SIMULATING THE SWARMING CITY: A MAS APPROACH

Arnaud BANOS
Lecturer
SET (UMR 5603 CNRS)
University of Pau
France
E-mail: arnaud.banos@univ-pau.fr

Sonia CHARDONNEL
Researcher
PACTE (UMR 5194 CNRS)
University of Grenoble, France
E-mail: sonia.chardonnel@ujf-grenoble.fr

Christophe LANG
Lecturer
LIFC (FRE 2661 CNRS)
University of Besançon, France
E-mail: lang@lifc.univ-fcomte.fr

Nicolas MARILLEAU
PhD Student
LIFC (FRE 2661 CNRS)
University of Besançon, France
E-mail: marilleau@lifc.univ-fcomte.fr

Thomas THEVENIN
Lecturer
ThéMA (UMR 6049 CNRS)
University of Dijon, France
E-mail: thomas.thevenin@u-bourgogne.fr

Abstract: Space-time-activity surveys have been widely used in France since the1970's. A national standardized procedure even exists, allowing comparisons between different sites and/or periods. However, these surveys have most of the time been exploited in a much aggregated perspective, providing very classical macro indicators. Nonetheless, they provide very rich and detailed information about the daily mobility of urban populations, for example on trip chaining. Given the increasing complexity of urban daily mobility and the increasing needs of urban planning, it then makes sense to improve our practice, including our capacity to reveal complex patterns. In such a perspective, our communication has two goals. First, we present an attempt to model and simulate the "swarming" city, using multi-agents systems (MADKIT platform). In our model, agents are designed to plan activity programs and perform the corresponding trips in a dynamic urban environment they need to explore, given their initial limited knowledge (presence of individual cognitive filters). This ever-changing environment is generated by the whole set of interacting agents, but also by collective patterns such as ambient traffic, generated using Markov chains and queuing algorithms. Then, we face the problem of visualizing the output of our individual-based mobility model. "Revealing by geovisualizing" is one of the mottos of our communication, based on the idea that we'd better learn to manage complexity, as we cannot always reduce it. In that perspective, we first propose a "place-based" approach to urban mobility, providing a global dynamic view of the swarming city based on map animation and interactive space-time exploration. Finally, we shift to a "people-based" paradigm, trying to visualize individual "space-time paths" using mobile objects within a GIS.

Keywords: Complex Systems, Geosimulation, Multi-Agents Systems, Time Geography, Urban Mobility

1 INTRODUCTION

The National Transportation Commission (CNT) of France, in a report published in 2001, identified three major strategies for improving the management of daily mobility in France's metropolitan areas (Bailly, 2001). Innovation in the domain of user services, plus the design of new tools to better control the forces at work in transportation constitute the first two avenues of approach. Both these orientations necessarily depend on a better understanding of trip behavior. This third strategy requires that managers and researchers tailor studies toward the issues of time geography and create tools well-suited for elucidating the movements that daily animate the city.

The MIRO project[1] (Model for Intra-Urban Daily Rhythms) subscribes directly to this outlook, as it aims to develop an approach to urban daily mobility that is comprehensive, generative, and interactive. Based on this, our project's second goal is to define a protocol for investigations and simulations that would be able to depict the varying territorial configurations produced by myriad individual trip trajectories. The ultimate goal is to help planners formulate new space-time policies and/or modes of transport, through perfecting simulation protocols based on multi-agent systems.

One state-of-the-art transportation model will enable us to situate MIRO on this constantly changing landscape. In particular, we will demonstrate the dual

[1] Model for Intra-Urban Daily Rythmes, a project financed by the French DoT [Department Of Transportation] by the PREDIT [program for research and innovation in land transportation] group (Group 1, Mobility, Territory, and Durable Development). Project website: http://lifc.univ-fcomte.fr/~lang/MIRO/

conceptual anchors of this project, centered in time geography on one hand, and in distributed artificial intelligence on the other. Finally, we will describe the multi-agent system model we are currently developping, prior to demonstrating various aspects of the simulator in action.

2 THE CONTINUOUS EVOLUTION OF TRANSPORT MODELS

The first transport models were developed in the United States in the early 1960s (Dupuy, 1999). The objective was to estimate the investment that would be necessary for the construction of transport infrastructures in an economic context particularly favorable to urbanization and to automobile use by households (Masson, 1998). Based mainly on neo-classical economic principles, this constantly evolving approach seems to be increasingly replaced by micro-simulation models.

2.1 Neo-classical Economic Models

Developed since the 1960s, the first-generation model, called four-step model (4SM), was designed to measure movements made within a given perimeter. The modelling of travel demand required that socio-economic data be linked with areal units of territory, whereas transportation supply was structured in a graph form. The four-step model moves ahead in a linear and sequential process that first establishes the overall quantities of arrivals and departures in each zone — the generation phase. A second phase, the distribution, involves estimating the flows emitted between an origin and a destination. In the third stage, this flow matrix is apportioned to the various modes of transportation. Finally, these modal flows are applied to the network — the attribution phase. These four steps thus correspond to the combination of specific models.

The 1970s marked a true breakthrough in methods used for predicting demand, with the appearance of disaggregated models. In a context of economic crisis, public authorities oriented themselves more toward short-term planning and sought to integrate behavioral data into their approach in order to alleviate the shortcomings of classic models (Masson, 1998). The key trait of disaggregated models lies in the shift of observation unit, which no longer refers to the average behavior of a group but to the movement habits of individuals. In these models, the individual was led to make a choice among several options. This usually had to do with determining the best mode of transportation for one person on one given trip. The decision-making process was constructed based on well-known probability models, models of discrete choice.

Disaggregated models require that research be done near transport-users, which increases the cost of study. Despite its advantages, this methodology is seldom used in France. Nevertheless, it offers an improvement over classical models, thanks to the creation of the model of four hybrid steps (ENPC, 1998). These second generation models were widely adopted by various commercial software packages, the most widespread being EMME2, MINUTP, and TRIPS (Ortuzar et al., 1995).

2.2 Activity Programs Using Micro-Simulation Models

Numerous researchers challenged the dominant models that were based on classical economic theory. M.G.McNally summarized their criticisms in five points (2000):

- No consideration was made of the chaining of activities in the course of one trip;
- Movements were not situated in a specific space or time;
- The portrayal of behavior was over-simplified. Efficiency was over-emphasized in explaining individual choice of transportation mode, to the detriment of studying many kinds of factors that might influence the choice;
- There was no specification of the relationships between trips, limitations associated with modes of transportation, or activity-plans or personal obligations;
- The decision-making process did not take into account the interactions among individuals and other household members, notably in the sharing of joint resources (a car, for example).

Strongly influenced by these comments, Jones (Jones et al., 1990) proposed to "re-establish the analysis of movements in a richer and more holistic framework, wherein every trip is analyzed in terms of one or more days as a function of the differing life-styles and activity programs of each person." In that context, models based on activity programs were developed between 1970 and 1990 (Lentorp, 1976; Jones et al., 1983; Recker, 1986). The first micro-simulation models made their appearances late in the 1990s, with the notable model Amos, developed by Kitamura (1996) in Washington, D.C., and the work undertaken by J. Bowman and M. Ben-Akiva (1997) to study daily activity programs.

The latter two authors have since joined in the enhancement of one of the most successful applications to-date for micro-simulation models in urban transport: TRANSIMS (Balmer et al., 2004). That application was developed in the United States, at the Los Alamos National Laborabory, and more specifically used to simulate movements in the city of Portland, Oregon. The architecture of TRANSIMS is based on the inter-relationship of 6 modules (Figure 1).

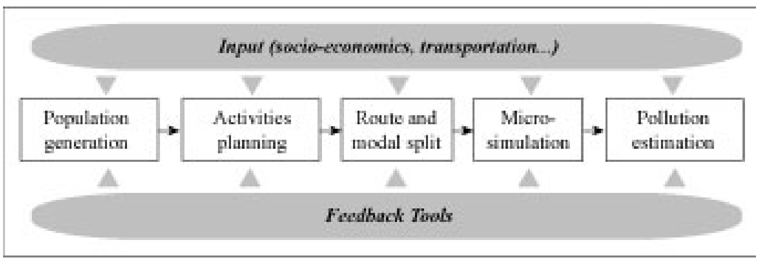

Figure 1. The Architecture of the TRANSIMS model

To begin, the population generation module reconstitutes the population and households of an agglomeration using demographic data from census categories and forecasts. These “artificial” households are distributed over the urban territory as reflects the census data. The second step, the activity generation module, permits assigning each traveler a schedule of specific tasks to accomplish. This artificial population of travelers is created from detailed research on the movements of individuals living in the metropolitan area under study. In this module, activities may be chained. As a result, each person in each household receives a list of activities associated with a transport mode: dropping off children at school on foot, going to work by car, coming back home by car, riding a bicycle for recreation, etc. In the third step, an itinerary is attributed by determining the fastest route by which the individual can get from one activity to another. At the fourth step, the micro-simulator recreates the second-by-second movements of vehicles on the transport network for a given period. The behavior of the travelers is produced integrating these parameters via a mini-program, so as to assemble an image as realistic as possible of the traffic in the agglomeration. Vehicles, sections of highway, as well as intersections are also reproduced by the micro-simulator. In the fifth stage, a pollution-estimator module converts the level of vehicle flow to the associated emission levels of carbon dioxide, monoxide, etc. A final module, dubbed the feedback tool, allows for performing feedback loops in order to calibrate the overall model. The program operator may also gather data on categories of movement or individuals, and monitor the quality of the itineraries that are automatically produced.

Since 2003, the TRANSIMS application has been available commercially. In any case, other initiatives well-suited for research have been launched in the last few years. Kai Nagel (Nagel et al., 2003) at the University of Zurich has recently created a freeware application named MATSIMS. Similarly, METROPOLIS, developed by André De Palmas' team at the University of Cergy-Pontoise (De Palmas et al., 2002), has been under continuous development since its first version.

3 TIME-GEOGRAPHY AND DISTRIBUTED ARTIFICIAL INTELLIGENCE

The state of the art detailed above shows the extent to which the overlapping of models based on activity programs and dynamic models form a pertinent approach for depicting the daily movements at the heart of the metropolis. The multi-disciplinary MIRO program, linking geographers and computer scientists, subscribes directly to this trend. Indeed, its purpose is to place the problem of daily human mobility back at the center of the broader problem, relating to the very functioning of our urban systems, with the final purpose of helping managers to define new temporal and/or transportation policies. Its outstanding feature rests in its readiness to simulate, over the short course of a day, the emerging conditions by drawing upon a multitude of individual behaviors and variable territorial configurations. It is from this vantage point that the MIRO team offers a simulation protocol, focused on people in motion, that allows for exploring the complex, and to a great extent self-organizing, system that is the city (Benenson, 2004; Portugali, 2000). This project thus entails a basic transition from the scale of the individual to that of the entire territory, in a manner that enables rationalizing in fine detail the city "in motion". With this perspective, and because it focuses on the moving individual and on the space-time context in which he/she operates, time geography offers an apt conceptual framework, which distributed artificial intelligence and especially multi-agent simulation allow to be formalized and put into operation.

3.1 Time-Geography

Our approach to the creation of individual activity programs is largely based on the conceptual framework of time-geography defined by Torsten Hägerstrand (Hägerstrand, 1970) in the 1970s. This underlying approach can be summarized in several broad unifying principles (MacNally, 2000):

- Treating movement as a demand deriving from demands for other activities independent of mobility itself;
- Focusing no longer on simple and segmented movements but upon sequences, the chaining of trips;
- Preserving the household as the base unit of the decision-making process, on the supposition that the behavior of one person in a household may impact the mobility behavior of other members of the household;
- Examining closely the chaining and duration of activities and trips;
- Integrating spatial, temporal, and social constraints, and similarly, the interactions between individuals and between individuals and their environment;
- Recognizing interdependencies between events separated in space and in time;
- Analyzing activities and movements in a fundamentally dynamic manner.

One of the main interests of this approach, in comparison to more classical econometric approaches, is, as mentioned above, its ability to focus not only on the decision-making processes at work but also on clusters of constraints of all kinds that may shape individuals' decisions (Burnett et al., 1982, Kwan, 2000). In particular, Torsten Hägerstrand identifies three types of constraints. Capability constraints limit the possible range of options for reasons that may be physiological (the need for places to withdraw into or in which to eat or sleep), technical (the velocity of movement) or topological (every trip option being delimited by a given area and by a return home). Coupling constraints cover the need to meet with individuals, tools, and materials in a shared space-time (bundle) for the purpose of producing, consuming, or interacting socially. Finally, authority constraints are those arising from the organization of space into hierarchically limited domains, stemming from the need to avoid conflicts over the sharing of resources among people who gather and live together in one place. Thus, "an individual's plans must be organized in time to reflect the time-slots available for different kinds of activities" (Chardonnel, 2001).

This theoretical prism draws all its meaning from its bottom-up approach which, by detailing controllable individual behaviors, will try to explore the emergence of complex global properties (urban rhythms) by virtue of an adequate non-centralized simulation strategy. Favoring a dual perspective, both person- and place-centered, on the city in motion, this approach will let us test, via simulations, the macroscopic impacts of scenarios by directly manipulating operational constraints (localization, type, frequency, and hours of service or urban transportation in particular). From this viewpoint, we have tried to define a meta-model capable of facilitating the generation of mobility models for a given set of problems. This tool enables us to represent common mobility phenomena in an incremental and controlled manner, thanks especially to its structure. All relevant moving urban objects are reflected in this model by agents. Any others (ambient traffic for example) are accounted for by probability laws.

3.2 The Meta-Model: a Methodological Platform

The recreation of the city in motion depends on a software architecture that links a Multi-Agent System (MAS) and a Geographic Information System (GIS). The geographic databases as well as mobility information are exported into 3 MAS modules (Figure 2).

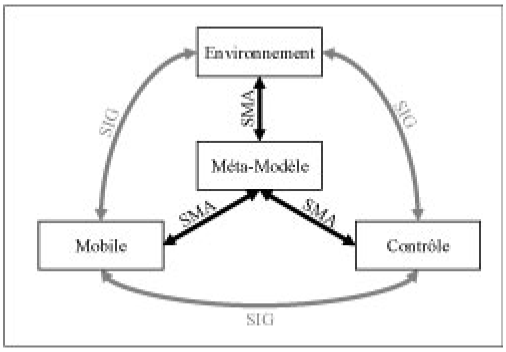

Figure 2. MIRO's methodological platform

The "environment", at the outset, consists of the layout of the virtual city, composed of places of transport activity (stations in time geography terminology), linked by transportation networks. Next, a second module, called "mobile" (mobile agent), lets us detail the travel behavior of the individual elements. These first two modules combine for the functioning of the third module, called "control", designed to demonstrate the results of the simulations, in particular the movements of the objects/agents around the city. At the core of this schema is the meta-model that lets us control the interaction between the modules.

3.3 Selection of a Study Area

Operational objectives of MIRO required our research team to select a study area. In addition to our existing contacts with the local transportation providers, it was the interest shown locally for the issues of timing strategies / policies, as well as the availability of a fair amount of data, that led us to choose Dijon. Its urban agglomeration is comprised of nearly 250,000 residents, distributed over 21 communes. An agreement with greater-Dijon's urban planning agency provided us with access to GIS data on many themes, as well as findings from the latest study of household mobility (1998).

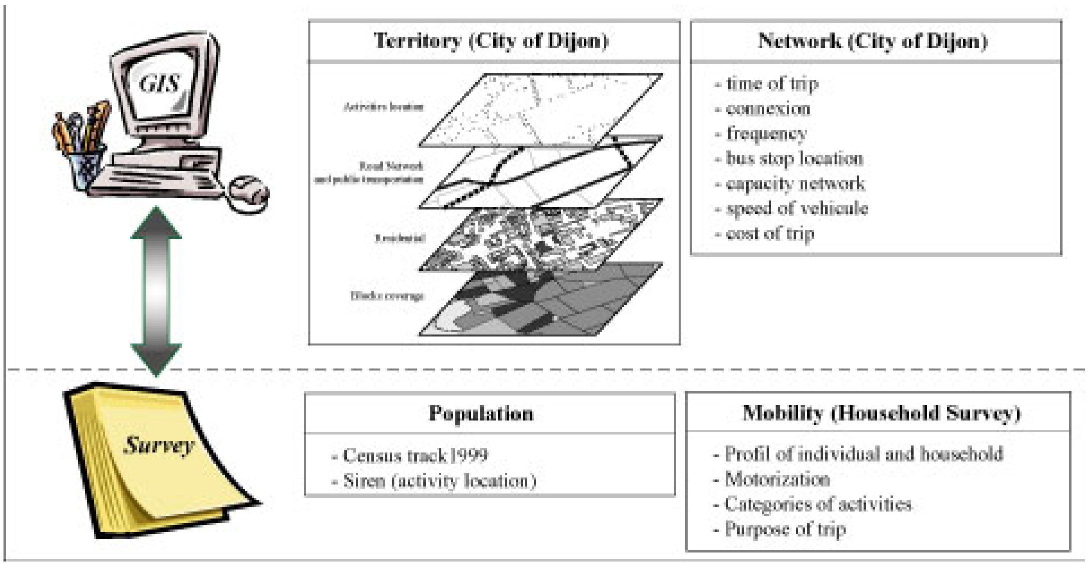

Figure 3. Acquiring Information on Dijon's Metropolitan Area

4 MULTI-AGENTS FORMALISATION

The individuals under study are represented as autonomous entities, humanized objects, that maneuver through the virtual city serving as their environment. The depiction of such a multi-agent system (MAS) requires the ability to represent both the individuals as well as describing their evolving setting.

4.1 Defining Mobile Objects

Each individual belongs to social affiliation groups, at the heart of which operate certain basic interactions, composing a daily custom. A fine-grained depiction of such mobile agents must thus be created at the individual level, and also at a scale sufficient for the group itself to remain perceptible. In action, describing mobile agents and groups operates as a progression, according to a method defined in (Marilleau et al., 2005). Initially, the general structure of individuals is represented at the center of a UML diagram (Unified Modeling Language). Then the behavioral rules of the agents are defined algorithmically by using a language called Ploom-Unity. This method consummates with the implementation of a simulation.

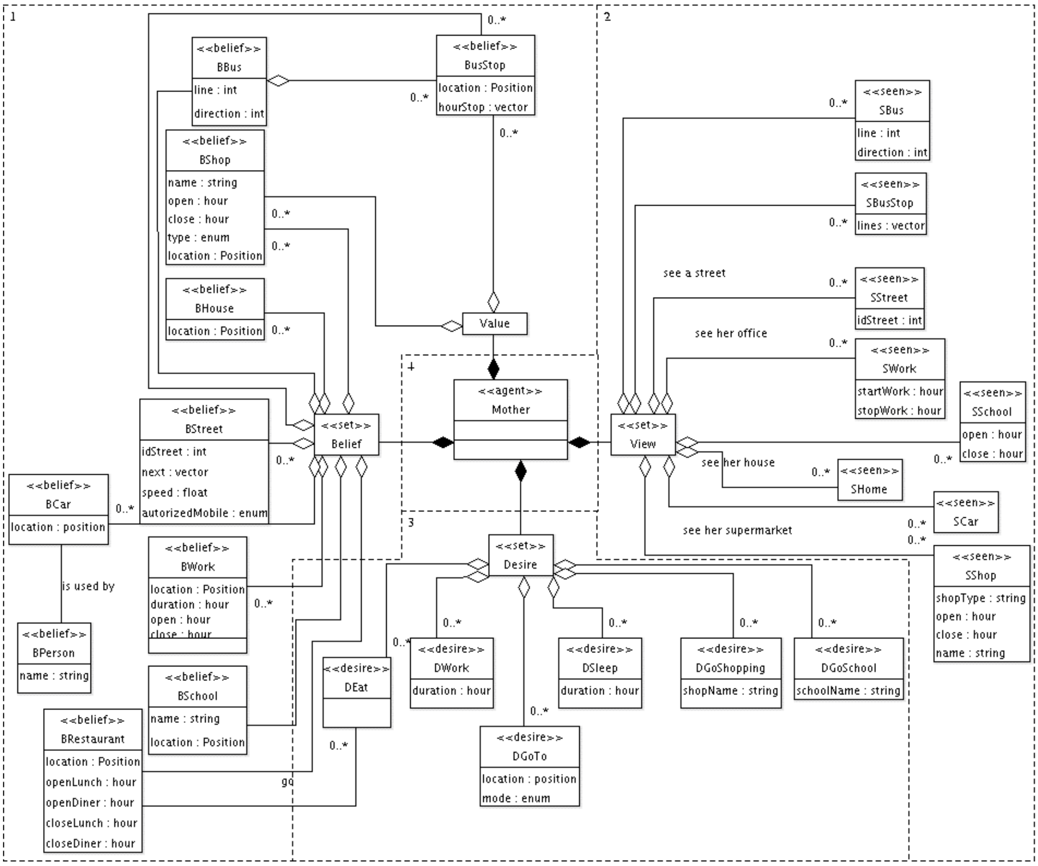

Figure 4. UML Diagram of the Object "Mother"

The general representation of mobile objects or agents follows a formalism already established. This description is broken down into multiple parts and thus permits specifying in near-entirety the parameters of the agents, namely (figure 4):

- A description representing the knowledge that determines the form and nature of the information held by the agent. Such beliefs can be considered as the preferences of the agents, thus allowing, to a certain degree, for inclusion of some notion of custom.

- A description of an agent's perception of environment that defines the ways by which an agent learns about his environment in the context of a "virtual" city. Thus each agent's ability to learn depends directly on this perception.
- A description of desires, aiming to define the different categories of personal tasks that the agent should accomplish during the period of the simulation.
- A core aspect, representing the heart of the agent, allows for identifying the category that contains its rules of behavior. This core is defined by a field that specifies the stereotype of that "agent".

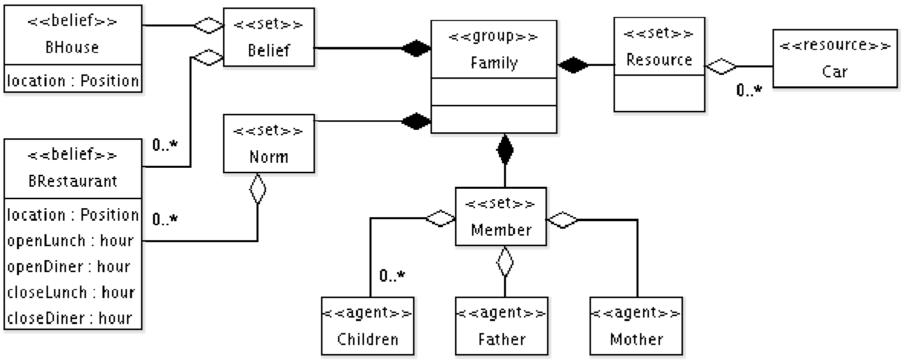

Figure 5. Definition of a "Family" Group

The general representation of groups follows the same logic as that of individual moving agents, and is meant to complement it. It involves the concepts of shared awareness (favorable or not) and shared wishes, that are already represented in the agent's UML diagram. Group representations also reflect additional concepts, like the notion of resources. For instance, in Figure 5, members of the same family have one vehicle, a car. This scheme also detail what categories of agents may belong to a group. For example, the social group "family" must here be able to incorporate a father, mother, and any number of children.

4.2 Describing the Environment

Describing the environment constitutes a critical stage during development of a mobility simulation. Indeed, this stage strongly affects what observations of simulated movements can be performed later, by defining an appropriate frame of reference.

In our system, the environment plays dual roles, static and dynamic. In fact, it is at once both a space of opportunities and physical constraints for the individuals being represented, and also the creator of the traffic and services that are offered to those agents.

Defining the public road network plays an important role in describing the virtual city. It is broken down, following the example of many mobility simulators, into segments composed of cells. Thus each moving agent can be assigned an approximate position, defined by a paired number (a street number plus a cell number). The road segments are interconnected among themselves by access roads that function in our system as queuing lanes. By this means, we avoid the problem of managing traffic lights and priorities at intersections. The mathematical representation of the network could also be displayed on a diagram in which the intersections are nodes and the roadway sections are arcs with orientations and attributes.

The urban environment is also composed of a certain number of localized buildings. The buildings both emit and receive urban traffic: they include residences, workplaces, sites for commerce, leisure activities, etc… For each of these places, we propose several states, which evolve through a daily life cycle. In this way, agents perceive a building as dynamic force, attracting, and leading them to adapt their behavior to daily scheduling constraints.

Let's take the example of the restaurant whose daily life cycle can be produced. Each agent coming into contact with the restaurant will be able to know if the premises are open, temporarily full, or entirely closed. If the restaurant is open and has seats available, that mobile agent may be tempted to go in.

These different environmental elements also permit the generation of an ambient traffic diffused across the entire area being modelled. The role of such traffic is to influence the simulated agents in a way that produces a realistic simulation, yet limits the number of agents involved. The ambient traffic is composed of a collection of particles moving around on the basis of underlying statistical models, like Markov chains. These particles influence the progression of the simulated mobile agents to the degree to which they clog the road network, especially in waiting lanes / queues, thus adding to the total transit time for every agent.

5 OVERVIEW OF THE SIMULATOR

The goal of the graphic simulator played out during an implementation sequence (see Figure 6), is to permit, thanks to a graphic interface, the dynamic tracking of the agents' movements around their virtual urban environment.

This tool was created using a Framework (Marilleau et al., 2005) based on MadKit's multi-agent library. This Framework aids in generating agents by offering abstract classes that allow specifying of agents' wishes, knowledge, and perceptive capacity. This development is facilitated further by the Framework's provision of a menu of basic agent movements in the virtual built environment.

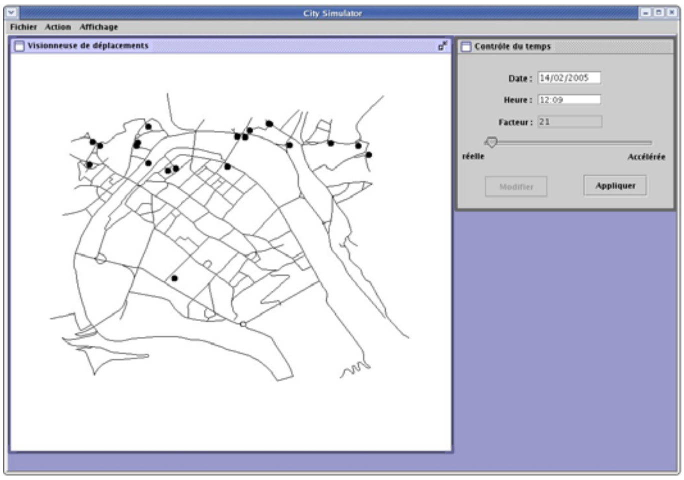

Figure 6. A Screen-Capture of the Simulator

5.1 Creating the Virtual City

Creating the virtual city is a preparatory step in the simulation. Its purpose is to define the virtual environment, and also to generate the various moving objects that will maneuver against that backdrop.

The structure of the city being studied is built and managed by a GIS (Geographic Information System). The simulator is able to fill these data-files (in Mif-Mid format) and analyze them, as well as create a virtual world comprised of streets that are composed of sub-cells of a uniform size. This city can quickly be fleshed out via an OPENGIS database (Percivall, 2003). The creation of mobile objects entails applying attributes to the agents and localizing them in the environment. This stage also requires defining the agent's cognitive map. This knowledge-base is composed of a certain number of strategic locations (workplace, home, stores) and of routes by which they can be reached. Several tasks are assigned to each mover, giving rise to his desire to travel.

5.2 Simulating the Swarming City

Our objective is to make the mobile agents move around in the virtual urban environment so that their travel, and more specifically their changes of behavior, may be observed. Behavioral changes may stem from three categories of causes: non-specifiable circumstances, the enlargement of one's cognitive map, or structural changes in one's environment (such as alterations in the road network and/or transportation supply, changes in available service…), especially in the forms of urban planning scenarios.

Simulated mobile agents must construct a daily schedule following rules about cost and custom, and taking account of any constraints encountered. At first, they formulate a plan based on whatever facts they know and on their list of tasks to get done. That schedule determines a path to cover. Then each agent moves along the planned trajectory. This plan can be altered at any moment by unforeseen turns of event, for example if the moving agent notices the buildup of a traffic jam. In that case, an alternate route is devised.

Over time, the mobile agents go on learning, thanks to their perceptions of the world and through interactions they may have with their surroundings (static and dynamic) and with other moving agents. Their schedule that was calculated on the basis of preliminary knowledge can be made to evolve and refine during the course of a simulation: Thus a mobile agent finding himself behind-schedule on d-day, might try to reduce his lateness on d-day+1, for example, by moving up his departure time.

5.3 Geovisualization

Simulating a city in motion by using a large number of mobile agents inevitably raises the issue of its visualization: how do you translate visually, and what is more, dynamically, this urban environment that is perpetually changing, criss-crossed by mobile agents on intersecting trajectories? The graphic translation of spatio-temporal trajectories proposed by Hägerstrand, seems to us mal-adapted to such a context. Figure 7, created by the American geographer Mei-Po Kwan (Kwan, 2000) from GPS data obtained during a research led in Portland, shows an impressive tangle of these individual trajectories akin to the indecipherable travel of balls in a set of pelote games. Confronted to this problem, we've chosen to adopt a multi-scale and multi-level visualization process, to reveal both the individuals and the collective flux of the entire city.

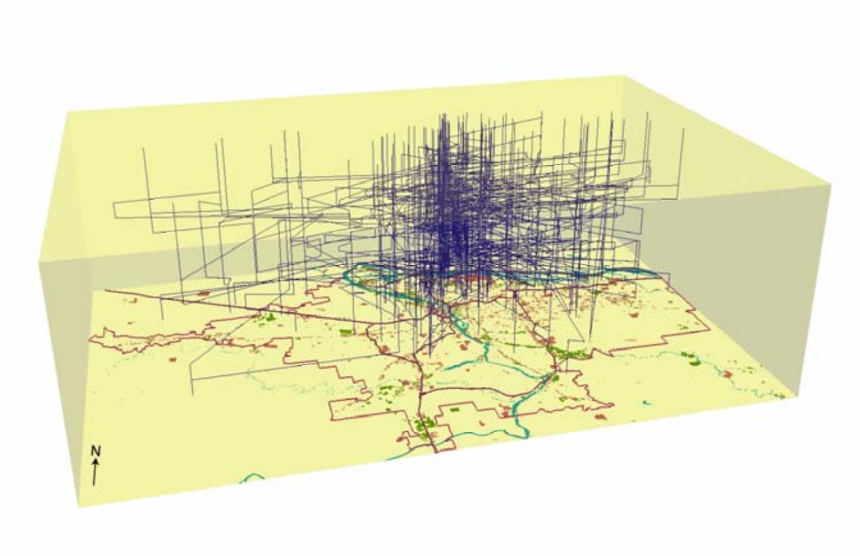

Figure 7. From Individual lifelines to the Collective Mess (Kwan, 2000).

Created within a geographer / computer-scientists partnership at the University of Pau and the Pays de L'Adour (Lesbeguerie, 2004), Figure 8 thus offers a preliminary view of the swarming urban "anthill", based on data from research on household movements in the greater-metropolitan area of Lille, France. The road network is shown by blue lines, the individual mobile objects by white dots, and the stationary ones by green dots. The spikes show the number of individuals present on the contiguous lines, for a given threshold of density. The image shows a simulated situation at a specific time-slot (7:47 AM), based on household research data, and takes on its entire meaning in the dynamic framework of a cartographic animation.

This first level of analysis, micro-scaled, must however be completed via a basic shift of scale, from individual movement to that of the overall flux of the city (Banos et Thévenin, 2005). It is indeed essential to place individual behaviors back at the heart of that larger woven tapestry which is urban space in all its richness and scope. Revealing and detailing a breathing metropolis, an entire urban region, laid out across ceasely renewing spaces that are both "full" and "empty" over the course of the same day, integrates powerful urban forces, which are worthy of considerable methodological investment.

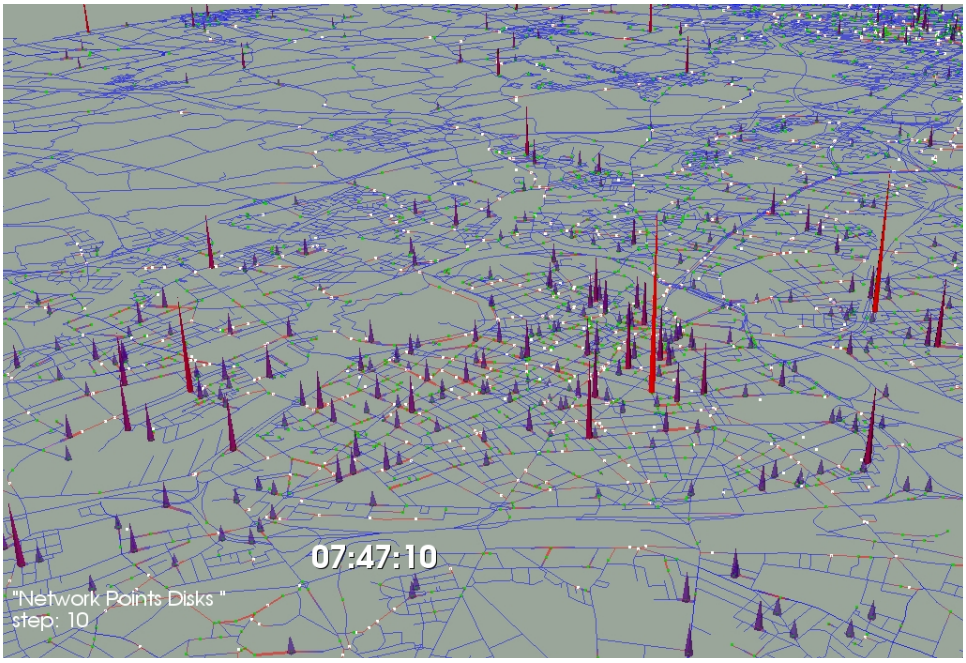

Figure 8. A Vision of the Urban Anthill[2] (Lesbegueries, 2004)

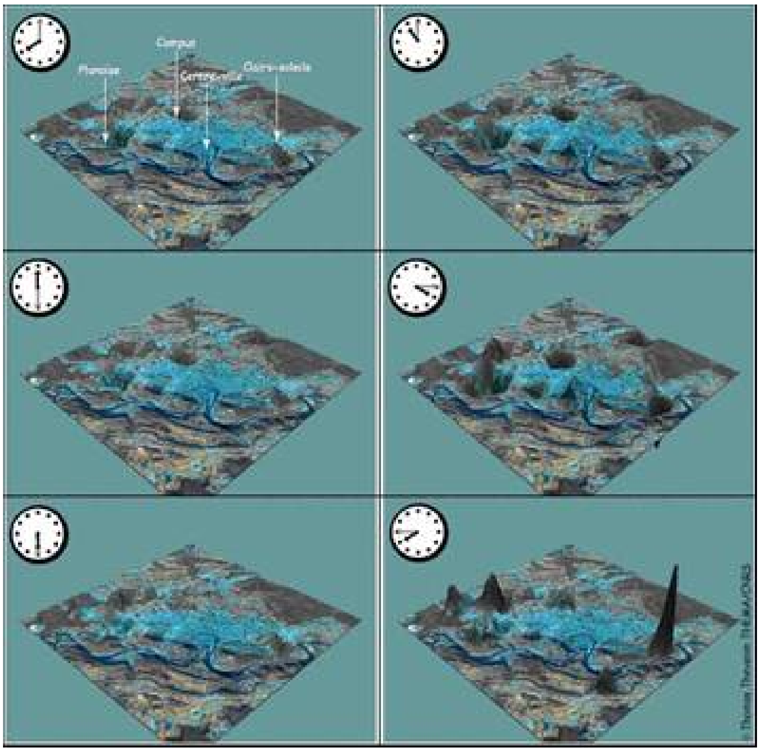

Figure 9. Global view of the city "in motion"[3] (Banos and Thévenin, 2005)

[2] View animation at : http://www.univ-pau.fr/~banos/etudiants-travaux.html

[3] View animation at : http://www.univ-pau.fr/~banos/geovisualisation.html

Figure 9 shows the evolution of the urban area of Besançon during the course of a typical day, here simulated on the basis of local study of household movements and the Origins-Destinations matrix. The depressions reflect areas that are emptying, while the up-swellings indicate localized population buildup in the given time-slot.

Being able to visualize personal behavior and the urban dynamics stemming from it means being in a position to help in decision-making: the animations produced should be sufficiently enlightening to foster public discussion, encouraging the emergence of an intelligent collective process.

6 CONCLUSION

Considering the increasing complexity of individual movements and the growing stakes involved in urban management and planning, it makes sense to seek a fresh approach to the "urban anthill". In the framework of the multi-disciplinary project we call MIRO, we offer an approach that, with its focus on the individuals in motion, allows for the exploration of the complex organized system that is a city. To this end, we place ourselves simultaneously in the theoretical camps of time geography and distributed artificial intelligence.

From this vantage-point, our goal is not to reproduce the various individual behaviors as precisely as possible, but instead to assess the influence of archetypical categories of rational personal behavior (oriented primarily toward planning and performing daily activity plans) for the collective functions of the urban space. This research posture seems promising in its offer, ultimately, of a conceptual, methodological, and technical framework that allows for testing, by simulation, of the macro-scopic impacts of varying urban scenarios, by manipulating the different constraints in play, and in particular the constraints of conjunction, capacity, and power as defined by Swedish geographer Torsten Hägerstrand.

From a computer-science perspective, this "person-centered" approach to the city in motion involves three major stages (model-building, simulation, and the visualization of results), multi-agent systems naturally being applied during the first two of them. The distributed systems indeed describe individuals with customs, constraints, and means of communication, interacting with each other and with their urban surroundings. Modeling these individuals has been achieved with the formal tools of UML and Ploom-Unity. In addition, the use of MadKit's multi-agent library enabled us to reach beyond the preliminary phase of model-building to that of computer simulation.

REFERENCES

Bailly, J.P., Heurgon, E. (2004) Nouveaux **rythmes urbains : quels transports ?** Ed. Aube, Coll. Prospective du présent, La Tour d'Aigues, 221p.

Balmer, M., Nagel K., Raney, B.(2004) Large scale multi-agent simulations for transportation applications, EIRASS Conference 2004

Banos, A., Thévenin, T. (2005) La carte animée pour révéler les rythmes urbains», **Revue Internationale de Géomatique, Vol. 15, no.1**, 11-31.

Benenson, I., Torrens, P. (2004) **Geosimulation: automata-based modelling of urban phenomena**, John Wiley and Sons, Chichester, 286 p.

Bowman, J., Ben-Akiva, M. (1997) Activity-based travel forecasting, **Proceedings of the Activity-Based Travel Forecasting Conference**, US Department of Transportation, Washington D.C.

Burnett, P., Hanson, S. (1982) The analysis of travel as an example of complex human behavior in spatially-constrained situations: definition and measurement issues, **Transportation Research, Vol. 16A, No. 2**, 87-102.

Chardonnel, S. (2001) La time-geography : les individus dans le temps et dans l'espace, in L. Sanders (eds). **Modèles en analyse spatiale**, Hermès , Paris, 129-156

De Palma, A., Marchal, F. (2002) Real case applications of the fully dynamic METROPOLIS tool-box: an advocacy for large-scale mesoscopic transportation systems, **Networks and Spatial Economics, Vol. 2, No.4**, 347-369.

Dupuy, G. (1999) **La dépendance automobile : symptômes, analyses, diagnostic, traitements**, Economica, Paris, 160 p.

Gutknecht, O., Ferber, J, Michel, F. (2000) MadKit: une architecture de plate-forme multi-agent générique, Report No. 00061, Laboratoire d'Informatique, de Robotique et de Microélectronique de Montpellier.

Hagerstrand, T. (1970) What about people in regional science ?, **Papers of the Regional Science Association, No. 24**, 7-21.

Jones, P., Dix, M., Clarke, M., Heggie, I. (1983) **Understanding travel behavior**, Aldershot, Gower.

Jones, P., Koppelman, F., Orfeuil, J.P. (1990) Activity analysis: state-of-the-art and future directions, in P. Jones (eds) **Developments in Dynamic and Activity-Based Approaches to Travel Analysis**, Aldershot, Gower.

Kwan, M-P. (2000) Interactive geovisualization of activity patterns using three-dimensional geographical information systems: a methodological exploration with a large data set, **Transportation Research Part C, No. 8**, 185-203.

Lenntorp, B. (1976) Path in space-time environments: a time-geographic study of movement possibilities of individuals, Royal University of Lund.

Lesbegueries, J. (2005) Reconstruction et visualisation des déplacements d'une population urbaine, Mémoire de DEA en Sciences Informatiques, University of Pau, 38p.

Marilleau, N., Lang, C., Chatonnay, P. and Philippe, P. (2005) Un méta-modèle à base d'agents pour modéliser la mobilité urbaine, **Troisième Conférence Internationale: Science Electronique, Technologies de l'Information et des Télécomunications**, SETIT 2005, Sousse, Tunisia. Accepted for publication

Masson, S. (1998) Interaction entre système de transport et système de localisation : de l'héritage des modèles traditionnels à l'apport des modèles interactifs de transport et d'occupation des sols**, Les cahiers scientifiques du transport, No. 33**, 79-108.

MATSIM (2004) Multi-Agent transportation simulation, http://www.masim.org

Mc Nally, M.G. (2000) The activity-based approach, in A. Hensher and J. Button (eds), **Handbook of transport modeling**, Elsevier Science Ltd, 2000.

Nagel, K., Marchal F. (2003) Computational methods for multi-agent simulations of travel behavior, **Proceedings of the 10th International Conference on Travel Behaviour Research (IATBR)**, Lucerne.

Ortuzar J., Willumsen D. (1995) **Modelling transport**, Wiley, Chichester.

Percivall, G. (2003) OpenGIS reference model, Report No. OGC-03-040, Open Geospatial Consortium Inc.

Portugali, J. (2000) **Self-organization and the city**, Springer-Verlaag, NY, 352 p.

Recker, W., McNally, M., Root, G. (1986) A model of complex travel behavior – theory and operational model, **Transportation Research A, No. 20**, 307-330.

Transims (2003) Transportation analysis traffic and simulation systems, Los Alamos National Laboratory, http://transims.tsasa.lanl.gov