewalks	
		Public road	
	Crossed surrounding	Type	Urban 30 km/h
			Rural 70 km/h
			Highway 120 km/h
		Density	Hyper-dense (>20000hab/km2)

			Very dense (8-10.000)
			Dense (4-5.000)
			Medium(2.000)
			Low (1.000)
			Very low (100-200)
			Rural (10)
		Urban quality	
		Circulation signal	Traffic light
			Roundabout
			Traffic sign
			Slope
			Pedestrian crossing
			Congestion
			Parking
			Other

- *External interactions:* interactions with the surrounding have a great weight on the context too. Each zone cannot be considered as isolated.

  They are split up into:
  - *Zones-external accessibility*;
  - *In/out, Out/in and Cross displacements;*
  - *External poles;*
  - *Migration flux;*
  - *Spatial correlation among zones;*
  - *Emissions;*
  - *Freight flux.*

Interactions	**Caracterization**		
Interactions	Zone-external accessibility		
	In-out displacements		
	Out-in displacements		
	Crossing displacements		
	External points of attraction	Services point	Personal service
			Trade
			Education
			Health
			Sport, leisure and culture
			Transport
		Point of attraction for employee	Number of jobs
			Job category
			Attractiveness of jobs
		Freight point	

	Migration flows	Residential mobility	
		Commuting mobility	
		Occasional or temporary mobility (tourism)	
	Spatial correlation within zones		
	Emissions		
	Freight flow	Goods delivery and collection	
		Goods trip loops	
		Vehicle occupancy of the road	

- *Impacts:* transportation systems play a significant role in urban air quality, energy consumption and carbon-dioxide emissions.

  The table ends with a section centers on impacts. Nowadays impacts represent a key issue in the world of mobility. It is clear that each object produces impact on the other or it is exposed impacts caused by other objects.

  The impacts considered in the table derived from transport and land use and impacts on population.

- *Transport impacts*: it is necessary to distinguish the atmospheric pollution and the noise pollution; the first one is represented by the *emission* and *dispersion* phenomenon due to the type of vehicle, infrastructure and circulation, weather conditions, building-way disposition, type of models and pollution cycle; on the other hand, noise is described by emission and propagation caused by vehicle speed, type of vehicle, distance from the source, buildings materials, facade geometry, air, neighbourhood morphology.
- *Land impacts* are the consumption of natural resources and pollution and noise emission;
- *Social impacts* are the effect on people life;

Impact	**Caracterization**				
General characteristics					

Transport impacts	Pollutants	Emission	Vehicle fleet	Moto-sidecar-trike	
				Light duty vehicle	
				Mid-sized vehicle	
				Heavy duty vehicle and coach	
				Energy-efficient vehicle	
				Diesel vehicle	
				Other	
			Infrastructure/Circulation	Road conditions	
				Driving style or behaviour	
				Start/stop cycle	
				Fuel consumption	Type of vehicle
					Type of ground
					Driving style
					Weather conditions
					Road conditions
				Mobility policy circulation	Traffic light
					Roundabout
					Road signs
					Slope
					Pedestrian crossing
					Congestion
					Road parking
					Parking
					Visibility
				Pollutants	Carbon monoxide CO, dioxine CO2
					Sulphur dioxide SO2
					Nitrogen oxides Nox
					Light hydrocarbons
					Volatile organic COV
					Suspended particles PM10/PM2.5

					Heavy metals:Lead Pb, Mercure Hg, Arsenic As, Cadmium Cd, Nickel Ni
					Aerosol
					Ozone O3
		Dispersion	Climatic conditions	Weather	
				External temperature	
			Physical conditions	Road conditions	
				Turbulence due to vehicle	
			Type of models (dispersal curve)	Eulerian	
				Lagrange	
				Gaussian	
				Canyon	
			Pollution cycle	Annual cycle	
				Weekly cycle	
				Daily cycle	
	Noise	Emission	Vehicle flow		
			Speed		
			Speed variation		
			Vehicle		
		Propagation	Vehicle		
			Distance from the source		
			Presence of noise barriers		
			Buildings density		
			Building materials		
			Geometry of the façades of the building		
			Air heterogeneity		
			Opening roads		
			Overall neighbourhood morphology		
Land impacts	Climate change				
	Environmental degradation				
	Environmental health				
	Land degradation				
	Land use				
	Land pollution				
	Desertification				
	Water pollution				

	Air pollution				
	Exploitation of natural resources				
	Ozone depletion				
	Waste				
	Air quality				
	Habitat fragmentation				
	Energy consumption				
	Soil contamination				
Social impacts	Quality of life				
	Culture life				
	Habitat fragmentation				
	Partecipation at political system				
	Quality of air and water people use				
	Health and wellbeing				
	Personal and property rights				
	Fears and aspiration				
	Risks				

3.3.Use of the table: How to fill in the table

The last step of the procedure lies in the compilation of the table. This means that, after a survey on models that will be handled in the next section, the main aspects of the studied models will be collected in the table so as to have a tool to compare models and understand their quality of detail in description. The action of filling in the table simply consists in answering the questions:

- *"Does the model under examination consider/take care about a definite object (agents, activities, displacements, territory, impacts)?"*
- *"Which attributes does the model consider for each object?"*
- *"Does the model is complete?"*
- *"Which level of details does the model take into consideration?"*

The filled table is provided in the annex.

To make the table easier to read and understand, each model is coupled with a color:

- MATSim: green;
- MobiSim: orange;
- TRANSIMS: blue;
- ILUTE: rose;
- UrbanSim: red;
- ANTONIN: yellow;

Moreover, when information were available, a more detailed description is provided directly in the table.

Once the table is filled in, it will be a support tool for an analysis of the characteristics of the investigated models. The analysis is provided in chapter 5.

Furthermore, it gives a whole broad of the quality of the model and can guide a first approach to them.

It is worth to underline that to find the characteristics of each models further application to real case have been observed.

The chapter 5 provides a review of the conclusion drawn from the analysis of the table.

Bibliography

HUET Sylvie, 2013. *Individual based models of social systems: data driven hybrid micro-models of rural development and collective dynamics of filtering or rejecting messages.* Université Blaise Pascal, Cleremon II, Ecole doctorale Sciences pour l'Ingénieur de Clermont-Ferrand.

NGUYEN Quoc Tuan, BOUJU Alain, ESTRAILLIER Pascal, 2012. *Multi-agent architecture with space-time components for the simulation of urban transportation systems*. Paper, L3I laboratory - University of La Rochelle, Avenue Michel Crépeau, La Rochelle, France.

EGT, Ile de France 2010. Available on the web site OMNIL, http://www.omnil.fr/spip.php?article86.

INSEE, Institut Nationale de la Statistique et des études économiques. Web site : http://www.insee.fr/fr/

SIRENE Base de donnés : la base de données des entreprises et des établissements. Web site : http://www.sirene.fr/

AIRPARIF, Association de surveillance de la qualité de l'air. Web site: http://www.sirene.fr/

Ministère de l'écologie, du développement durable et de l'énergie. Web site : www.developpement-durable.gouv.fr

CHAPTER 4:
Models review

4.1.MATSim

4.1.1.Introduction

MATSim (Multi Agent Transport Simulation) is a dynamic sthocastic model. The agent-plan evolution and agent-based traffic flow simulation is the core of MATSim among a group of other modules. The rationale of MATSim employs evolutionary optimization techniques and micro-simulation to optimize individual agent's choices for a given plan including path, departure time, activity location/duration and mode choice.

MATSim executes the traffic assignment through the following procedures:

1. Initial demand: given the individual agents' initial activity plans containing the precise description of the activity chain, each activity location, their duration, start and end time and the trips connecting two activities including its mode and route, every agent is loaded into the Mobsim simulator based on her/his plan;
2. Execution: every agent is loaded into the Mobsim simulator based on her/his plan. This step represents the interaction among agents and it provides with a physical simulation of the day plan;
3. Scoring: according to the simulation results, a score for the plan is calculated on the utility function. The plan score is compared with those in the agent's memory and the plan with the worse score is eliminated;
4. Re-planning: mutation and/or crossover operation of the evolutionary algorithm is done via variation of routes and/or departure time of agent's plan. Only a certain percentage of agents are allowed to re-plan and the other reuse one of their existing plans. The chosen agents create new plans which are executed and evaluated in the next iteration.

   When each agent's utility remains constant over time, it indicates that the system reaches a relaxed state approaches to the system best score.
5. Analyses: the final traffic assignment results from the iteration (event) of the executed plan of each agent when the system reaches a stationary state.

Therefore, MATSim's demand modeling procedure is an optimization process based on the concept of evolutionary algorithms while the traffic assignment is the microscopic and completely time dynamic execution of each agent individual demand based on system constraints given by the transport network and its attributes.

4.1.2.Overview of the MATSim architecture and dataset

In MATSim the input data could be split up in:

1. Network data: the network file gives information about the transport infrastructure. A MATSim network contains links and nodes each with its specific attributes such as the node coordinates or the link capacity;
2. Plans/population: plans represent the population and the demand of a scenario;
3. Configuration file: the configuration file is the way to adapt the behavior of MATSim;
4. Additional input: for example facilities and count data. Facilities are an optional part of MATSim. They can roughly be interpreted as buildings. Count data is one of the most important sources for validation as obviously they are associated to a small measurement error;

Plans file and *population file* are synonyms in MATSim. The MATSim plans file describes the MATSim population and its travel demand. Each person needs a unique identifier and at least one plan. The plan contains activities and legs. The activities need at least the type, a coordinate-pair (x, y), and an end time. Legs between activities need a mode, usually set to "car", but do not need any route information at this stage. The simulation expects all activities to take place on links or in facilities.

Network files contain links and nodes. Links are defined by a start and an end node. Further important link attributes are length, capacity, free-flow speed in meters per second and number of lanes. An attribute specifying by which transport modes the link can be traveled was added.

Facilities are an optional but helpful input component. MATSim agents perform activities at links or alternatively in facilities. Facilities can roughly be interpreted as buildings.

The count data is the counted hourly volume.

Focus on the structure MATSim is a modular approach and the modules are:

- FUSION;
- IIDM;
- EXEC;
- SCORING;

- REPLANNING.

The first two processes rely on the available data of the region of interest. Since the quality and quantity, and resolution of data can vary a lot from a scenario to another, the scenario creation and the initial demand modeling process steps can vary as well. MATSim therefore provides in its core only the resulting data representation of the infrastructure (network and facilities) and the population including each person's individual demand.

The module FUSION or IIDM has as input data network, land-use and population information and it creates a network, facility or population as a rough approximation of the existing ones. If at the later stage, more detailed information occurs the system allows one to add another module that replaces the already created one. Each created scenario can be part of MATSim and therefore, another user with the same needs is able to reuse the modules for his/her own scenario.

The analysis process works in the same way, with the difference that now the input data follows MATSim standards and therefore is useable for any given scenario.

The iterative demand optimization process (exec, scoring, replanning) is, in a way, the core of MATSim. While all other steps are run once in a sequential order defined by the user, this part optimizes the demand for each individual synthetic traveler in the scenario such that they respect the constraints (network, facilities) of the scenario and the interaction with all the other action of the region.

Usually, a method of relaxation is used to find an equilibrium state. For route choice the Wardrop equilibrium (Wardrop, 1952) describes such a relaxed state. But not only route are optimized in MATSim.

Instead, the complete daily plan, including routes, times, locations, sequence of activities, activity types, and so on, of each agent is optimized. Each agent tries to execute its day with highest possible utility. The utility of a daily plan depends on infrastructural constraints (capacity of street, opening times of shop, etc.) and on the daily plans of the other agent in the system. This implies that the effective utility of a daily plan can only be determined by the interaction of all agents. This is the place where co-evolutionary algorithms come into play. It is important to note that within a co-evolutionary algorithm the individuals are the plans, while the synthetic travelers are the entities that co-evolve.

The execution of the daily plan (EXEC) is handled by a corresponding traffic flow simulation module, in which the individuals interact with each other and they may generate congestion on streets of high usage. The SCORING module calculates the utility of all the executed daily

plans. Plans with a high utility (high “fitness”) survive, while plans with a low utility, for example caused by long travel times because of traffic jams, are eventually deleted.
The creation and variation of daily plans (REPLANNING) is distributed among different modules that are specialized on varying specific aspects of daily plans. The modifications in the plan of a single agent are completely independent on the replanning of all the other agents’ plans.

To conclude, MATSim is consistently constructed around the notion that travelers (and possibly other objects of the simulation, such as traffic light) are “agents”, which means that all information for the agent should always kept together in the simulation at one place. Agents are synthetic persons and they are specified by demographic attributes like age, gender, car license ownership, car availability, public transport ticket ownership and employed status.
As a consequence of agent design, it is easy to maintain several plans per agent. This facilitates to interpret the iterative part of MATSim as a co-evolutionary algorithm, where every agent draws on a population of plans in order to find better solutions for him/herself.
Finally, the traffic flow simulations produce information about where each agent is at a specific time of the day and what it is doing at that time. Each agent generates for each of its actions (begin/end of an activity, entering or leaving a link, etc) a temporally and spatially localized event.

4.2.MobiSim

4.2.1.Introduction

The simulation model, named MobiSim, was elaborated on the demand of the French Ministry of transport. The objectives were to create the tool for a relevant assistance in strategic decision-making on the transportation system development in the relationships with the territory development in the metropolitan area.

The principal objective of MobiSim is to integrate the diverse processes that structure the urban areas in order to study, understand and manage the dynamics of urban mobility in European cities for the next twenty years. The core of the model is the system of interactions between household's and enterprises behaviour, transportations system and urbanisation processes.

4.2.2.Overview of the MobiSim architecture and dataset

MobiSim is a LUTI model (Land Use and Transport Integrated) which is based on:

1. Behavioural modelling;
2. Multi-level approach;
3. Forecasting methodology;

This means that it takes into consideration both the data concerning the population and other factors strictly related to the population such as the environment where it develops.

The pattern is organised in three steps:

1. Construction of a synthetic agent/space framework: characterization of people, households, housing, amenities, neighbourhood and networks;
2. Daily mobility modelling: modal and temporal distribution of traffic flows by trip motives;
3. Residential mobility modelling: residential satisfaction and propensity to move/construct;

These three steps are strictly linked and they produce different effects on each other such as the accessibility and nuisances due to daily mobility alters the quality of life and the environment, or residential mobility modifies the distribution of traffic flow and urban structure. To take into account these connexions in MobiSim, the modules are successively employed to distinguish the phases of Initialization, Modelling and Iteration.

1. Initialization:

- construction of a synthetic agent/space framework (time t);
- construction of transport networks and amenities;
- daily mobility modelling (time t) and identification of transport network characteristics (access time, congestion, etc).

2. Modelling:
   - demographic evolution (time t +1);
   - daily mobility modelling (time t +1);
   - residential mobility modelling (time t +1);
3. Iteration: n time iteration of the modelling steps till t +n.

These phases are represented as modules that concurrently develop in MobiSim. There are four many groups of modules:

1. Data module (D);
2. Process module(P);
3. Impact module (I);
4. Visualisation module (V);

The Process module stands for the core of the program because the dynamic simulation of transport and population takes place by means of it.

For each year, the model simulates household activity programs and calculates people displacements and good transport. It gives a congestion overview and estimates total demand for each mode (road, public transportation and light modes). People fluxes are generated by the demand for mobility by objective and by zone on the basis of transport supply (possible distance and maximal speed). Flux intensity compared to system capacity decreases the speed of displacement. The increase in travel time is an important factor to determine modal choices (by private car, by route's collective transport, by railway's collective transport or by light modes). Environmental quality is partly linked to urban mobility, to displacements and to flux intensity. These factors affect the quality of the air (noises and atmospheric pollution due to transport activities) and the land use (housing, transportation networks and infrastructures, employment areas, natural spots, etc.) through the location choices of households and enterprises and through global agent decisions.

Concerning data, the model uses:

1. Socio-demographic data sets posted on the INSEE web portal. They are grouped in five files:
   - Population;

    - Households;
    - Education;
    - Activities;
    - Housing.
2. Socio-economics data sets posted on the file SIRENE (INSEE) in which it is possible to distinguish:
    - Establishment type of activity;
    - Number of employees;
    - Demand;
    - Localization;
3. Geographic data sets posted on BD Topo (INSEE, GIS shapefiles) that specify:
    - Buildings;
    - Their localisation;
    - Their geometry;
    - Their function;

<u>Spatial characterization</u>

The studied system is limited to the urban area. It is an “open system” because of the exchange with the external world is considered through the medium of macroscopic scenarios. The model deals with the localization of activities and household on the territory of the urban area.

The system “urban area” is disaggregated into zones that correspond to a geographic entity. Every zone is characterized by statistic data consistent with the model detail degree. According to the French conglomerate, a zone is equivalent to an IRIS zone or to a group of them.

A physic mesh, (25 ha), is provided to complete the spatial description of the territory.

It is useful to simulate the dynamic land occupation and to assess the social and environmental impacts due to mobility.

Finally, the zones could be disaggregated in cells according to the different type of soil occupation even if the dynamic agents (household and enterprise) remain localised at zones scale.

Temporal characterization/scale

The year 2025 is the simulation horizon of the project. MobiSim goal is to integrate the different dynamics (daily mobility, employment dynamic, activity dynamic, residential localization, infrastructure, territory developing) that structure the urban area and change the urban mobility.
The model time of reference for the demographic events, the choice of localization, etc. is the year. This is a great limit of it in terms of traffic modelling. Then, people trips and freight transport are simulated on some given days of the year of reference.

Construction of a synthetic agent/space framework

The MobiSim model simulates the interaction of several types of agents.
The Spatial agents represent the urban morphology where the trips of dynamic agents are located.
Then, the Dynamic agents, represented by the households and the enterprises, get around the urban area realising their activity program.
Moreover, the Static agents that form the infrastructures and transport offer of the territory, finally the Global agents, that stand for political maker and transporters that can influence Spatial and Static agents.

- Spatial agents

  The spatial agents refer to the different urban zones and their amenities that help to calculate zone’s attractiveness for each household and enterprises depending on its own characteristics. The attractiveness depends on several factors: the cost of housing, the environmental quality, the accessibility of urban amenities, and the supply and quality of transportation services (frequency and comfort).

  The geographic space is depicted in three different scales:

  1. global scale: the urban area that cover the entire system;
  2. zonal scale: static and administrative zones;
  3. fine netting scale: mesh and cells.

  Concerning the Urban Area, the demographic and macro-economic scenarios are the input data, and the global performance indicators of urban mobility are the output. In addition, there are two hypothesis relate to the interaction of urban area and the nearby area: they assume the presence of an impact on urban mobility and population evolution caused by that interaction.

In the matter of Zones, they are defined as geographic entity which statistic data are associated. Households and enterprises localisation and their journeys are studied at that spatial dimension. Zone’s size depends on the simulation capacity and it has to be as considerable as to keep the heterogeneity of the territory.

The Mesh is the finest scale of the area representation. Anonymous households and enterprises dates are matched to each cell in order to quantify how many households are associated to the mesh and how many of them are exposed to traffic pollution.

The spatial zones agents are characterized by their buildings, housings fleet, urban and rural amenities and their accessibility. These characteristics will set zone attractiveness.
Buildings are divided in residential and non-residential and for any of them localisation, shape and function are known.
Housings are classified according to:

1. their size: five classes (from F1 to F5);
2. their interior: individual housing and collective housing.

The type of housing occupation (property, tenant, social housing) is associated to the household as their characteristic.
Enterprises rooms are represented by:

1. commercial surfaces;
2. offices;
3. surfaces devote to specific establishment such as factory, warehouse, hypermarket, supermarket, etc.

The model designates a number to each trade that represents the frequentation of the building. There is a further distinction for the enterprises between journal and night job and their attractiveness is weighted by the number of employees.
Urban and rural amenities are categorized in:

1. neighbourhood poles: trades;
2. schools: primary school, high school, college, university;
3. cultural and sportive amenities: gym, swimming pool, cinema, restaurant, etc.;
4. public amenities: hospital, public service;

The presence of different amenities in a zone lets highlight its attractiveness, assess the zones use for the different motives and they are factor of mobility.

➢ Dynamic agents

The dynamic agents evolve at a yearly time-step in size, number, locations in urban area and activities. The model takes into account the demographic events (birth, death, marriage and divorce, child emancipation), the economic transitions of individual (activity/inactivity, work/unemployment), the residential choice of household, macro-economic scenarios (unemployment rate, long-term trends in educations, motherhood and cohabitation behaviour), the location strategy of enterprises, and housing and labour markets.

The dynamic agents are divided in individual, household and enterprise.

The object Individual is characterized by:

1. sex;
2. age;
3. age of the end of school time;
4. household of reference;
5. company of reference;
6. status (child, bachelor/spinster, common-law, parent);
7. salary (for categories, age and age of final school time);
8. time (length of time) of daily journeys;
9. driving licence.

Each individual is matched to a household with a method of minimisation of the difference of age and the level of education.

The Household characteristics are:

1. size;
2. type of cohabitation (single, couple without enfant, mono-parental family, family);
3. household members;
4. household chef;
5. salary and housing/transport budget;
6. housing (type, price, surface);
7. number of vehicle;
8. daily trips (motif, place and time);

9. satisfaction degree.

Each household is allocated in a housing itself settled in a building. To realise this operation, the model adopts a minimisation of the difference between the household and housing size weighted by the households incomes.

Concerning the agent Enterprise, there are three different types of agents to distinguish the evolution of employment supply:

1. particular enterprises;
2. small trades;
3. other employment;

The particular enterprises are the one that requires specific resources and their land use is regulated. The small trades are combined in surface unit of 300 m2 that represents neighbourhood poles.

The class other employment grouped the office employments that are dealt with a zones mesoscopic approach. The approach consists in defining the number of active population for each household at the time t, than it subtracts the number of trade and particular enterprises workers. The rest of workers are split up in the other employment. Finally, the workers are arranged in socio professional classes and the office workers distribution on the zones depends on the surface availability and rental and moving costs.

The enterprise attributes are:

1. reference to the mesh and the zone;
2. number of employee;
3. type of activity (agriculture, artisan, industry, wholesale trade, department store, retailing, tertiary, warehouse)
4. kind of rooms and surface;
5. parking capacity.

In MobiSim model, the dynamic agents evolve in the time. In order to be as realistic as the life cycle of agents, MobiSim employs a micro simulation model called Destinie with the purpose of representing the population ageing and renewal.

The methodology consists in the following steps:

1. evolution of individual characteristics: age variation, deaths and end of study age determination;
2. agents socio economic status definition;

3. number of births in a couple and creation of new matched agents;
4. number of separation and creation of new household;
5. child emancipation and household modification;
6. creation of new couple.

Population dynamics could be referred to a short, medium and long term.

➢ Static agents

This class includes the territory infrastructures and transport supply and their costs:

1. infrastructure for private transport (capacity, distance, maximum speed, use cost);
2. public transport network (capacity, frequency, length of time, pricing);
3. parking lot fleet (capacity and pricing).

The aim is to quantify the mobility and its costs, impacts and evolution.

In the model provides accurate information concerning:

1. the assessment of the congestion circumstance probability at peak hour;
2. the evaluation of trips number, cross distance, speed, trips time, modal choice for individual and day;
3. the estimation of mobility and impacts costs.

The physical representation of the infrastructure for private transport consists in highways, principal roads, secondary roads, local roads and their node such as interchange and intersection.

Concerning tolls, they are divided in three types:

1. spatial typology: road section, boundary, zone;
2. pricing: km, forfeit, length of time;
3. temporary variation: peak hour and off-peak hour;

Considering tolls means to add a cost parameter for every road section that will be take into consideration on the generalized cost and it will influence the modal choice.

In the field of parking space, they are divided in parking lot assigned to a particular site (enterprise, station, trade, housing), and in undifferentiated parking lot (road parking and parking area).

The further parameters matched to the parking places are the:

1. type of parking (localised, widespread);
2. pricing (toll, toll-free);

3. number of parking place;
4. residential parking, worker parking, customer parking.

The same approach has been used for the representation of public transport network: physical description of intra zones public lines and a wider representation of zone to zone lines.

4.2.3.Daily mobility

Once the construction of agent/space framework is realised, MobiSim carries on the modelling of agent activities and the correlated trips and freight mobility.

The trips flow distribution is done in two steps:

1. activities program generation;
2. agents' trips distribution.

The time of reference is a standard working day and the activities are concurrent in that day (optimisation approach).

Since knowing the activities program exactly is logically impossible, the model provides with seven activities, called trip's reasons:

1. job;
2. looking for a job;
3. study;
4. shopping;
5. accompany;
6. social net;
7. leisure time.

To generate the activities program, the model arranges an order, a priority and compatibility to the group of activities and it assigns to each agent the more realistic planning mixing up the seven activities.

The mobility distribution rests on the gravitational model (type D.L. Huff) that is implemented in MobiSim: for every trip's reason, the probability of realising a displacement is randomly computed and, finally, it is possible to know the daily trips of every agent.

Concerning freight mobility, MobiSim employs Freturb model and it estimates the value of goods delivery and collection, the goods trip loop, CO_2 emissions and vehicle occupancy of the road.

The modal choice rests on a model based on preferences and behaviours in which nine transport modes are selected and differentiated by costs, speed, comfort, environmental impact and networks.

The costs is a generalized cost that takes into account both the functional aspects of the displacements and the aspects connected to the different users. The model computes:

1. transport generalized cost;
2. trip generalized cost;
3. mode generalized cost (agent weighted characteristics: comfort, agent equipment such as drive licence, ecologic sensibility);
4. minimum cost;
5. relative difference by mode;
6. probability by mode.

The further step consists in the computation of the itinerary that is made by the Dijkstra algorithm: optimization (the shortest way), omniscience (a priori knowledge of the existent ways), optimum path, congestion, Wardrop equilibrium.

4.2.4.Impacts

Starting from the output data of the model regarding trips and modes, it is now possible to calculate the transport environmental impacts in the urban area in three steps:

1. emissions (CO2, pollutant and noise) starting from vehicle fleet and public transport characteristics;
2. exposure population (data at mesh level);
3. effects on population.

The pollutant emissions are computed through emissions/km-speed curves for about twenty pollutant then the noise emissions are deducted from a noise exposure simulation in which the situation of reference and the desynchronization scenario are compared.

According to the last point, the effects are classified as following:

1. health;
2. risks;

3. accessibility;
4. social diversity;
5. equity
6. effects on house prices.

The evaluation of the effects is based on the emissions and exposure population.

4.2.5.Residential mobility

The residential mobility is the last aspect connected to the population that could be modelled through MobiSim. The purpose is to represent the household moves and their new residential localization. This MobiSim module operates together with the daily mobility module.

The model compared the utility function of the actual housing of the household with that of other housing. The goal is to maximize the utility function.

To compute the satisfaction and the utility function, housing weigh is greater than those one matched to the residential environment. To better get real the modelling the update of the housing fleet is necessary since the number of housing is a parameter considered in the computation.

To resume the simulation, there are:

1. household life cycle evolution;
2. residential environment of every housing: residential satisfaction, housing attractiveness, household mobility, housing fleet;
3. at each iteration: variation of housing number according to household expectation.

To conclude, the model functions logically and correctly in its large lines; Nevertheless, the model remains again a tool more for reflection then for forecasting. It is an instrument for thorough comprehension of complex relationships between urban space and development of the transportation systems, inducing the daily displacement evolution in French agglomerations of average size.

4.3.TRANSIMS

4.3.1.Introduction

The Transportation Analysis and Simulation System (TRANSIMS) is a set of tools that are used to conduct travel studies. TRANSIMS was originally developed by Los Alamos national laboratory and includes population synthesizer, activity generator, router and microsimulator and many other tools that are mainly developed to prepare the input and output data. It not only can synthesize the travel demand, but also its router and microsimualtor can be used to analyze the demand impact on the network and generate time dependant link volumes and travel times.

The TRANSIMS microsimulator employs car following, lane changing, and gap acceptance formulations to move vehicles on the network. TRANSIMS microsimulator design and its computational efficiency, makes it a suitable tool for regional transportation analysis.

The TRANSIMS purpose is to develop a set of mutually supporting realistic simulations models and data bases that employ advanced computational and analytical techniques to create an integrated regional transportation systems analysis environment. By applying forefront technologies and methods, it simulates the dynamic details that contribute to the complexity inherent in today's and tomorrow's transportation issues. The integrated results from the detailed simulations support transportation planners, engineers, and others who must address environmental pollution, energy consumption, traffic congestion, land use planning, traffic safety, intelligent vehicle efficacies, and the transportation infrastructure effect on the quality of life, productivity, and economy.

4.3.2.Overview of the TRANSIMS architecture and dataset

TRANSIMS is based on six primary modules: *population synthesizer*, *activity generato*r, *route planner*, *traffic microsimulator*, *emission estimator,* and *feedback controller*. Using these components, TRANSIMS estimates activities for individuals and households, plans trips satisfying those activities, assigns trips to routes, and creates a microsimulation of all vehicles, transportation systems, and resulting traffic in a given study area.

It differs from previous travel demand forecasting methods in its underlying concepts and structure. These differences include a consistent and continuous representation of time; a detailed representation of persons and households; time-dependent routing; and a person-based microsimulator. These advances are producing significant changes in the travel forecasting process.

TRANSIMS simulates the second-by-second movement of persons and vehicles throughout a region. A simple set of rules is used to govern vehicle movement. A 7.5-meter grid describes vehicle location. This grid results in rough instantaneous speed estimates for individual vehicles however average link speeds are estimated reasonably well for time intervals as short as 15 minutes. The time varying data from the microsimulator provides a more accurate representation of queuing and congestion over the course of an entire day compared to methods used for typical static equilibrium assignment models. It is worth to note that it does not simulate complex driver behaviors, detailed pedestrian movements, or precise intersection operations.

Focusing on the primary modules, they are six and with the following characteristics:

- Population Synthesizer: It uses Census data to build synthetic households for the study area, and also uses land use data to locate the households relative to the transportation network. The output of the Population Synthesizer module is the synthetic households with a set of information associated with each household and each individual living in that household. It also provides the household location in the TRANSIMS network including the information on vehicles belonging to each household.

  Synthetic households are usually generated for a block group within a census tract, and each synthetic household is classified either as:

  - family;
  - non-family;
  - individuals living in group quarters such as dormitories.

  Each individual has an associated set of demographics which may consist of age, income, status, etc. These demographics are matched closely to the demographics of the real household. Using the census data of STF-3A (Census Standard Tape file 3), and PUMS (Public Use Microdata Sample), the population synthesizer can estimate a proportion of real households for each block group in each demographic category using iterative proportional fitting (IPF). Synthetic households are drawn from the PUMS data for each block group according to these resulting proportions. TRANSIMS not only creates synthetic households but also matches the demographics between synthetic households and real households. This includes the household structure, the individual incomes and ages, those individuals who work and those who attend school.

After the synthetic households are created, they are distributed spatially to approximate regional population distribution. The Population Synthesizer associates these households to activity locations on the walk link of the TRANSIMS network according to land-use characteristics associated with the activity locations on that link then vehicle ownership is generated for each synthetic household as given by the PUMS data. All the outputs obtained from the Population Synthesizer are used as inputs for the Activity Generator module.

- Activity Generator: the purpose is to generate household activities, activity priorities, activity locations, activity times, and mode and travel preferences. TRANSIMS generates a list of activities for each individual in a synthetic household by using this module.

  Households and businesses have activities that must be, or are desired to be, performed during the day. Many of these activities require the transportation system to move a load (individual or freight) to a certain place at a certain time. Thus, activity demand generates travel demand. These activities and how they are performed depend on the demographics of the household and its individuals, or on the nature of the business.

  Focus on traveller activities, modelling commercial load activities will be difficult until more data is available on shipping. Traveller activities are designated as:

  - Individual activities: require the participation of a specific person in the household, for example going to a workplace;

- Household activities: may be divided or shared among the people in the household, for example going shopping;

Household activities then are estimated from probability distributions dependent on the household demographics. These demographics include:

- the ages of the inhabitants;
- the household family type (single, married couple, married couple with small children, married couple with older children, etc);
- the household income;
- the number of cars on the household;
- the members of the household who can drive.

These demographics are produced by Population Synthesizer module.

Associated with each activity is a set of parameters defining:

- the activity importance;
- the activity duration;
- a time interval during which the activity must be performed.

If it is performed at all (for example, work is mandatory, so a work trip must be made, but a shopping trip is typically not as important and may be skipped on a given day if the scheduling is too difficult).

Locations, such as the household address and the workplace and school addresses, will be provided for mandatory activities. Locations of other activities (shopping) are not specified, the planner will choose these from a list for the locality. Furthermore, to locate the non-home activities, TRANSIMS uses a model that considers the zonal attractiveness value, the travel times between activities and the intensity of activities within the zone.

Also travel behaviour is modelled and that is the propensity of individuals or households with given demographic characteristics to exhibit certain travel patterns or behaviour. Travel behaviour is more global than is travel demand. For example, the choice of driver in a family household given the household's socioeconomic characteristics may be similar (in a probabilistic sense) across all sections of the country.

At a minimum, it is modelled mode preferences for every individual and the travel characteristics in a family household. In particular, it is important to model carpooling and travel arrangements (for example, which person shops) within family households. Furthermore, models of car availability rather than ownership are considered.

Although extremely difficult to accomplish, additional activity demand models for non-passenger trips, including freight, service, and commercial trips are developed.
All models are probabilistic in nature in that for a given set of demographics, a distribution of activities will be produced. The actual activities passed to the planner will be chosen by randomly selecting from this distribution. Logistic regression, classification and regression trees algorithm and neural nets are examples of tools that produce these distributions.

- Route Planner: when combined, the Population Synthesizer, Activity Generator, and Route Planner create individual travel plans in a computer-generated environment. However, to simulate realistic traffic, individuals must interact with the environment and with each other, as anyone who has been in a traffic jam can attest. The Traffic Microsimulator, the module that follows, is designed to meet this need. It produces route plans for every individual according to the activity list generated from Activity Generator. Moreover, the Route Planner also selects the shortest-time (or minimal cost) path in the network for each individual trip. In addition to the activity list from the Activity Generator, the inputs to the Route Planner module include TRANSIMS network (Transit data and Network data), the vehicle file and the link travel times.

A "load" is a traveller or a commodity. A trip plan is a sequence of modes, routes, and planned departure and arrival times at the origin, destinations, and mode changing facilities projected to move the load to its activity locations. It is assumed that travel demand derives from a load's desire or need to perform activities. The Activity Generator provides the Planner with disaggregated activity demand and travel behaviour.

The Planner assigns activities, modes, and routes to individual loads in the form of trip plans. The individual trip plans are input to the Traffic Microsimulator for its analysis.

Trip plan selection is related directly to a load's desire to satisfy individual (or in the case of freight, corporate) goals. Goals measure a trip plan's acceptability and depend on the load's socioeconomic attributes and trip purpose. Typical goals include:

- cost;
- time;
- distance minimization;
- safety and security maximization.

The load's objective is to minimize the deviations from these goals.

Mode and route preferences also are important in the Planner. Typical preferences include departure time, origin-destination directedness, and congestion avoidance. These preferences reduce the Planner's (activity, mode, and route) solution space and offer significant computational savings.

The travel demand problem is formulated as a iterative process. First, the individual's travel behaviour preferences are adjusted iteratively to satisfy the travel goals. After every load has a feasible, or reasonable, trip plan, the network characteristics are updated based upon the projected interaction of all trip plans. The method then returns to the individual load trip planning phases and the entire process is repeated. The iterative process terminates when either all trip plans are feasible or after some criteria are satisfied.

The trip plans are evaluated with respect to the individual's travel goals. For some loads, all travel goals are satisfied. For others, the plans may not satisfy some or any of the individual's travel goals. In these instances, those plans that minimize the goal deviations will be retained.

It is important to note that if a transportation infrastructure change is considered and its value can be measured by the reduction in the population's travel goal deviations. Unplannable activities are those that the load must forego because of the transportation system's deficiencies. The Planner will attempt to route the load's low priority activities after all high priority activities have been scheduled.

Loads plan their trips based on:

- activity requirements;
- knowledge of the transportation system;

- travel goals;
- assumptions about other load trip plans.

The result will be trip plans that represent regional travel demand and its activity, mode, and route choice variability.

➢ Traffic Microsimulator: it executes travel plans and computes the overall intra- and inter-modal transportation system dynamics. The Traffic Microsimulator is updated every second to ensure that dynamic vehicle behaviors are captured with enough fidelity to generate realistic overall traffic behavior. Interactions of travelers produce emergent traffic behaviors, such as congestion, which consequently are used to compute vehicle emissions.

The input data flow of the microsimulation consists of

- TRANSIMS network;
- vehicle file;
- traveller plans obtained from the Route Planner.

Each individual moves from one activity to another according to the plan obtained from the Route Planner, using combinations of modes such as walking, driving or riding in a vehicle. All vehicle movements are simulated in detail to include:

- driving on roads;
- stopping for signals;
- accelerating;
- decelerating;
- changing lanes;
- stopping to pick up passengers;

Vehicles follow a set of rules that guarantee that no vehicle collisions will occur. This movement is accomplished by using a cellular automata principle. Each section of roadway is divided into cells. Each cell either contains a vehicle or is empty. This simulation is carried out in discrete timesteps. For each second, the vehicle decides whether to accelerate, brake, or change lanes in response to the nearby vehicles in the grid. The simulation guarantees that each vehicle makes decisions based on the state of every other vehicle in its surrounding at the same time.

Concerning output, they can provide a detailed, second by second history of every traveler in the system over a 24-hours period. There are three major types of output from the Traffic Microsimulator:

- Traveler Event Output Data: which report almost everything that happens to a traveler;

- Summary Data: which consist of spatial and temporal data. Spatial summaries include data aggregated over user-defined sections of roadway along the street networks, for example, densities and total flow in a 150-meter section. Temporal summaries include data about travel times along streets at various times of day;

- Snapshot Files: Traffic animation can be produced from the snapshot files, which contain time, position, and velocity information for each vehicle in the simulation;

➢ *Environmental estimator.* The purpose of the environmental module is to translate traveller behaviour into consequent air quality, energy consumption, and carbon dioxide emissions. The environmental module will use information from the planner and the microsimulator and it will support the analyst's toolbox. It also could provide information on fog to the microsimulator. Using the vehicle information generated in the microsimulator module, the emission module forecasts the nature, amount, and location of motor vehicle emissions. Then, the emission information is used in urban air shed models to predict air quality.

It is designed to produce fleet average emissions rather then emissions from individual vehicles. It requires information on:

- Fleet composition;

- Vehicle loads;
- Traffic patterns.

Furthermore, it is divided into three submodules:

- Tailpipe emissions from light-duty vehicles;
- Tailpipe emissions from heavy-duty vehicles;
- Evaporative emissions.

For light-duty vehicles, TRANSIMS uses the Comprehensive Modal Emissions model (CMEM) and the evaporative emissions are calculated using algorithms that closely follow the EPA MOBILE6 methodology.

The output is aggregated on 30m segments for a 1h period.

➢ Feedback Controller*:* this module uses an iteration script provided by the user to control the overall framework of Transims. It makes decisions such as:

- what percentage of the regional trips should be fed back between modules;
- which trip should be fed back;
- how far back the trips should go for replanning;
- when to stop iterating to reach stability in the results.

In the feedback controller module there are three modelling tools:

- Collator;
- Stratifier;
- Selector;

The Collator gathers data from network file and transit route file and extracts data from the output files of the population synthesizer, the activity generation, the route planner and traffic microsimulator. All data collected are then put in the Collator Iteration database.

The Stratifier divides trips into Binnings and Stratifications based on the criteria the user has defined. Their numeric identifier is added to the iteration database and the database is developed into the Stratifier Iteration database.

The selector model's responsibility is to pick up a subset of travellers from the Stratifier Iteration database. The output for each selected subset will consist of one activity feedback and one route planner feedback file. They are both sent back to the activity generator and route planner and the user is free to use either or both of them according to his/her intention.

4.4.ILUTE

4.4.1.Introduction

ILUTE **(**Integrated Land Use, Transportation, Environment) represents an extended experiment in the development of a fully microsimulation modelling framework for the comprehensive, integrated modelling of urban transportation - land use interactions, and, among other outputs, the environmental impacts of these interactions. ILUTE modelling system is under development at the University of Toronto.

The ILUTE project represents the attempt to "commit fully" to a microsimulation approach to urban systems modelling. In so doing, it fundamentally changes the way how urban systems are viewed and modeled.

The long-term research question being addressed within the ILUTE project is, quite simply, to investigate the extent to which the abstract promise of the microsimulation approach can be realized within a practical, operational model.

The model simulates activities of individual agents as they evolve over time. The agents include persons (within households and families) transport networks (road, transit networks, bike and walking modes), the built environment (houses and commercial buildings), firms, the economy (interests and inflation) and job market (Miller 2008). The ILUTE simulator evolves the urban system with basic time step being one month with no assumptions concerning system equilibrium.

Given that ILUTE is a microsimulation model, the system state is defined in terms of the individual persons, households, dwelling units, and firms that collectively define the urban region being modeled.

Some key processes that are modeled explicitly within ILUTE in the context of the defined urban region as defined by Miller (2008) are: changes in population demographics (ageing, mortality), changes in household composition (marriage, divorce, births, children leaving/returning home), supply of new housing and commercial floorspace, firm growth/decline, location/relocation resulting changes in the amount, type and location of employment, changes in labor force and school participation, changes in housing residential location, changes in household auto ownership levels (persons possession of drivers licenses and transit passes), commercial vehicle movements and person-based activity and travel.

Spatial markets play a central role within ILUTE, in that it is through market demand supply interactions that all spatial processes of interest within ILUTE are modeled. The spatial markets include: land market, residential housing market, commercial floorspace market, labor market, regional economic (non-land/real estate) markets. Within ILUTE a consistent conceptual structure is applied in modeling individual consumers within a given market. This involves a three stage process consisting of: the decision to become active in a market; search; and bidding and search termination.

4.4.2.Overview of the ILUTE architecture and dataset

Representing Population: persons, households, decision-making units

Three distinct (but interconnected) entities or agents are used within ILUTE to represent the resident population, and, thereby, to provide the framework for modelling spatial-temporal socio-economic processes: persons, households and “decision-making units”.

Persons are obviously the most basic unit of population, as well as the level at which many decisions/processes of interest within the model occur. These processes include: aging, mortality, fertility, marriage, education status, employment status, and travel to participate in out-of-home activities.

The second entity explicitly represented is the household. A household is defined as a group of people living together within a single dwelling unit. Households play two critical roles within the model. First, since households occupy dwelling units, the household is the means by which individuals are allocated to residential locations. Second, as the physical “container” within which individuals are located, the household defines much of the social/physical/economic context within which person-level decisions are made. This occurs in several ways, including: households typically share resources; the needs and activities of household members can impose constraints on the activities of other household members; household structure/composition/etc., conditions person-level decisions; and households themselves “generate” activities which translate into activity/travel decisions by individuals within the household.

The household as an “organizational construct” is thus fundamental to understanding virtually all population related processes of interest within the model. Representing households and household-based processes within operational models, however, has always proved to be a difficult, cumbersome, and computationally burdensome problem, primarily due to the very wide variety of “types” of households exist: husband-wife couples with and without children; single-parent families; multi-generation families; multiple-family households; non-family households; etc.

In object-oriented analysis terms, the existence of a “messy” solution usually implies that the current set of abstractions being used to represent the system has not been “well chosen” or “optimized”. In this case, a third entity or agent is introduced into the model: the decision making unit (DMU). A DMU is defined as one or more persons within a household who has/have the authority and the means to make “significant” decisions affecting the DMU’s current state. In particular, the DMU has responsibility for decisions concerning the continuing existence of the DMU as a functioning entity, the residential location of the DMU, and the DMU’s automobile holdings.

A DMU must include at least one adult, since it is assumed that young children are not competent to make major decisions of this nature. A household will consist of one or more DMU’s. In particular, it appears that all household structures can be expressed in terms of combinations of one or more of the following three basic DMU’s:

1. Spousal family (SF): it consists of an adult male and an adult female living in a marriage-like relationship, with or without children under the age of majority.

2. Single-parent family (SP): this consists of a single mother or father with one or more children under the age of majority.

3. Single adult (SA): this consists of all single adult males and females who do not have children living with them, regardless of the household structure within they are currently living.

While introduction of DMU’s into the model results in another set of objects which must be maintained within the database and the computational process, they possess two major advantages which more than justify this additional overhead:

- They reduce the number of “hard-wired” categories from at least several dozen (inevitably somewhat arbitrary) household types to three very robust, fundamentally sound DMU types. These three DMU types provide the “building blocks” from which households of virtually any type and complexity can be constructed.
- Representation of key decisions is considerably simplified. In particular, changes in household structure now result either from demographic processes (births, deaths), residential relocation decisions and/or marriage/divorce events, each one of which can be modelled in a systematic, consistent fashion, rather than also requiring separate (and, again, usually quite *ad hoc*) “household type transition” procedures.

Representing Economic Activity: firms, establishments and jobs

The spatial distribution of economic activities (jobs, stores, etc.) is at least as important to the definition of urban form and the determination of personal travel as the distribution of the resident population. In addition, the flows of goods and services within and into/out of the urban area are obviously driven by the level, nature and distribution of economic activities.

While quite disaggregated models of the residential housing market are common, detailed models of economic activities and processes are much less frequent. In current land use models, "employment" by zone by broad industrial category is the usual level of analysis. This may be an appropriate level of representation of the economic system, given practical constraints related to data, theory, etc.

At least three key elements are envisioned for such a model. First, three classes of objects are required to characterize the economic sector: firms, establishments, and jobs.

Firms belong to a specific industry (i.e., produce specific goods and services), possess capital, employ workers, make decisions about their own evolution (expand, contract, relocate, etc.), and interact with other firms through the exchange of goods, services, information, capital, etc. An establishment is defined as the component of the firm which occupies a single location and which typically serves a specific function (or coordinated set of functions) within the firm. A firm always consists of one or more establishment(s). Firms employ one or more worker(s) in jobs, which are located within specific establishments.

Second, a regional input/output (I/O) model is required to "drive" the economic sector microsimulator in terms of providing "control totals" to the microsimulator by industry by time step, as well as to model the export/import relationships between the urban system being modelled and "the rest of the world".

Third, the economic exchange of goods and services within the economic sector should translate into the shipment of commodities over the multi-modal transportation network, as well as the flow of business-related person travel.

Treatment of space and time

At least two fundamental spatial entities are required in the model. The first is the zone. While zones will play no role in the behavioural processes being modelled, they are essential and unavoidable elements of model's spatial data management system, for at least two reasons. First, much of the base, input data to the model is only available at the zone level (traffic zone, census tract, etc.). Disaggregated lists of individual persons, households, firms, etc. must be synthesized for input into the microsimulator. Second, zones are often a very convenient and practical means by which to summarize and display model results, as well as to compare these results with observed data for validation purposes.

The second entity of interest within the model is the building. Buildings house people, firms and activities. As such, they are the fundamental entity which links people, firms and activities to points in space. Representing the demand supply processes which determine the construction, allocation and use of building stock is the *raison d'etre* of the "land use" component of integrated urban models. In particular, the land development sub-model determines the evolution over time and space of the supply of building stock by type, size, quality, etc., while housing and firm location sub-models allocate households and firms, respectively, to specific buildings located at specific points in space. Note that "land development" is taken here to include all aspects of development and redevelopment of building stock. That is, it includes conversion, filtering, demolition and redevelopment activities, as well as the original development of green-field sites.

A final, very important spatial component of the model is the representation of the transportation networks.

Along with space, time is the second major "physical" component of a dynamic urban systems model. ILUTE is essentially a time-driven simulator, with one year being the nominal time step within the model.

The basic unit of time used within the model, however, is the month (which translates into a nominal time step of 12 months), thereby providing the option for finer time steps for specific sub-processes which may require adoption of a finer level of temporal fidelity.

<u>Modelling market processes</u>

Many of the key processes within the model involve market interactions between demanders (buyers, consumers) and suppliers (sellers, producers) of a given good and service. The list of market processes of potential interest within ILUTE include: residential housing market; labour market; commercial real estate market; land market; markets for goods & services; personal use vehicle market; and travel markets (for both persons and goods).

Within ILUTE a consistent conceptual structure is applied to modelling individual consumers within a given market. This involves of a three-stage process consisting of:

1. The decision to become active in a market;
2. Search;
3. Bidding and Search Termination.

<u>Information requirements and agents interactions</u>

Four types of population-related processes have been identified which can be characterized in terms of their information requirements and the extent to which they involve interactions with other agents in the system for their resolution. These are as follows:

1. Demographic processes: aging, fertility, mortality and divorce processes all can be adequately modelled "within" the agent in question, based on the current attributes of the agent. The models used to represent these processes can be relatively simple probabilistic state "transition" models

2. Triggering processes: it is assumed that active participation in a given market involves a sudden transition from a passive to an active state at an arbitrary point in time. Since the triggers for market activity can be either or, some level of information from "outside" the agent making the activity decision about the "system state" will generally be required.

Models applicable to triggering processes can include probabilistic state transition models, but in most cases will involve more complex models which permit greater sensitivity to DMU and system state attributes and contexts (hazard models, random utility models, rule-based methods, etc.).

3. Search processes: search by consumers who are active in a market obviously involves the explicit

acquisition of detailed information concerning other agents or objects in the system. Models used are rule-based in nature.

4. Bid/accept market interactions: the resolution of market interactions within a microsimulation framework involves "bringing together" individual buyers with individual sellers and then determining buyer-seller pair by buyer-seller pair whether a transaction (buy/sell house, offer/accept a job, etc.) will occur, and, if so, at what price. Models at this level of detail are not generally well developed, although well understood random utility methods presumably are applicable in many instances given the primarily economic nature of most market processes.

Activity and travel

Key features of the ILUTE approach to activity-based travel modelling include the following.

The activity/travel model must be household/DMU-based. It is persons who participate in activities and travel; but, as has already been discussed, they do so within a household/DMU context, and the scheduling and execution of individual's activity/travel patterns can only be properly understood when explicitly considered within a household context. Seven-day models capable of capturing a full week's worth of activity/travel behaviour are required.

It is assumed that:

- The model is one of the process by which activity schedules are developed and eventually executed by individuals (within a household context) over time.
- Activity scheduling is clearly a continuous process, in which schedules are constantly being "filled in", revised, etc.
- Each individual is assumed to possess an agenda, consisting of the set of activities which they might engage in at some point in time during a given day. The scheduling process involves selecting items from this agenda to include in a day's schedule, with the anticipation that these activities will then be executed at the scheduled time. Agenda items possess a number of attributes which affect the scheduling process, including spatial and temporal constraints (work start and end times, etc.), information concerning the frequency with which the given activity is likely to be chosen, activity duration information, etc.
- The "priority" for selecting a given activity from the agenda for inclusion in the schedule is a dynamic quantity, which depends both upon the attributes of the activity (how constrained in time/space it is, how frequently it must be executed, etc.) and the current personal and interpersonal context within which scheduling decisions are being made.

From the point of view of the current discussion, which is largely focusing on software architecture issues, the most interesting aspect of this emerging model of activity scheduling is the definition of two very important classes: the agenda and the schedule. This very sharp delineation between the agenda (i.e., the list of possible or potential activities) and the schedule (i.e., the specific set of activities currently planned for execution within a specific day), and the explicit definition of the scheduling process as being one which takes the agenda as input and generates the schedule as output serves in the design of a general model of activity/travel behaviour.

Sequencing and processes

As has been described above, the ILUTE model consists of at least three loosely connected major "modules": a population module; an economic module; and an activity/travel/network module.

These modules "speak to each other" through the database. Although described above as being "loosely connected" (in that many of the processes associated with a given module are wholly "resolvable" within the module itself), significant linkages between each of these

modules do exist. These include: the land development process must weigh options for investing in both residential housing (population module) and commercial developments (economic module); the labour market directly links the population and economic modules together, since households supply workers while firms supply jobs for these workers; households consume goods and services; firms supply them; and activity/travel decisions are obviously conditional upon household and firm location choices, as well as the economic interactions of people and firms.
Within each module, of course, sequential processing occurs, requiring hard and ultimately somewhat arbitrary decisions about the sequence in which processes will be executed.

To conclude, ILUTE is still a work in progress, and testing is underway for calibration and validation of the overall model system. However, some of the components in ILUTE are yet to be implemented like firmographics, commercial vehicle movements, and traffic assignment and so on although early applications using MATSIM and emissions estimation have already been produced by the Miller group in Toronto.

4.5.UrbanSim

4.5.1.Introduction

UrbanSim simulates the development of urban areas, including land use, transportation, and environmental impacts, over periods of 20 or more years. It is a LUMs model, land-use models. Its purpose is to aid urban planners, residents, and elected officials in evaluating the long-term results of alternate plans, particularly as they relate to such issues as housing, business and economic development, sprawl, open space, traffic congestion, and resource consumption. From a software perspective, it is a large, complex system, with heavy demands for excellent space efficiency and support for software evolution. It consists of a collection of models that represent different urban actors and processes, an object store that holds the state of the simulated urban environment, a model coordinator that schedules models to run and notifies them when data of interest has changed, and a translation and aggregation layer that performs a range of data conversions to mediate between the object store and the models.

The UrbanSim simulation approach differs along several lines from prior urban simulation models. It is far more disaggregate than any operational model implemented to date. It uses a dynamic, path-dependent approach that does not impose simplifying assumptions of general equilibrium. It is designed for operational use to examine the effects of land use, transportation, and the environmental plans and policies. And it adopts an assimilative approach that draws from multiple streams of ongoing research in urban simulation, including multi-agent, cellular automata, and macro-scale models.

4.5.2.Overview of the UrbanSim architecture and dataset

To simulate an urban region, UrbanSim employs a collection of interacting models, representing different actors and processes in the urban environment, such as residents, businesses, land developers, and transportation networks.

Each model encodes the behavior of agents in the simulation, as well as the objects they operate upon, such as land parcels and buildings. Objects correlate directly with easily identifiable objects in the real world, making it easier to reason about their properties and behaviors. Agents can be shared across models, as can the objects they operate upon. Much more than other urban modeling systems, the UrbanSim model is very disaggregate and has high data requirements. These requirements enable modeling of processes to be done at a fine level, which allows use of detailed spatial data in a manner not possible with more aggregate systems. At the same time, this makes the design and implementation of the system more difficult from a software perspective.

In addition to the models, the other principal components of UrbanSim are a *model coordinator* that schedules models to run and notifies them when data of interest have changed, an *object store* that holds the shared representations of agents and other entities in the simulated world, and a *translation* and *aggregation layer* that performs a range of data conversions to mediate between the Object Store and the models. The models do not communicate directly with each other; rather, they communicate via shared data held in the Object Store, mediated by the translation and aggregation layer. This extensible, modular architecture supports system evolution, in particular replacing a model with a revised one, and creating and integrating new models. It allows models to define and share common sets of objects that they all operate upon, via the Object Store (regardless of the original source of the data), and also allows them to monitor changes to data fields, providing a convenient method for models to synchronize their actions.

A primary goal of this architecture is to move as much of the software complexity out of the individual models and into the supporting infrastructure as possible. The models, on the other hand, are both numerous and frequently changing due to rapidly evolving theory, methods and modeling needs. Often, specifying them is difficult, requiring considerable domain-specific expertise, specialized data.

The UrbanSim architecture meets the following requirements:

- agent-level microsimulation of choice behavior;
- a grid-based structure to represent spatial information, to facilitate detailed spatial queries and simulation;
- easy replacement of one model by a new version, to support system evolution;
- easy integration of new models;
- support for different temporal and spatial scales;
- support for visualization of the model output and its processes, for explanations and debugging.

Models represent different actors or processes in the urban environment. In addition to encapsulating the behavior of the actor or process, each model is also responsible for defining the set of object types it operates on, and the fields of those objects with which it is concerned. A model can specify that it wishes to share fields also declared by other models, thus providing one technique for data-level coupling and integration of models via the Object

Store. A model can also declare new object types that encapsulate domain-specific data not previously declared (e.g. a water quality model might declare a nutrient load value). A model may specify a set of object types and fields it wishes to monitor for updates, creations, or deletions.

Each model is also responsible for indicating how frequently it wishes to be executed; there are no external constraints on how frequently or regularly a model need run.

Implemented models

Each model runs once per simulation year, unless otherwise noted. All of these models consist of a collection of domain-specific case-based rules or decision rules that are encoded in Java code. The models operate on a database consisting of individual households, jobs, and grid cells of 150x150m containing real estate and land. Most of the models simulate the choices of households, businesses and developers using discrete choice models (multinomial Logit) and Monte Carlo simulation.

Here is the list of the implemented models:

- Demographic Transition Model: it is responsible for modeling births and deaths in the simulated population of households;
- Household Mobility Model: it simulates the choices of households deciding whether to move from their current residential location;
- Household Location Choice Model: it is responsible for determining a location for each household that has no current location;
- Economic Transition Model: is responsible for modeling job creation and loss;
- Employment Mobility Model: it determines which jobs will move from their current locations during a particular year;
- Employment Location Choice Model: it is responsible for determining a location for each job that has no location;
- Accessibility Model: it encapsulates the interface to a (possibly external) travel model. It is responsible for maintaining accessibility values for objects within each traffic analysis zone;
- Land Developer Model: it simulates the action of a developer making decisions about where and what kind of construction to undertake (if any), including both new development and redevelopment of existing structures;
- Land Price Model: it simulates the evolution of land prices at each grid cell as the characteristics of locations change over time.

Temporal scale

UrbanSim provides a much more disaggregate and detailed simulation than other urban land use models. Even so, to keep the computation manageable, the model makes many simplifying assumptions.

For example, the Demographic Transition Model, like most of the models, runs once per simulated year. Each simulated year, it adjusts the total population values and distributions, but in reality people are born and die, and move into and out of the region, every day.

Similarly, the Land Price Model simulates the operation of the real estate market at a temporally aggregate level, adjusting prices once per year rather than continuously. The software architecture has been designed to accommodate events based on any time scale specified by a model, to allow the integration of models with different time steps.

Model coordinator

The Model Coordinator is responsible for managing the collection of models present in a simulation. It is responsible for determining the execution order of models, resolving any data dependencies one model may have on another, and notifying a model when another model has changed data it is monitoring.

Some key methods defined by the Model Coordinator class are:

- runSimulation: run the simulation once the event queue has been populated;
- executeEvent: execute a single event;
- getOrdering: determine a total ordering among a collection of events.

Object store

The representations of agents in the world (such as households and businesses), and the objects they operate upon (such as buildings and land parcels), are held in the Object Store. The Object Store serves as an in-memory database that can be queried or updated, and that supports filtering on entity attributes.

The basic interface to the Object Store is through its postQuery and postUpdate methods. A model constructs a Query object by filling in the object type and set of fields to query for (e.g. the age and size category fields for households), and adds any Filter objects to the Query as desired (e.g. a filter that returns only households with a given number of workers). The postQuery invocation returns a QueryResult object, which contains a copy of all relevant data from the Object Store, including internal object IDs for all values returned. Updates work in a symmetric fashion, with a model constructing an Update object whose form is similar to QueryResult with the addition of the update type (create, modify, remove).

From a software engineering point of view, the Object Store also serves to encapsulate representation decisions about the entities in the simulation. From outside the Object Store, these act as traditional instances in an object-oriented language.

However, they are represented more efficiently within the Object Store. Further, rather than defining these objects by writing a class definition, information in the Model Definition Files are used to give a description of just the portion of each object relevant to the corresponding model. These partial descriptions are then integrated by the system during the code generation phase to produce the eventual object definition.

Objects in the Object Store consist of the union of all fields defined by models for each object type and by the set of default object definitions (which are shared by most models). Queries can return copies of any of the fields of objects, and updates can modify fields or create or remove instances of objects. The Object Store's functionality has been tailored to the needs of UrbanSim-style models, including the ability to perform spatial queries on geo-referenced data (a task poorly performed by traditional databases).

The complete definition of each object type, and the Java code used to access and query it, is generated automatically from these partial object descriptions. For example, the Zone object type represents a traffic analysis zone. Partial definitions of Zone are given by both the default object definitions and the Developer Model.

These definitions are combined, and used to generate the final version of the Zone object. Query/Update access methods, and routines that enable objects to be saved or loaded from disk, are generated automatically as well.

The translation and aggregation layer

The Translation and Aggregation Layer (T/AL) is responsible for converting between different levels of spatial and/or temporal aggregation from queries or updates and the objects in the Object Store.

For example, models can query for zonal population totals. The Translation/Aggregation Layer computes and maintains these totals independent of the information in the Object Store, which consists of population information at the grid cell level.

At present, the T/AL is implemented using a set of methods in the Model Coordinator, rather than as a separate component, and serves only to cache query results for data aggregated at the zonal level. The two key methods that implement the T/AL, both in ModelCoordinator, are postQuery and postUpdate, to post a query or an update to the Object Store, respectively.

<u>Data import and export</u>

On the input side, UrbanSim requires a substantial amount of data to simulate an urban area, including census, employment, parcel, zoning, and transportation network data. A suite of custom data preparation tools can convert data to the formats we require, merge datasets, detect inconsistencies, and in some cases fill in missing data or correct errors in base year input data using heuristics. This input data is generally made available to UrbanSim in the form of delimited ASCII text files.

On the output side, UrbanSim's output module is responsible for gathering, aggregating, and exporting data from the Object Store to a set of external ASCII text files containing requested extracts or summaries from the Object Store.

Currently, the export model writes output files containing households and jobs by type, housing units, non-residential square footage, and land and improvement values, summarized by grid cell and by Traffic Analysis Zone. These files are then passed on to other systems (including GIS software, statistical software, spreadsheets, and the external travel model) for subsequent analysis and graphical display. To simplify the software engineering aspects of data export, the output module is defined as a model, analogous to the Demographic Transition Model, the Household Mobility Model, and so forth. This allows the Export Model to be scheduled to run at defined times, querying the Object Store to take a snapshot of the state of the simulation. Conceptually, however, it is not a model like the Demographic Transition Model or others, since it does not represent an agent in the simulated world, and only performs reads of the Object Store, not writes.

Finally, in addition to input and output files, the system can write a snapshot of the current state of the Object Store to an external file, allowing the system to be restarted quickly from a given point in the simulation.

To conclude, UrbanSim is both a vehicle for research on modeling urban systems and a practical system that has been used in planning work in several US cities. The software uses a modular architecture that allows models to be written as independently as possible, and that provides for a clean separation between the models and the data on which they operate.

One of the most important software feature is the value of moving as much of the complex functionality out of the individual models and into the supporting infrastructure as possible;

specific techniques for achieving this include implicit invocation, efficient object representation in an encapsulated object store, and extensive use of automatic generation of code from declarative specifications.

4.6.ANTONIN

4.6.1.Introduction

Based on the EGT 1991/92 (Enquête Globale des Transports) a transport model was developed in the early nineties to analyse future travel behaviour for the Ile-de-France region. This model, named ANTONIN ("ANalyse des TranspOrts et de Nouvelles INfrastructures"), is built under a disaggregate modelling framework using (multinomial) Logit models to predict the various choices made by travelers in the region. ANTONIN includes disaggregate model components to describe license holding, car ownership, tour frequency, destination and mode choice in the region, followed by detailed (mainly public transport) network assignment modules. The model system is unique in the use of a great number of travel modes (especially Public Transport is available in 10 combinations of station access and in-vehicle travel modes) and purposes (10 purposes, modeling both primary and secondary tours). Combined with its use of some 1000 travel zones, it allows for a detailed look at model results. Since its inception some 10 years ago it has been used by the Syndicat des Transports d'Ile de France in numerous forecasting and project evaluation studies in the region.

Recently the various components of the model system were re-estimated using the EGT 2001/02. Given that the original structure of both the EGT survey and the disaggregate Logit models were kept very similar, model estimation results could be analysed over a period of 10 years time, thus allowing to compare the various factors determining travel behaviour over that period.

A new feature in the updated ANTONIN model is the modelling of Public Transport pass ownership. Until recently, decision rules were used to determine PT pass ownership, but the recent update of the model system allowed to actually modelling the use of these passes, thus allowing for the various personal and household characteristics to be taken into account.

4.6.2. Overview of the ANTONIN architecture and dataset

The structure of ANTONIN is based on that of widely accepted disaggregated transport models such as the Dutch National Model System. It is built under a disaggregated modeling framework using multinomial Logit models to predict the various choices made by travelers in the Ile de France region. ANTONIN is designed to be able to give results at different geographical scales, from the whole region to the local level. To achieve this goal, the region is split in 984 zones. Zones are defined to be pertinent with respect to the transport networks and the density of population and jobs.

For each zone, the model uses different variables to describe the population (number of inhabitants in total, by age, by sex, etc.), employment (number of jobs), the number of places of students and parking costs. The data used to estimate the models are mainly obtained from the 1990 census but with the last EGT 2001/02, the disaggregated models have been re-estimated based on this new dataset.

Concerning transport networks, they are both road and public transport described in the model. The variables matched to the road networks are:

1. Highway of Ile de France;
2. Extra-urban roads;
3. Urban roads;
4. Local roads;

For each link is specified: speed (influenced by road nature, localization, day period), distance (Km), hourly capacity per lane, lanes number per way, road name. Since the transport network in Ile de France offers a wide variety of modes and services, it is chosen to use in the modeling 13 different travel modes instead of a basic choice between public transport, car and slow modes. To be more precise travel modes are classified as follow:

1. Individual modes:
    - Car driver;
    - Car passenger;
    - Slow modes (walking/2-3 wheels);
2. Public transport PT modes:

- Rail only;
- Metro only;
- Bus only;
- Rail/metro;
- Rail/bus;
- Metro/bus;
- Rail/metro/bus;

3. Walk access;
4. Drive access;
5. Walk or drive access;

For the PT, it is specified also: line name, direction and way.

Regarding to the architecture of the model, according to the results of the EGT2001/02, ANTONIN is based on different disaggregated models.

Applied Models

1. Models applied to individuals

The first is the *Driving License Holding Model* that calculates the probability of having a driving license for the head of household and/or his/her partner and other adult in the household. This model includes the following alternatives:

- None;
- Head of household;
- His/Her partner;
- Both.

The variables taken into consideration are: sex, age, income, household, household localization, level of study, socio-professional situation. Further effects are taken into account such as the differences in saturation level between males and females and also of the age effect for women over 60-65 years.

The results of the driving license model are input to the *Car Ownership Model* which is applied to household. To analyze the travel behaviour of persons, it is important to know what options travelers have in deciding on modes to travel. Therefore, it is necessary to estimate the number of cars within a transport zone and the characteristics of the household to which they belong. According to this model, a strong correlation exists between the number of driving licenses and number of cars. That's why, the household with one license in majority have one car then households with two licenses have either one or two cars. The more licenses the less apparent the relation becomes.

Two separate car ownerships models are estimated based on the number of cars and licenses per household: one model for household with 0 or 1 car and only one license and one model for households with 1 or more licenses.

The other model applied to individuals is the *Tours Frequency Model*. Tours are defined as return trips based at home or at work/education place. They are a simplification of reality as complex chains of trips are converted in go and return trips according to a hierarchy among trip purposes. Ten purposes of tours are considered:

➢ Home based tours:

- Home-Work (high income);
- Home-Work (low income);
- Home-Business;
- Home-School (children below 18 years);
- Home-Education (students above 18 years);
- Home-Regular shopping;
- Home-Other shopping;
- Home-Social activities;

➢ Non-Home based tours:

- Work-Business;
- Work/education-others;

These models are organized in two types:

1. 0/1+: models to determine whether a person would make any tour;

2. S/R: Stop-Repeat models to determine whether a person would make another tour.

For each purpose, separate 0/1+ and Stop/Repeat models are estimated. In four of the purposes, owning a PT pass leads to a higher probability of making one or more tours on a day.

The combination of the results of the first three models and their expansion for each zone gives a number of tours for each origin zone per day and purpose.

The last model is the *Public Transport Passes Model*. Public transport pass ownership is an important factor in mode and destination choice, especially in large metropolitan areas such as the Ile de France, which has an extensive public transport system. Owners of passes are much more likely to choose public transport than non-pass holders, and as pass ownership changes then so will the PT mode share.

The alternatives that are taken into account are:

- None;
- One subscription (type Orange: weekly, monthly, annual);
- One subscription (type Immagine'R: included 11-25 age individual);

2. Models applied to trips loop

Combined mode and destination choice model is adopted for tours produced by each zone. A Logit model provides to jointly select the mode and destination. At each purpose corresponds a different Logit model. Model takes into account variables that describe the individual including his/her localization, the characteristics of different destination (number of employees, commercial surface, inhabitants number, etc.) and the level of service between the origin and destination. For the trips, the model compares the utility function of 13 x 1400 couple mode x destination, too. The results of this last model are daily tour matrices for each of the ten purposes.

Prototypical sample and expansion factor

The technique of prototype sample and expansion factor is used to obtain the matrices zone by zone trips. It allows moving from results obtained at disaggregated level to aggregated level.

The models previously mentioned are applied to the individuals and households of the EGT 2001/02 sample and it is statically representative of the population of the Ile de France. The prototypical sample is then expanded zone by zone in order to obtain the number of tours by purposes emitted by each zone. The expansion phase consist in the calculation of weights to apply to each individual of the sample in order to match targets value for each zone such as the total number of inhabitants, the split by age/sex classes, the size of households, etc.

Pivot point process

This process is then applied to obtain the final trips matrices for a scenario. The principle of the pivot point process is that only changes in results of the model between the base scenario and a future scenario should be applied to an existing origin-destination trip matrix to ensure the best quality of forecasts. Because of the unavailability of a detailed enough origin-destination matrix, ANTONIN uses the EGT matrix and splits these matrices on the basis of the results of the mode and destination choice model. Concretely, corrective factors are calculated by O-D for 3 modes and 3 purposes and are applied to ANTONIN results. These corrective factors are kept in memory and applied again to results of future scenarios.

Time of day process

The time of day process convert the daily tour matrices in time period trip matrices (for instance peak matrix covers the 7.30 – 9.30 time period). First of all, tours are split in two trips, the go and the return trips. Based on EGT observations, percentage are calculated to know which percentage of the first part of the tour is made during a given time period. This percentage differs according to the purposes.

Assignment phase

This phase is mainly focused on public transport. For the car traffic assignment is used a classical iterative capacity constrained assignment technique. The public transport assignment spreads traffic over alternative competing public transport paths that have a common stop node. It is done separately for the ten modes/ access combinations which mean that if different combinations are available for an O-D pair, many paths can be used during the assignment.

Bibliography

MATSim

DUBERNET Thibaut, 2011. *Introducing joint trips in a multi-agent transport simulation: from agents to clique replanning.* Diploma project. UTC.

CETIN Nurhan, 2005. *Large-scale parallel graph-based simulation*. Thesis, Swiss Federal Institute of Technology, Zurich.

BALMER Michael, 2007. *Travel demand modeling for multi-agent transport simulations: algorithms and systems.* Thesis, ETH Zurich.

MobiSim

MobiSim. Laboratoire ThéMa, Université de France Comté Besançon. Available on : www.mobisim.org

ANTONI J.P., 2012. *Présentation générale du modèle*. Laboratoire ThéMA, CNRS.

Plateforme de simulation pour létude prospective de la mobilité urbaine des agglomerations Française et Européennes. Rapport de recherce. Ministéère de l'Euipment, des Transports, de l'Aménagement du territoire, du Tourisme et de la Mer, 2005.

CASANOVA Philippe, KOLTCHANOV Vladimir. *The Actors Behaviour Improving in the MobiSim Model.* ATN.

KOLTCHANOV Vladimir, KARSKY Michel, CASANOVA Philippe. *The individual daily mobility simulation Model : Mobisim.* ATN, KBS, ATN.

TRANSIMS

PARADKAR Rajan, 2001. *Alternative methodology to household activity in Transims.* Thesis, Virginia Polythechnic Institute and State University.

RILETT Larry, 2003. *El Paso Transims case study.* Texas Transportation institute.

KOOHBANANI Mansoureh Jeihani, 2004. *Enhancements to Transportation Analysis and Simulation system (TRANSIMS).* Dissertation submitted to the Virginia Polythechnic Institute and State University.

C.L. Barrett, R.J. Beckman, K.P. Berkbigler, K.R. Bisset, B.W. Bush, S. Eubank, K.M. Henson, J.M. Hurford, D.A. Kubicek, M.V. Marathe, P.R. Romero, J.P. Smith, L. L. Smith, P.L. Speckman, P.E. Stretz, G.L. Thayer, E. Van Eeckhout, and M.D. Williams. *Chapter 1 - Framework; Chapter 2 - Population Synthesizer; Chapter 3 - Activity Generator; Chapter 4 - Route Planner; Chapter 5 - Traffic Microsimulator; Chapter 7 - Emissions Estimator; Chapter 8 - Output Visualizer.* Available on : http://ndssl.vbi.vt.edu/transims.php

JAVANMARDI Mahmoud, 2011. *Integration of TRANSIMS with the ADAPTS activity-based model.* Department of Civil and Materials Engineering, University of Illinois at Chicago.

ILUTE

SRINATH Ravulaparthy, GOULIAS G. Konstadinos, 2011. *Forecasting with dynamic micosrimulation: Design, Implementation and Demonstration.* Final report of review, model guidelines and pilot test for a Santa Barbara County application, University of California Transportation Center (UCTC).

MILLER J. Eric, FAROOQ Bilal, CHINGCUANCO Franco, WANG David, 2010. *Microsimulating Urban Spatial Dynamics: Historical Validation Tests Using the ILUTE Model System.* Workshop on Urban Dynamics Marbella, Chile.

UrbanSim

http://www.urbansim.org/Main/UrbanSim

SRINATH Ravulaparthy, GOULIAS G. Konstadinos, 2011. *Forecasting with dynamic micosrimulation: Design, Implementation and Demonstration.* Final report of review, model guidelines and pilot test for a Santa Barbara County application, University of California Transportation Center (UCTC).

WADDELL Paul. *UrbanSim: Modeling Urban Development for Land Use, Transportation and Environmental Planning.* Department of Urban Design and Planning and Daniel J. Evans School of Public Affairs, University of Washington.

WADDELL Paul, 2010. *Status report on UrbanSim and the open platform for urban simulation.* Department of city and regional planning, UC Berkeley

FELSENSTEIN Daniel, AXHAUSEN Kay, WADDELL Paul. *Land Use-Transportation Modeling with UrbanSim: Experiences and Progress.* Hebrew University of Jerusalem, ETH Zürich, University of California, Berkeley

ANTONIN

GOMEZ SERRA Juan Manuel, 2010. *Modèle Antonin 2, quelle approche pour le mode tramway ?,* Master Thesis.

JAN GERRIT Tuinenga, MARITS Pieters, RAND Europe, DEBRINCAT Laurence. *Antonin: updating and comparing a transport model for the Paris Region*. Syndacat des Transports d'Ile de France.

STIF. *Etude: enjeux transports et etudes de traffic*. STIF, Paris.

INVENTUR. *Modèle Antonin. Présentation générale, description scientifique et technique, description libre.* Available on : http://archives.cerma.archi.fr/inventur/inventur019.html

CHAPTER 5 :

CONCLUSION

5.1.Introduction

To recap the "origin" of the present study it is necessary to recall the context taken into consideration: the urban system. In this context, if analysed under a finer scale, interactions in a neighbourhood are the aspect that more weight on its operating and on the land use. In particular, their spatial localisation, their impacts and who generates them.

Thanks to the analysis of the models, illustrated in chapter 4, it is possible to understand that each of them is characterized by a huge quantity of aspects, structural and non-structural. Here's why, a group of themes of analysis are chosen to better lead a comparison among the models. The themes are based on the spatial, temporal and decision/choices dynamics of urban system:

- Temporal scale: "*Which temporal scale is taken into consideration in the models?*"
- Spatial scale: "*Which spatial scale is taken into consideration in the models?*"
- Type of decision (residential/professional localisation, type of activities, equipments choice, activities programme): "*Which type of decisions, made by agent, is taken into consideration in the models?*"

Based on these three themes, a table of comparison has been created: it gathers together the principal deducted models characteristics. The table is here provided.

0. Model **T:** traffic **M:** mobility **L:** land settlement **I:** impact	**MATSim** (open-source) **T** ETH Zurich/ University of Berlin	**MobiSim** (open-source) **T – M – L** ThéMA	**ANTONIN** **T** STIF Ile-de-France Public Transport Executive	**TRANSIMS** (open-source) **T – L – I** Los Alamos national Laboratory	**UrbanSim** (open-source) **L – I – M** Waddell-Ulfrasson/University of Washington	**ILUTE** **T – L – M** McGill University Montreal/Toronto
1. Equipments choice : Subscription Vehicle	Explanatory model: subscription and vehicle	Descriptive	Explanatory model: subscription and vehicle	Descriptive: vehicle	No	Descriptive: vehicle and subscription
2. Building: One by one identified Identified per zone Non-identified	Per zones	Per zones, per cell, identified one by one	Per main employment/residential zones and per activities	Not identified	Identified one by one and per cell (for professional/residential mobility)	Identified one by one (housings/establishments)
3. Agents : Indivudual Household	Individual, household data integrated to individual	Individual, household	Individual, household	Individual, household + aggregation per zones for household	Household, jobs, developers	Individual, household
4. Activity : Individual activity ; Activities plan ; Trips chain (loop)	Trips chain organized by daily optimized plan, descriptive	Optimized activities plan	Trips chain	Activities plan per individual and per household	Individual activity (home-based, non-home based)	Daily activities plan per individual and household
5. Localisation Per address Per zone Per cell	Coordinate x,y, per infrastructure section	Per cells	Per employment/commerce/residential/low-rise residential/communal housing/city-center zones	Per address for workplace and domicile, cells for traffic	Per zones and cells	Per zones and buildings
6. Soft modes Pedestrian/bicycle Flat-sum Specific representation	Pedestrian and bicycle, Flat-sum	Pedestrian and bicycle, specific description	Pedestrian and bicycle, flat-sum	Pedestrian and bicycle, flat-sum	Pedestrian and bicycle, flat-sum	No
7. Capacity : Parking Building	Only capacity for workplace and schooling place	Parking capacity and cost is counted but not taken into consideration	Cost and number of parking counted but the filling not computed	Presence of parking only	Building (for household localisation choice)	Building (housing/establishment)
8. Emissions/Noise	No	No	No	Localised emission at urban scale/ dispersion and impact, air quality/ CO2	Emission and land impacts	No
9. Model : Dynamic Static	Dynamic model for the analysis of traffic	Dynamic model for the analysis of traffic, Dynamic model for the analysis of residential mobility, population	Static model for the analysis of traffic: AM/PM peak hours and off-peak hours	Dynamic model for the analysis of traffic and emissions	Static model for the analysis of traffic, Dynamic model for the analysis of urban development	Static model for the analysis of traffic, Dynamic model for the analysis of urban development

Table of comparison of the models.

Before passing to describe the deductions of the comparison, it is worth to better explain the criteria of the above illustrated table.

The criteria are the following ones:

0. T= Traffic: *"Does the model compute traffic?"* ;
   M= Mobility: *"Does the model compute mobility (residential, professional)?*";
   L= Land settlement: "*Does the model take into consideration land settlement?"*";
   I= Impact: *"Does the model compute impacts?"* ;
   They represent the main employment domains of the models;
1. Equipments choice: *"Does the model take into consideration the agents' equipments choice (possession of vehicle or/and subscription to public transport) and how does it is represented (explanatory/descriptive)?";*
2. Buildings: "*Does the model take into consideration buildings and which is the level of detail of their representation (one by one identified/not-identified/identified per zone)?";*
3. Agents: *"How population is represented (individual/household)?";*
4. Activity: "*How do activities are handled (individual activity, activities plan, trips chain)?";*
5. Localisation: "*Which is the level of detail of agents/objects localisation (per address/per zone/per cell)?";*
6. Soft modes: "*Do soft modes (pedestrian/bicycles) are taken into consideration and how do they are represented (flat-sum/specific representation)?";*
7. Capacity: "*Does the model take into consideration the capacity of parking and buildings?";*
8. Emissions/noise: *"Does the model compute emissions or noise?";*
9. Model: *"Does the model is dynamic or static?";*

The table here provided together with the complete table, in the annex, let reach further and different conclusions.

5.2.Deductions

The *actors* - households, businesses, developers, and governments - make decisions *about production and consumption* activities and their location, leading to changes in *land use.* These decisions affect, directly and indirectly, the biophysical system through *land conversion,* the *use of resources,* and the generation of *emissions and waste.* Businesses make choices about production, location, and management practices. Households make choices about employment, location, housing type, travel mode, and other lifestyle factors leading to consumption. Developers make decisions about investing in development and redevelopment.

Governments make decisions about investing in infrastructures and services and adopting policies and regulations. Decisions are made at the individual and community levels through the economic and social institutions. The actors interact in three submarkets: the job market, the land market, and the housing market. These actors also interact in nonmarket institutions including governmental and other nonprofit and nongovernmental organizations. Decisions are influenced by demographic, socioeconomic, political, and technological factors represented in the model by exogenous scenarios, and are affected by environmental conditions and changes predicted by the biophysical modules. The types of activity and the context in which the activity takes place both determine the level of pressure and the patterns of disturbances.
As already illustrated in the previous chapter and here recalled, modelling an urban system together with its interactions and evolution is a great issue because of their complexity.

Since each model could be integrated with others, according to the simulation necessity of the user and simulation capacity of the model, it is important to understand which models, when integrated, offer the best all-embracing approach to the urban system complexity.
Say that signify looking for an "ideal" representation of the urban system. The notion "ideal" is not here meant as "utopia" but as looking for a model, that lead an ideal representation, with the following characteristics:

- Disaggregated model at the building scale;
- Multi-agent model: type of agent (individual, household, building, establishment, green space);
- Activity-based model able to describe and take into consideration individual trips;
- A model able to take into consideration hierarchy of activities in a trips chain;
- A model that explicit the agents' choice: localisation of activities, housing, employment. This leads to a great effort in the creation of the disaggregated O-D matrix;
- A model that contemplates the use of soft modes;
- A model that considers parking and building capacity;
- Dynamic model.

According to the table, a support tool to look for that "ideal representation", it is possible to assert that:

1. It is possible to create three main groups as a function of their equivalence:
    - MATSim/ANTONIN/TRANSIMS;
    - UrbanSim;

- ILUTE/MobiSim;

2. ANTONIN and MobiSim are LUTI models, Land use and Transport Integrated models;
3. UrbanSim is a LUM model, Land Use model;
4. Residential localisation and mobility is more visible in MobiSim, ILUTE and UrbanSim;
5. Daily trips localisation is better represented in MATSim, MobiSim, TRANSIMS;
6. In MATSim and ANTONIN is possible to see a better representation of the equipments choice;
7. In UrbanSim and ILUTE is more visible the activities localisation;
8. UrbanSim and ILUTE take into consideration all the pricing aspects that could influence in the land development/changes and localisation choices;
9. All these models have an open structure: this is a great feature because it gives to the model the possibility to be integrated with other ones and so to acquire a high simulation potential;
10. Defining the characteristics of each models is a great effort because it depends a lot on the integrated models;
11. When choosing for the models to integrate with other one, it is better to lead the choice aiming for the structural characteristics of them such as if it is a dynamic or static model. As a rule, such characteristics are the discriminating one for the models;
12. For the simulation requirement of this study, a model such ILUTE or a combination between UrbanSim and MATSim, turn out to a high simulation potential solution.

Why ILUTE?

ILUTE provides:

- It consists of a "behavioural core" of four inter-related components: Land Development, Location Choice, Activity/Travel, Auto Ownership;
- Each of these behavioural components involves a complex set of sub-models that incorporate supply/demand interactions, and interact among each other;
- In modelling travel, ILUTE adopts an explicit activity-based approach;
- It is modelling the actions of both persons and firms, since both of these actors make decisions that directly influence travel demand. Households are also modelled as a specific entity within the model because certain choices such as residential location and automobile ownership tend to be made at the household level, and there is usually a sharing of resources within a household which also contributes to shared household decision-making.
- To modelling individual persons, comprehensive microsimulation models also treat other objects at the micro-level: firms, dwelling unit roads, vehicles, land parcels, etc.

Why MATSim and UrbanSim?

MATSim provides:

- Flexible handling of a large variety of input data;
- Extensibility of models and algorithms;
- Simple interface for new models and algorithms;
- Simple disaggregation for different spatial resolutions;
- Unlimited number of individuals;
- Simple interface to handle new input data elements.

On the other hand, UrbanSim provides:

- Capacity in capturing complex interactions in the markets for land, development and transportation;
- Valuable tool for improving the level of understanding of how a metropolitan region is developing and how various combinations of land use and transportation policies and investments are likely to shape these trends;
- Preservation of land in green space would be feasible to incorporate within the model by earmarking specified parcels for green space preservation and could be tested as an attractor for residential or business location;
- The urban design issue could similarly be explored, given the parcel-level capacity of the developer module, and the ability to incorporate a flexible set of terms in the location choice equations for businesses and households;

These are the aspects that justify the choice of ILUTE or UrbanSim/MATSim.

By the way, the present study represents the first step of the research. The following advancement consists of a better comprehension of the possible combination of models and as a consequence the proposal of a new integrated (transport-building) model. This research will be carry on at LVMT, Laboratoire Ville Mobilité et Transport in Paris.

Bibliography

GRETHER Dominik, CHEN Yu, RIESER Marcel, BEUCK Ulrike, NAGEL Kai, 2008. *Emergent effects in multi-agent simulation of road pricing.* Transport systems planning and transport telematics technical University of Berlin.

KICKHOFER Benjamin, GRETHER Dominik, NAGEL Kai, 2011. *Income-Contingent user preferences in policy evaluation – Appliocation and discussion based on multi-agent transport simulations.* Transport systems planning and transport telematics technical University of Berlin.

MILLER J. Eric, FAROOQ Bilal, CHINGCUANCO Franco, WANG David, 2010. *Microsimulating urban spatial Dynamics: historical validation test using the ILUTE Model System.* Workshop on urban dynamics in Marbella, Chile.

ANNEX:

TABLE OF THE MODELS

The whole table in which the characteristics of each models are illustrated, is now provided.

The order of the table is:

1. Paper AGENTS;
2. Paper ACTIVITIES;
3. Paper DISPLACEMENTS;
4. Paper TERRITORY;
5. Paper EXTERNAL INTERACTIONS;
6. Paper IMPACTS.

In each paper it is possible to visualize the characteristics of the analyzed models. The method followed to create and fill in the table is illustrated in chapter 3.

It is worth to here recall the color matched to each model so as to help in the lecture of the table:

- MATSim: green;
- MobiSim: orange;
- TRANSIMS: blue;
- ILUTE: rose;
- UrbanSim: red;
- ANTONIN: yellow.

Model	**Color**
MATSim	green
MobiSim	orange
TRANSIMS	blue
ILUTE	rose
UrbanSim	red
ANTONIN	yellow

Table of the colors coupled with the models

\

Agents	Characterization				MATSim	MobiSim	TRANSIMS	ILUTE	UrbanSim	ANTONIN
Population simulation					Synthetic persons, individual	Synthetic agent/space, individual, household	Synthetic households: family/non-family/individuals living in a group quarters/ zonal aggregation of household	Agents: persons/households/Transport networks/Buidings/Establishment/decision making unit	Agents: households, jobs, developers	Agents: indivudual and household
Individual	Personal characteristics	Age								
		Excluded age classes								
		Gender								
		Disabled persons (reduced mobility)								
		Persons with health issue								
		Level of educatio/schooling								
		Web purchase								
		Web admnistrative formalities								
	Occupation and professional situation characteristics	Social-professional status, current or passed								
		Social-professional status (level of detail)								
		Principal occupation								
		Primary work location								
		Type of workplace								
		Availability of parking at workplace								
		Availability of bike-parking at workplace								
		Income								
	Family circumstances	Family circumstances								
		Dependent child								
		Temporal evolution								
	Residential situation	Resident/non-resident								
		Permanent resident								
		Other								
		Occupancy status								
		Housing								
	Access to transport	Public transport subscription	Yes		Seasonal?					
			Non							
			Type of subscriptions	Weekly						
				Monthly						
				Annual						
			Number of transit journeys	Limited						
				Unlimited						

			Concerned transport network							
			Zones							
		Other subscriptions								
		Cost per persons (supported by persons)								
		Shared-transport subscriptions	Car-sharing							
			Bike-sharing							
			Car-pooling							
			Type of subscription	Weekly						
				Monthly						
				Annual						
				Daily						
		Driving license (cat.B)								
		Driving course								
		Accompained driving								
		Driving license for mopeds (cat.A)								
		Car availabiltiy								
		Individual exclusively use vehicle (the entreprise makes vehicle available)								
		Rent of parking, insurances costs, maintenance costs supported by persons								
		Rent of parking supported by the entreprise								
Household	Personal characteristics	Age of the head of the household								
		Socio-professional status of the head of the household								
		Members of the household								
		Reletionships with the other members of the household								
		Temporal evolution								
	Economic characteristics	Number of working persons (actives)								M/W
		Total income of the household								
		Socio-economic characteristics								
		Rent or amounts of reimbursement excluding charges								
		Rental subsidity								
		Amount of charges								

		Rent of parking supported by the household								
		Vehicle maintenance costs supported by the household								
		Vehicle insurance costs supported by the household								
	Access to housing	Household dwelling								
		Occupancy status								
		Nomber of dwellings available for the household								
		Parking places owned by the household								Average parking cost (on the road)
		Telephone availability in the housing								
		Wi-fi availability in the housing								
	Access to transport	Light weight vehicle available for the household (the entreprise makes it available)								
		Number of driving license (cat.B)								Driving license Holding model
		Number of vehicles								Car ownerchip model
		Number of bikes								
		Number of electric bikes								
		2/3 wheel vehicle available for the household								
		Vehicle status								
Individual and household updating	Individual	Births								
		Deaths								
		Ageing								
	Household	Changement of the workplace								
		Divorces								
		Creation of new households								
		Modification on primary households								
		Residential mobility								
Level of education/schooling (exemple EGT)	Persons in period of schooling									
	Primary school									
	Secondary school									
	High school									
	College									

	University									
	Master									
	Learning period									
	Other training postsecondary (sanitary, social, artistic)									
	Persons without education									
Type of occupation/job	Type 1 :								List of jobs	
	People that live in the housing the most of the time:									
	Persons temporarily absent (persons on leave) for holidays, business trip, less than 1 month hospitalization, etc.									
	Infants									
	Roommates or subleasees									
	Adult that live in the housing for the schooling period									
	Domestic employee, workers and young au pairs that live in the housing									
	Type 2 :									
	Minor children lodged outside parental home for schooling period									
	Spouse with another domicile for business purpose and that come back to the housing during week-end/holiday									
	Type 3 :									
	Minor children that live in the housing for schooling purpose and parental home is elsewhere									
	Spouse									
Principal occupation (exemple EGT)	Full-time active									
	Part-time active									
	Student									
	Student at learning center with qualification contract									
	Primary or secondary school student									
	Unemployed, previously employed									
	Retired, former employee, retires from business									
	Unemployed									
	Homemaker, people without profession									

	Inactive, pensioner									
Place of work	Office									
	Trade, shop, large-scale distributors									
	Warehouse, factory, workshop									
	University, college, lycee									
	Hospital									
	Hospital/station									
	Shop									
	Special areas (rungis, port)									
	Domicile									
	Other									
Intra-household, inter-pesonal relationships	Individual family situation									
	Single									
	Married									
	Divorced									
	Widowed									
	Spouse									
	Children/son in law/daughter in law									
	Ascendant/step-parent									
	Small-child									
	Other parent									
	Salaried household worked and lodged									
	Other non-parent									
Occupant status	Owner									
	Accessing to the ownership									
	Tenants of HLMs or social sector									
	Private rented housing fleet									
	Other type of private rented housing fleet									
	Free accomodation/accomodation provided by employer									
	Free accomodation									
	Other									
Vehicle-use status	Owned by the household/individual									
	Owned with participation									
	Owned by the employer									
	Other (rental, leasing, loaned by someone)									
PCS level1	Farmer									
	Artisans, traders, leaders of entreprises									

	Upper intellectual profession									
	Intermediary profession									
	Employees									
	Workers									
	Retaired									
	Other, without professional activity									
PCS level 2	Farmers									
	Artisans									
	Suppliers									
	Business manager (entreprise > 10 persons)									
	Liberal professions									
	Managers in the public service, intellectual/artistic profession									
	Corporate executive									
	Educational, health, public service intermediary professions									
	Administrative and commercial intermediary professions									
	Technicians									
	Foreman, supervisor									
	Public service employees									
	Admnistrative employees									
	Commercial employees									
	Service and sale workers									
	Qualified workers									
	Non-qualified workers									
	Farmer workers									
	Old farmers									
	Old artisans, suppliers, business manager									
	Old manager									
	Old employees and workers									
	Unemployed									
	Other inactive									

Paper ACTIVITIES

Activity	Characterization		MATSim	MobiSim	TRANSIMS	ILUTE	UrbanSim	ANTONIN
Activity	Motives (EGT)	Domicile (go out, go back)	No time restrictions				Home-based trips at the household level	Home-based trips (10 cat.)
		Second home, occasional dwelling, hotel, other						
		Working at the work place	Time window:7 a.m.- 6 p.m.	Job				
		Working at an other place						
		Have prosessional meeting						
		Nannies, crèche, etc.						
		Go to preschool, primary school	Time window:7 a.m.- 6 p.m.	Study				
		Go to High school	Time window:7 a.m.- 6 p.m.	Study				
		Go to Lycee	Time window:7 a.m.- 6 p.m.	Study				
		Go to College	Time window:7 a.m.- 6 p.m.	Study				
		Go to University	Time window:7 a.m.- 6 p.m.	Study				
		Go to the shopping centre	Time window:8 a.m.- 8 p.m.	Study				
		Go to the hypermarket, supermarket, shopping arcade		Shopping	Shopping			
		Go to the small and medium-sized trade		Shopping	Shopping			
		Go to the covered market and open air market		Shopping	Shopping			
		Receive health care						
		Submission of an application and looking for a job						
		Look for a job						
		Take part in leisure cultural, sporting and associational activities	No time restrictions					
		Take a walk, take driving lessons						
		Go to the restaurant						
		Visit family and friends						

		Accompany someone						
		Look for someone						
		Bring somebody to transport modes						
		Pick somebody up from transport modes						
		Make a professional tour						
		Sport						
		Leisure						
		Culture						
		Other					Non-home-based trips at the zonal level	
	Place	Zone						
		Place (job, purchase, culture, hobby,sport)						
		Geographical localization			Address only for mandatory activities: work and domicile			
	Time	Activity day (working day, Week-end, etc.)		Working day		Seven-days model		
		Frequency						
		Time slot						
		Duration of the activity						
	Practical modalities	Groupage (alone/group)/capacity for each given activity			Household activities(activities divided or shared among the members/Individual activities(partecipation of a single person)			
		Context/modalities				Interpersonal context		
		Private constraints	Time constraints					
		Schedule flexibility						
		Priority			Mnadatory activities: work/domicile			
Activities program/plan	Agents							Agents:loop
	Principal motive beyond domicile							
	Day	Working day, week-end, holiday, etc.	General day	Working day				Day/peak hours
	Starting time		Restrictions on time window during wich can be performed					
	Average duration							
	Elementary activities							
	Standard deviation of the average activity duration							
	Order							
	Timetable of the program							

Place of work	Office							
	Trade,shop							
	Warehouse, factory, workshop							
	University							
	Hospital							
	Airport							
	Shop							
	Special zone (port, Rungis, etc.)							
	Other							
Place of purchase	Small shop							
	Store							
	Supermarket							
	Large-scale shop							
	Hypermarket							
	Mall							
	Shopping arcade							
	Market							
	Flea market							
Cultural place	Cinema							
	Theatre							
	Museum							
	Art Gallery							
	Library							
Sport and leisure place	Cycle lane							
	Protected natural area							
	Heritage places							

Paper DISPLACEMENTS

Displacement	Caracterization					MATSim	MobiSim	TRANSIMS	ILUTE	UrbanSim	ANTONIN
Displacement/trip/journey	Social effects	Mimétisme, entourage impact (ecological sensibility), habits									
	Trip purpose/motives	Activity at origin: place and motive								Home-based work, home-based non-work, non-home-based work, non-home-based non-work)	Home-work/personal purpose/school/regular shopping/leisure/culture/restaurant/social purpose, Work-business/other
		Activity at destination: place and motive									
		Size of departing group									
		People with disability									
	Time	Duration									
		Departure time									
		Arrival time									
		Frequency									
		Punctuality									
		Reliability									
	Itinerary (computational algoriythm)					Time-dependant Dijkstra algorithm		Logistic regression, regression trees, neural nets			
	Modes	Sequence of patterns	Departure time								
			Arrival time								
			Path								
			Mode								
			Unit	Persons							
				Freight							
		Contraintes	Displacement genaralized cost					Cost minimization			
			Mode genarelized costs					Cost minimization			
			People's equipment					Car availability			
			Ecological sensibility								
			Comfort								
			Distance					Distance minimization			

			Distance on foot								
			Accessibility								Walk/drive access
			Aspects linked to time					Time mnimization	Work start-end time		
			Aspects linked to space								
			Equipment quality								
			Quiet and security					Safety and securit maximization			
			Crowded place								
			Parking availability								
		Principal mode of displacement	Individual transport	Light weight vehicle	Brand and model						
					Type of vehicle	Car plans (FIFO queue)		Automobile		Vehicle, drive alone/shared	Vehicle, driver/passenger
					Turism vehicle: different size (break, berline, commercial) or commercial vehicle < 800kg						
					Commercial vehicle: 800-1000kg						
					Commercial vehicle > 1000kg de charge utile mais <3.5tonne de PTAC			Trucks			
					Camping-car						
					Car without permission						
					Vehicle's energy						
					No-plomb						
					Super						
					Diesel						
					Hybrid						
					Electric						
					Year of placing into circulation of the vahicle						
					Puissance fiscale						

					Average yearly mileage						
					Check mileage						
					Status						
					Consumption						
				2/3 wheels motorized	Brand and model						
					2 wheels						
					Moto						
					Scooter						
					Other						
					3 wheels						
					Type of engine						
					2 stroke engine						
					4 stroke engine						
					2/3 wheels energy type						
					Electric						
					Fuel						
					Year of placing into circulation of the vahicle						
					Engine size/cubic capacity						
					<50cm3						
					50-125cm3						
					>125cm3						
					Average yearly mileage						
					Check mileage						
			Public transport (Ile de France)	Type of vehicle		Non-car plans					
				Train de banlieue SNCF				Light rail, commuter rail			Train only (Train/metro, train/bus, Train/metro/bus)
				RER							
				Orly Val							
				Metro							Metro only (train/metro, Metro/bus, Train/metro/bus)
				Tramway							
				TVM							
				Bus RATP Paris				Bus			Bus only (Metro/bus, Train/bus, Train/metro/bus)
				Bus RATP banlieue							
				Bus OPTILE							
				Noctilien							

				Bateau bus / vogueo							
				TAD							
				Transport Employeur							
				Ramassage Scolaire							
				Thandicapé							
				Autres TPC							
				Taxi							
				Avion							
				TGV							
				Grandes Lignes SNCF autre que TGV							
				TER							
				VP Conducteur							
				VP Cond Covoit							
				VU1 Cond							
				VU2 Cond							
				Cond 2RM Non Immat							
				Cond 2RM							
				VP Pass							
				VP Pass Covoit							
				VU1 Pass							
				VU2 Pass							
				Pass 2RM NI							
				Pass 2RM							
				Bike-sharing							
				Autre VLS							
				VAE							
				Fauteuil / voiturette							
				Roller, skate, trot							
				Autre							
				Type of energy							
				Enleaded petrol							
				Super							
				Diesel							
				Hybrid							
				Electric bike							
				Methane							
				Capacity							
			Soft modes transport	Type of vehicle							
				MAP							
				Bike		Non-car plans					
				Roller, skate, trot							
				Bike-sharing							
				On foot		Non-car plans					
				Electric bike							

Territory	Characterization			MATSim	MobiSim	TRANSIMS	ILUTE	UrbanSim	ANTONIN
Territory	Mesh	Whole size		Region		Region	Urban area	Urban area	Region
		Mesh (spatial unit)	City						
			Region						
			Distirct						
			Neighbourhood						
			Building				Land-development model	Employment location model/ Residential mobility and choice	
			Zone	Links and nodes					Matrices zone by zone trips/ Employment,commercial, center,residential zones
			Cell/parcel			Cellular automata traffic model		Parcel (residential choice model: each building belongs to a parcell), Grid cell: 150x150 m (households location by grid-cell)	
	Morphology et topography								to create zones(urban morphology)
	Climate								
	Land use (objects)	Building							
		Green space							
		Public space							
		Infrastructures							
		Public transport network							
	Density	Building							
		Housing							Influence on the creation of zone
		Employment							
		Population							
		Bio-diversity							
		Equipment and service							
	Point of attraction	Type of service	Personal services						
			Trade						
			Education						
			Health						
			Sport, leisure and culture						
			Transport						
		Distance	Proximity range					Influence on household location choice	
			Mid-range						
			Higher range						
		Type of point of attraction	Park						
			Classified building						

			Point of attraction for employee					Influence on household location choice	
			Industries						
	Accessibility (transport network)	Spatial						Influence on household location choice	Level of service between O-D
		Temporal						Influence on household location choice	
Infrastructure	Type	Section							
		Crossroads/station							
		Roadway							Line name/direction/way
		Railway							
		Bikeway							
		Pedestrian networks							
	Circulation regime	Reserved lane							
		Tidal flow lane							
		Bus/taxi/bike/rail reserved lane							Bus/metro/train
	Access conditions	Number of lanes							
		Flow capacity							Hourly capacity per lanes
		Private access way							
		Sidewalks							
		Public road							
		Intermodality							
	Crossed surrounding	Type	Urban 30 km/h					Nearest arterial to the zone/gridcell	Road name
			Rural 70 km/h					Nearest arterial to the zone/gridcell	Road name
			Highway 120 km/h					Nearest arterial to the zone/gridcell	Road name
		Urban quality							
		Circulation signal	Traffic light						
			Roundabout						
			Traffic sign						
			Slope						
			Ramps						
			Pedestrian crossing						
			Congestion						
			Parking						
			Other			Grades, turn lanes, signalized/unsignalized intersection			
Services	Mission	Route planning							
		Sequence of service station							

		Opening range							
		Frequency per period							
	Vehicle (private and public)	Type of vehicle							
		Vehicle capacity (sitting, size)							
		Optional service (bike transport availability, wi-fi,etc.)							
		Contraints (transport volume/transported weight)							
Plubic space	Type	Green space							
		Park							
		Yard							
		Square							
		Market place							
		Other							
Parking	Parking size (size of the vehicle that can stand)	Light duty vehicle							
		2/3 wheels motorized							
		Bike							
	Type of parking	Presence of parking							
		On the road							Parking cost
		Parking with time limit							
		Parking with parking tags for local resident							
		Free parking							
		Non-authorized parking							
		Private parking							
		Free of charge							
		Owned parking							
		Tenant with or without reservation							
		Fleet public/commercial parking							
		Free parking							
		Propriétaire							
		Locataire avec ou sans réservation							
		Pay per hour parking							
		Other							
	Station	Bike-sharing parking							
		Car-sharing parking							
	Services	Public charge spot							
		Type of function							
	Parking capacity								
Building	Building-related activity	Establishments present in the building						Non-residential building	
		Housing present in the building						Residential building	
		Occupancy scenarios							

	Building category	Classified building							
		High-rise building (IGH)							
		Public building							
	Physical characteristic	Number of storeys							
		Shape							
		Accessibility							
		Surface area							
		Energy quality							
		Energy/water storage							
		Energy production							
		Capacity							
		Building occupancy							
		Age of the building							
	Services	Availability of parking space							
		Type of parking							
	In/out flow	Material							
		Energy							
		Persons							
		Supplying food							
		Waste							
		Used water							
		Water							
		Emission/pollutant							
		Noise							
	Density	Taken into consideration							
		Hyper-dense (>20000hab/km2)							
		Very dense (8-10.000)							
		Dense (4-5.000)							
		Medium(2.000)							
		Low (1.000)							
		Very low (100-200)							
		Rural (10)							
Urban shape and building updating	Creation of new housing (type, place, number, date)								
	Change of the existing housing								
	Change of the function								
	Filling in of wasteland								
	Change of zone status (N->AU) (AU->U)								
	Change of service supply								
	Change in price								
Establishment	Identification	Name							
		SIRET (SIRENE number)							
	Activity characteristic	Principal business activity carried out (APET)							

		Establishment status (active/close)							
		Date of creation							
		Indicator of company size (employee size classes)							Number of employees
		Number of customers							
	Physical characteristic	Establishment address							
		Surface							Commercial surface
		Number of buildings							
		Buildings							
		Head office address							
	Flux in/out	Freight deliveries	enterprise-shop						
			intra-enterprise						
		Professional mobility (agent and reason)							
		Parking capacity							
		Establishment vehicle fleet							
Enterprise	Identification	Name/social policy							
		Acronym							
		SIREN number							
		Legal category							
			Non						
			Individual Entrepreneur						
			Grouping, endowed with legal personality						
			Juristic person under foreign law						
			Legal person of public law						
			Trading company						
			Legal person recorded in the register						
			Legal persons under administrative law						
			Private specialized organism						
		APEN code: principal activity code	Private foundation						
			Non						
			Agriculture, Forestry, Fishing						
			Extractives industry						
			Manufacturing industry						
			Electricity, gas, steam, water supply distribution						

			Water supply, sewege, waste management and remedetion activity						
			Construction						
			Commerce, repair of automobiles and motorcycles						
			Transportation and warehousing industry						
			Accomodationa nd restoration						
			Information and communication						
			Finance and insurance activity						
			Estate activity						
			Specialized activity, scientific and technical						
			Administrative and support activity						
			Public administration						
			Education						
			Human health and social work						
			Arts, entertrainment and recreational activity						
			Other service activity						
			Activity of household as employers, undifferentiated goods- and service- producting activities of households for own use						
			Extra-territorial activity						
		Enterprise status							
		Date of creation of the enterprise							
	Physical characteristic	Head office address							
		Establishment number							
Enterprise and establishment updating	Change of status (active/closed)								
	Change of the volume activity								
	Establishment								

	physical change								
Housing		Type of housing	Individual accomodation without garden						
			Individual accomodation with graden <300m2						
			Individual accomodation with garden >300m2						
			Housing < 50 units						
			Housing: 50-100 units						
			Housing >100 units						
			Other: Atelier/loft/studio/etc.						
		Number of rooms in the housing							
		Total surface							
		Energy quality	Charges						
			Rent/monthly cost						
		Accomodation cost							
	Nearby services	Secure parking places for bikes availability							
		Parking place availability							
		Type of parking place							
		2/3 wheels parking place availability							
		Type of parking place (2/3 wheels)							

Paper INTERACTIONS

Interactions	Caracterization			MATSim	MobiSim	TRANSIMS	ILUTE	UrbanSim	ANTONIN
Interactions	Zone-external accessibility								
	In-out displacements							Influence the location choice (households and employment)	
	Out-in displacements								
	Crossing displacements								
	External points of attraction	Services point	Personal service						
			Trade						
			Education						
			Health						
			Sport, leisure and culture						
			Transport						
		Point of attraction for employee	Number of jobs						
			Job category						
			Attractiveness of jobs						
		Freight point							
	Migration flows	Residential mobility							
		Commuting mobility							
		Occasional or temporary mobility (tourism)							
	Spatial correlation within zones								
	Emissions								
	Freight flow	Goods delivery and collection							
		Goods trip loops							
		Vehicle occupancy of the road							

Impacts	Caracterization					MATSim	MobiSim	TRANSIMS	ILUTE	UrbanSim	ANTONIN
General characteristics								Emissions model, regional metereological model, local effect model, dispersion model		Road particulate emissions, Mobile source emissions, Carbon footprint analysis	
Transport impacts	Pollutants	Emission	Vehicle fleet	Moto-sidecar-trike							
				Light duty vehicle							
				Mid-sized vehicle							
				Heavy duty vehicle and coach							
				Energy-efficient vehicle							
				Diesel vehicle							
				Other							
			Infrastructure/Circulation	Road conditions							
				Driving style or behaviour							
				Start/stop cycle				Off-cycle/cold-starts			
				Fuel consumption	Type of vehicle			Moving and stationary vehicle			
					Type of ground						
					Driving style						
					Weather conditions						
					Road conditions						
				Mobility policy circulation	Traffic light						
					Roundabout						
					Road signs						
					Slope						
					Pedestrian crossing						
					Congestion						
					Road parking						
					Parking						
					Visibility						
				Pollutants	Carbon monoxide CO, dioxine CO2						
					Sulphur dioxide SO2						
					Nitrogen oxides Nox						
					Light hydrocarbons						
					Volatile organic COV						

					Suspended particles PM10/PM2.5						
					Heavy metals:Lead Pb, Mercure Hg, Arsenic As, Cadmium Cd, Nickel Ni						
					Aerosol						
					Ozone O_3						
		Dispersion	Climatic conditions	Weather							
				External temperature							
			Physical conditions	Road conditions							
				Turbulence due to vehicle							
			Type of models (dispersal curve)	Eulerian							
				Lagrange							
				Gaussian							
				Canyon							
			Pollution cycle	Annual cycle							
				Weekly cycle							
				Daily cycle							
	Noise	Emission	Vehicle flow								
			Speed								
			Speed variation								
			Vehicle								
		Propagation	Vehicle								
			Distance from the source								
			Presence of noise barriers								
			Buildings density								
			Building materials								
			Geometry of the façades of the building								
			Air heterogeneity								
			Opening roads								
			Overall neighbourhood morphology								
Land impacts	Climate change										
	Environmental degradation										
	Environmental health										
	Land degradation										
	Land use										
	Land pollution										
	Desertification										
	Water pollution										
	Air pollution										
	Exploitation of natural resources										
	Ozone depletion										
	Waste										

	Air quality										
	Habitat fragmentation										
	Energy consumption										
	Soil contamination										
Social impacts	Quality of life										
	Culture life										
	Habitat fragmentation										
	Partecipation at political system										
	Quality of air and water people use										
	Health and wellbeing										
	Personal and property rights										
	Fears and aspiration										
	Risks										

ACKNOWLEDGMENTS

My gratitude goes to my Family, Professor Luca Mantecchini and Professor Fabein Leurent, Professor Nadia Postorino and Natalia Kotelnikova.