Commutation as an Emergent Phenomenon of Residential and Industrial Location Decisions: from a Microeconomic to a MMASS-based Model

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Abstract— In this paper we describe one of the results of the research activities that have been conducted by an interdisciplinary research group composed by computer scientists and economists during the Exystence Thematic Institute on "Regional Innovation Systems and Complexity" (Wien, September 2004). The main aim of work is to apply the Multilayered Multi Agent Situated Systems (MMASS) to model socio-economic processes in residential and industrial development. Some of the group members have previously experienced in modeling this type processes according to a microeconomic agent-based approach (and they have already developed a simulation system). The specific model we considered in this work assumes that commuter traffic in urban regions can be studied as an emergent phenomenon of the decisions of individual heterogeneous agents (i.e. households decide on residence, firms on location). We will show that the adoption of the MMASS approach provides modelers with the necessary expressive power that the problem requires and, at the same time, it allows to obtain a model that is simpler both to be developed and to be used. The typical use of this type of model is, as in the case we describe, to develop a simulation system that implements it. Thus, a software tool (like the one provided by MMASS) that allows to design and develop simulations can be fruitfully exploited by domain experts that are interested in model domain validation and domain analysis. In this paper we report the first phase of one of the researches that will be conducted during a research framework that involved the Austrian Research Center Seibersdorf (ARCS) and the Department of Computer Science, Systems and Communication (DISCo) of the University of Milano-Bicocca.

***Index Terms*—MAS-based modeling of complex system, complex system in economics and land use, MMASS modeling**

I. Introduction

THIS paper reports a research activity that has been conducted during the Thematic Institute "Regional Innovation Systems and Complexity" within the Exystence framework (http://www.complexityscience.org). The working group was composed by computer scientists and economists and they collaborated in order to define a common framework where to conduct a joint research on complex systems that could be fruitful and interesting for both the involved research disciplines.

The main objectives of this collaboration can be summed up as follow:

- Investigation on the notion of agents in microeconomics and its classification according to concepts and notions that are traditionally considered by agent research in computer science (i.e. agent architectures and behavioral models, interaction models within Multi-Agent Systems, relationship between agents and their surrounding environment, …).
- Investigation on the use of agent-based simulations in economics. This part of the work concerns an overview of the main motivations and goals that bring economists in developing software simulation systems in their researches and work (e.g. model validation, prevision, analysis, and so on). Moreover, particular attention is paid to the identification of the set of requirements and tools from the viewpoint of system developers (e.g. computational models, software platforms) and of simulation users (e.g. analysis approaches and tools).
- Definition of a common framework starting from analogies and differences emerged from the analysis of the different use of the notion of agents and interactions within computer science and economics. The common framework aims at concerning the conceptual, modeling, as well as computational point of views.

This working group aims to the definition of a set of methodological and software tools to support researchers and experts in landuse management in their research activities. In order to reach this long-term research goal, the working group has identified a set of activities to be conducted together or by group members individually. On one hand, a set of activities

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will be conducted by the members of the working group individually (even if a coordinated way). An example of these individual activities consists in overviewing available computational models (e.g. agent-based, based on Multi Agent Systems and Cellular Automata or their composition, and so on), focusing in previous experiences in adopting agent approach in Economics. The main aim of this activity is to formalize a set of fundamental simulation requirements that are coming from Economics (in particular from new emerging approaches to study complex systems from an economic viewpoint).

On the other hand, this paper will describe one of the activities that will be conducted by interdisciplinary working groups (here we report the one that has been conducted during the Wien Thematic Institute hosted by ARCS). The aim of this activity was to experiment the application of the Multilayered Multi-Agent Situated Systems [Bandini et al., 2002] to model socio-economic processes in residential and industrial development. Some of the group's members have previously experienced in modeling this type of processes according to an agent-based approach and a microeconomic simulation tool has already been developed. The specific model we considered in this work assumed and demonstrated that commuter traffic in urban regions can be studied as an emergent phenomenon of the decisions of individual heterogeneous agents (i.e. households decide on residence, firms on location).

In this paper we will show that the adoption of the MMASS approach provides modelers with the necessary expressive power that the problem requires and, thus, allows representing the commutation problem as an emergent phenomenon of the residential-industrial complex systems composed by situated interacting agents. At the same time, the MMASS allows to obtain a model that is simpler to be developed, updated and, thus, used. The typical use of this type of model is, as in the case we describe, to develop a simulation system that implements it. Thus, after having introduced field data about the area that is object of the study (i.e. the Wien area in this case), domain experts analyze the simulation runs in order to reach the simulation aims (maybe, for instance, the validation of the model itself, or the prevision or explanation of known phenomena). During this process, very often, the originally developed model may require to be updated. In fact, different versions of a model are usually developed, enriching first versions with previously not considered elements, additional parameters that had previously been disregarded, ignored or unknown, and so on.

The paper is organized as follow: first, we draw an overview about the adoption of distributed approaches (based on agents, MAS and CA) in economic theory (focusing in land use and traffic simulation contexts). Then, we will briefly overview the agent-based microeconomic model that has been previously proposed to study commuting as an emergent phenomenon, and we propose a model of the same problem according to the MMASS approach, pointing out the motivations of the adoption of MMASS among other MAS-based modeling tools. Finally the paper will end with some considerations on this proposal.

II. Why an Agent-Based Model?

Over much of its history economic theory has been preoccupied with explaining the optimal allocation of scarce resources. As a consequence of the notion of an optimal solution equilibrium between supply and demand of goods has become the central concept in economics. In order to be able to analyze partial and total equilibrium models, they have to be extremely simplified. It is especially the, usually necessary, assumption of homogeneity (i.e. a single agent called 'representative') that misses important aspects of economic reality. Traditional economics focuses primarily on the market as a selection mechanism, but neglects the market as a cause of variation and innovation. Of course, there have been many theories (e.g. [Schumpeter, 1999]) dealing with the evolution of economic systems, but they always lacked the rigor of equilibrium economics. For evolutionary models new methods were required, and agent-based modeling approach suggests interesting research directions. This approach is certainly adequate for analyzing economic models characterized by heterogeneity of agents, bounded and contradicting rationalities of agents, strategic behavior, imperfect information, imperfect competition, and other factors leading to out-of-equilibrium dynamics [Arthur et al., 1997]. Agent-based modeling helps to understand the economy as a co-evolutionary system, linking the economic macrostructure to the microeconomic behavior of individual agents (Batten, 2000). However, for a really evolutionary model of the economy, it is not sufficient to build agent-based models only to explain the emergence and change of relations between agents (e.g. as suggested by network models). Agent-based modeling has also to contribute to the understanding of the emergence and change of behavioral norms, organizations and institutions, which, at present, seems to be a much more difficult task [Tesfatsion, 2003].

Self-organization models, used to explain urban development or traffic flows, are not new. Until now, most models have focused on one of these issues only. So far there have been only few attempts to deal with urban development and traffic flows in a combined model in order to understand their mutual interdependence. As far as urban development is concerned, the limits of equilibrium-based approaches have led to an increased interest in simulation which is better able to capture the complex dynamics of interactions between heterogeneous agents. Cellular Automata (CA) have been the most frequently applied method [Portugali, 1999]. The fact that already simple rules can lead to complex dynamics and the direct applicability on spatial processes have made CA to a widely used tool for analyzing patterns of urban development that are characterized by self-organization. One of the first CA-models in economic research analyzed the emergence of social segregation caused by the preference of people to live in the neighborhood of other people belonging to the same social class [Schelling, 1969]. Other CA-models concerned land use patterns and their change over time (e.g. [Colonna et al., 1998]). As far as traffic is concerned, simulation has been used as a tool to improve traffic planning and management of traffic flows. For this purpose CA as well as MAS-based models have been proposed (e.g. [Raney et al., 2002]; [TRANSIMS]). Agent-based traffic simulation models are especially useful, because they enable the identification of each individual car, truck, bike or pedestrian. As a consequence, it is possible to analyze individual objectives, route plans, search and decision strategies [Batten, 2000] as well as effects of learning and changes of strategies on the traffic flows [Raney et al., 2002].

Within our interdisciplinary research, we claim that economy researches requires dedicated and more specific tools (both at the methodological and software levels) to be applied to this growing and interesting direction. Moreover, we claim that researches and studies on agents in computer science are ready to provide these modeling and computational tools in order to fruitfully support economy theory.

III. The microeconomic model

The microeconomic model by which this work has been inspired is based on the decisions of individual heterogeneous agents: households decide on residence, firms on location. Commuting is both a result of decisions of individual agents (i.e. an emergent feature in the urban system), and a feedback factor influencing the decisions of households and firms. The here described model focuses on self-organization of households and firms, while other agents (e.g., regulation of land use by municipalities) are taken as given.

A. Residential and industrial choice of location and commuter flows

The model consists of two classes of agents: *households* of employed persons and *firms*. Both classes are heterogeneous with respect to preferences on location. Specific types of households prefer given residential locations as well as specific firms prefer given sites. They regard different location factors and they attribute different weights to certain factors. In particular, on one hand *households* looking for residence take the following factors into account:

- the residential density at their location and in the surroundings;
- the availability of private services at their location and in the surroundings;
- the green space at their location and in the surroundings;
- the distance to the city centre.

On the other hand, *firms* looking for their optimal location focus on the following factors:

- the industrial density (as an indicator for the price of a certain location) at their location and in the surroundings;
- the ratio between demand and competitors at their location and in the surroundings;
- the proximity of related firms (suppliers, services, customers) within a cluster at their location and in the surroundings;
- the distance to the next transport node (highway exit, railroad station).

In the model the notion of distance between two locations does not indicate the topological distance, but it is given by an estimate of the time needed to reach a location from the other one taking into account the type of available connections (e.g. roads, underground line, train line). In the model experimentations these values have been computed according to collected field data and considering the availability of the different transportations in the experimentation territory (i.e. Wien urban territory).

The behavior of households in trying to find out their residential location is based on a location utility function and a cost function which considers commuting and relocation in case of changing residence. Commuting is a result of the choice of residence and the randomly determined new job opportunities or losses. Employed persons and jobs, accordingly, are differentiated by levels of qualification, so that not any job is accessible for every employed person. The behavior of firms is based on their location utility and a cost function of relocation in case of changing the site.

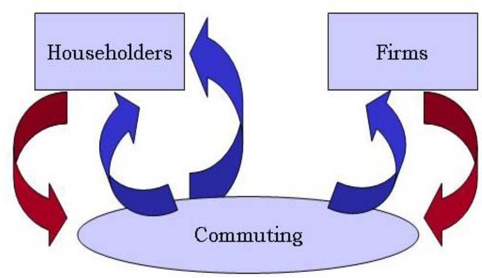

Figure 1: Influences and feedbacks between householdders, firms and commuting

Combining the decisions on residential and industrial locations, as well as the random job matching, leads to commuter flows between the locations which, in turn, enter the residential choice of households. Further feedback (represented in Figure 1) concerns the change in residential and industrial density, both being factors on which households and firms base their respective decision-making processes. Moreover, other factors that influence residential and industrial development and commutation are determined exogenously (for instance: location preferences of firms, changes in residential preferences life cycle of households, changes in job opportunities and employment, zoning and restrictions of land use, provision of traffic infrastructure).

The chart in Figure 2 gives a short overview of the whole microeconomic model. In the following sections we describe its modules in more detail.

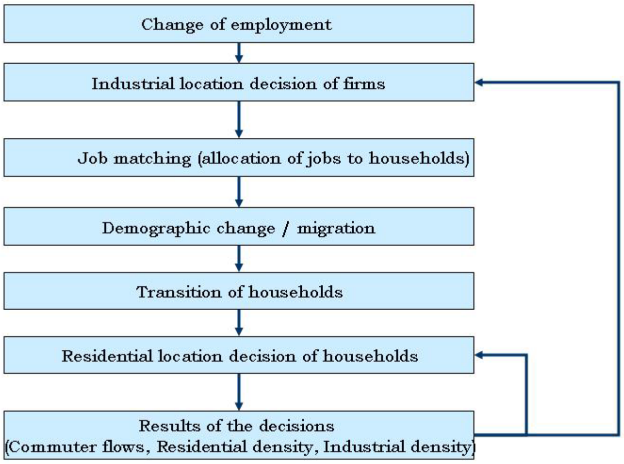

Figure 2. Structure of the model

B. *Endogenous processes*

As previously introduced, there are two different types of location decisions performed by the two types of agents that the model considers: *households* decide on their residence, while *firms* on the production site. Information needed for both decisions can be either perfect or distance-dependent. In a first model version, we supposed agents to have perfect information all over the urban region; in a second one, a distance discount parameter (i.e. σ) has been introduced in order to let agent sensitivity to information decreases with the distance.

Using information regarding the relevant location factors any household maximizes its residential utility and takes into account commuting and relocation costs (Table 1 lists and schematically describes all the involved parameters):

$$H: \alpha\, R + \beta\, S + \delta\, G + \gamma\, D_{ic} - (C3 + C1) \rightarrow \max$$

TABLE 1: RESIDENTIAL LOCATION FACTORS

Households H	H	
Residential density	R*	$R_i = H_i/B_i$, $R^*_I = R_i + \Sigma_j R_j$ e^-σ D_{ij}, normalized: % of R'
Private services (relative supply)	S*/H	$S^*_I = S_i + \Sigma_j S_j$ e^-σ D_{ij}, normalized: % of H
Green space	G*	$G^*_I = G_i + \Sigma_j G_j$ e^-σ D_{ij}, normalized: % of A
Distance between I and j	D_{ij}	
Downtown distance	D_{ic}	normalized: % of D_{max}
Residential relocation cost	C1	
Residential area	B_i	

On the contrary, according to the information regarding the relevant location factors (either in perfect or distance-dependent information versions) any firm maximizes its location utility considering relocation cost (see Table 2):

$$F: \varphi\, I + \lambda\, P + \mu\, X + \pi\, D_{in} - C2 \rightarrow \max$$

TABLE 2: INDUSTRIAL LOCATION FACTORS

Firms F	F	
Industrial density	I*	$I_i = F_i/M_i$, $I^*_i = I_i + \Sigma_j I_j$ e^-σ D_{ij}, normalized: % of I'
Demand / competition ratio	P*	$P^*_i = (H_i + \Sigma_j H_j$ e^-σ $D_{ij}) / (S_i + \Sigma_j S_j$ e^-σ $D_{ij})$
Cluster (relative supply)	X*/F	$X^*_I = X_i + \Sigma_j X_j$ e^-σ D_{ij}, normalized: % of F
Distance between I and j	D_{ij}	
Transport node distance	D_{in}	Normalized: % of D_{max}
Industrial relocation cost	C2	
Industrial area	M_i	

Both types of agents, households as well as firms, are heterogeneous regarding their location preferences (households also with regard to their qualification). According to their type (i.e. 'household' or 'firm'), agents apply the above utility function, but they differ with respect to the weights associated to each location factor (see, respectively, Table 3 and Table 4). Symbols in Tables 3 and Table 4 indicate the relevance of each parameter and the type of its effects (i.e. either positive or negative).

TABLE 3: CLASSES OF HOUSEHOLDS AND PREFERENCES

		Residential preferences			
		α R	β S	δ G	γ D_{ic}
Highly qualified suburbanites	(Q=1)	--	0	++	-
Highly qualified urbanites	(Q=1)	+	++	0	++
Less qualified suburbanites	(Q=2)	-	0	++	-
Less qualified urbanites	(Q=2)	0	+	0	+

TABLE 4: CLASSES OF FIRMS AND PREFERENCES

		Location preferences			
		φ I	λ P	μ X	π D_{in}
Private services	(S)	0	++	+	0
Cluster firms	(X)	-	0	++	-
Large scale manufacturing	(V)	--	0	0	-
Utilities	(U)	0	0	0	0

In order to solve conflicts in case of density constraints, in the here presented model, "First come – first locate" strategy with random order (i.e., reordering of agents after each step) was applied. Alternative strategies such as comparison of the added value (e.g. those with the highest value are allowed to locate, the others either stay where they are), or have to choose second-/third-best locations, are possible but have not still been applied.

C. *Exogenous processes*

All the actual parameters and several parameters for the model experimentation have been determined exogenously (several sets of parameters are tested in the simulation runs). This concerns residential preferences, industrial location preferences, generation and loss of jobs, zoning and maximum density and transport infrastructure.

Industrial location preferences are constant; they do not change during the simulation period. On the other hand, residential preference for suburban or urban locations changes probabilistically according to an assumed household life cycle (see Table 6). When a household reaches age 60 we assume that it retires, stops commuting and does not change location. Transition probability is estimated according to the frequency of households with and without children per age class (mean value of all municipalities is more than one municipality is considered). Moreover, the qualification level does not change according to age.

TABLE 6: TRANSITION PROBABILITIES OF HOUSEHOLDS

			Probability per age class		
			-30	*31-45*	*45-60*
Highly qualified suburbanites	→	Highly qualified urbanites	low	very low	Negligible
Highly qualified urbanites	→	Highly qualified suburbanites	low	very high	High
Less qualified suburbanites	→	Less qualified urbanites	very low	Negligible	Negligible
Less qualified urbanites	→	Less qualified suburbanites	Negligible	low	very low

The generation and loss of jobs is defined by the respective national industrial activity. The latter changes randomly within a specific industry the job opportunities offered by a certain firm and, after matching with people looking for jobs, it leads to the actual employment of any firm.

As far as spatial information is concerned, the regulation of land use (zoning), the upper limits of density and the provision of infrastructure (traffic capacity) are determined exogenously and may change discretely over time

IV. THE MMASS-BASED MODEL

Among models based on Multi Agent Systems (MAS [Ferber, 1999]), within our research framework we decided to adopt the Multilayerd Multi Agent Situated Systems (MMASS [Bandini et al., 2002]. The main motivations of this decision are strictly related to problem features and peculiarities (i.e. relevance of spatial features of agent environment, strong role of agent situatedness in their behaviors and interactions …) that we will overview in the following section. Then our proposal of applying the MMASS approach to model the above described problem[1] will be described.

A. Why MMASS?

Some features that we identified as interesting in relation to the considered problem are:

- It explicitly describes the spatial structure of agent environment (i.e. space): a multilayered network of sites where each node can host an agent, and represents a part of the distributed medium for the diffusion of signal emitted by agents to interact (e.g. to provide information to other agents).
- MMASS agents can be characterized by heterogeneous behaviors that are space-dependant: an action is performed by an agent since it belongs to some given type, it is currently characterized by some given state and it is situated in a given spatial location.
- Interactions between MMASS agents are heterogeneous and space-dependant (i.e. the distance between agents is an element that determines its nature – e.g. synchronous vs asynchronous, direct vs indirect, local vs at-a-distance):
  - MMASS agents interact according to direct interaction mechanism (i.e. MMASS *reaction*) when they are situated in adjacent positions and have previously agreed to synchronously change their states;
  - not adjacent agents can interact according to an indirect interaction mechanism based on emission-diffusion-perception of signals (i.e. *MMASS fields*) emitted by agents themselves
- Multilayered spatial structure (i.e. multiple situated MAS can coexist and interact): MMASS allows the modeler to exploit multiple layers in order to represent a high-complexity system (like the one of the reference problem) as composed by multiple interacting systems of lower complexity. Heterogeneous aspects that contribute to the behavior and dynamics of the whole system can be described by distinct MAS situated in distinct (but interconnected) layers of the spatial structure

B. The proposal

In order to apply the MMASS approach to represent the above described problem model, we first distinguished *territorial elements (i.e. territory)* from those entities that populate the territory and behave according to their type, their state and the state of the local environment they are currently situated.

We describe a territory as a discrete set of locations where either residential or industrial buildings are allowed (other location types have not been considered). A suitable representation of the territory set of locations in a graph-like structure (see the top of Figure 3), where each node of the graph represents a territory area (and its type), and graph edges represent connections between territory areas. In this representation, an edge exists between two locations only when some transportation infrastructure (e.g. road, train line) exists between them. Useful available information can be associated to each graph node and edge. For instance, edges can be labeled with information about the type of available transportation, the average number of cars per hour when it represent a road, mean delay time if it represents public transportations, and so on.

In adopting this type of representation of the territory, we have adopted a first feature of the MMASS model that is, the

[1] A detailed description of the MMASS approach is out the scopes of this paper. Details on the model can be found in [Bandini et al., 2002]; for some examples of its applications within the research context of modeling and simulation of complex systems see [Bandini et al., 2004a] and [Bandini et al., 2004b].

possibility to describe the structure of the environment that is populated by a set of active entities (i.e. agents). MMASS agents can represent thus those system entities that perform some kind of decision-making process (according to their features and state and the ones of the environment they are situated in).

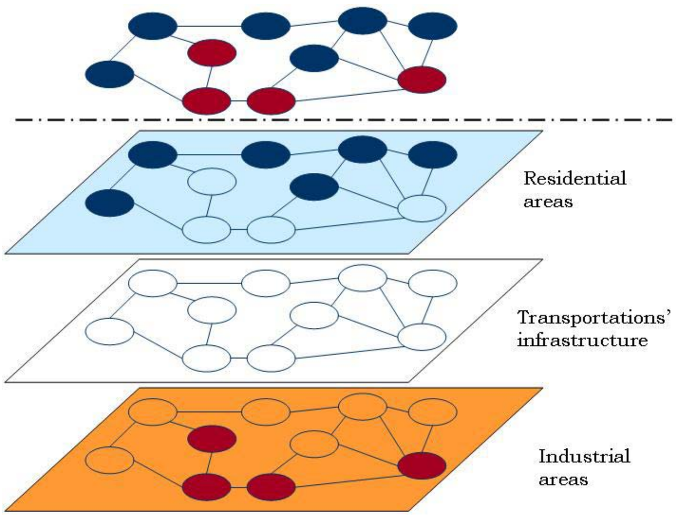

Figure 3. Multi-layered representation of the territory

The second feature of the MMASS approach that we exploited concerns the possibility to represent the environment where agents are situated according to a multilayered structure. Thus, given a territory, we represent it according to a structure composed by three layers. Two layers (the ones on the top and bottom of Figure 3) are devoted to represent those territorial areas in which, respectively, residential and industrial buildings are allowed. Each layer can be seen as a sort of "view on the territory graph representation" where only subsets of the graph nodes are considered.

The main motivation of this choice is related to the fact that, in this way, at residential and industrial layers we can represent two distinct complex sub-systems (i.e. "Householders' System" and "Firms' System" respectively). In fact the effect of householders' decisions, first of all, occurs within the system they are part of, but at the same time, householders and firms belong to two different complex systems. The third sub-system we considered is represented by "Commuting". We will not describe here into details the behavior, architecture and interaction abilities of agents that constitute each system since they are mainly based on the firms' and householders' models that have been described in Section 2.

According to system description (see Section 2 and Figure 1), we have identified three main influences that can occur between these three sub-systems (Figure 4):

1. *Householders' and Firms' systems* → *Commuting*: commuting is the result of decisions of householders and firms;
2. *Decisions in Firms' System* → *Householders' System*: decisions in the Firms' System influences the Householders' System since a firm may move to a location that may cause a change in decisions of some householders. This influence is not bidirectional since the availability of 'manpower' in the surroundings has not been considered by domain experts as a fundamental factor in firms' decisions-making process.
3. *Commuting* → *Householders' System*: the level of commuting is one of the main elements in householders' decisions (while it is not a factor influencing firms' decisions on their location).

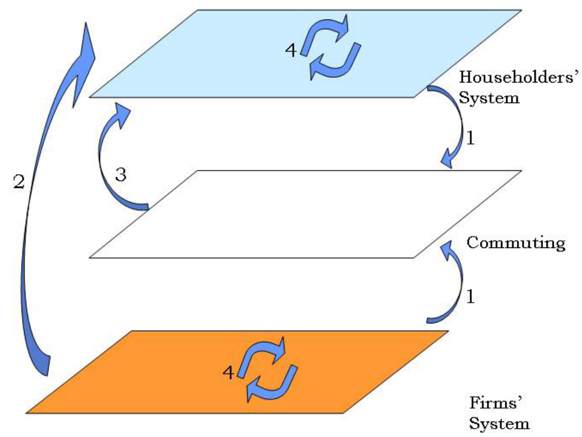

Figure 4. Influences between Systems

C. *Some observations on the proposal*

From the MMASS-based model description, we can draw some first observations and conclusions about the suitability of the adoption of the MMASS approach for the considered problem. In fact MMASS allows modelers to

- represent all the elements of the microeconomic reference model (that already demonstrated to fruitfully allow to represent the considered problem);
- better separate different elements involved in the complex system dynamics (e.g. territorial and decisional ones);
- explicitly represent influences, feedbacks and interactions between sub-systems;
- simpler update, and incrementally improve, the model.

Moreover, MMASS, despite other MAS-based modeling approaches, allows domain experts to simpler develop simulation software in order to experiment, validate, and update the model according to the problem requirements. In fact, a simulation platform for models based on MMASS is already available [Bandini et al., 2004c].

V. CONCLUSIONS AND FUTURE WORKS

In this paper, we have described a microeconomic agent-based model of a complex system where commuting is strongly involved in system dynamics (it is the result of householders and firms decisions and, at the same time, it is involved in their decisions). We have not included in this paper a discussion on the quality of this model. For this work, this model is the reference model and it is out of the scopes of this paper to validate it and verify its suitability.

Thus, we have proposed a MMASS-based model of the same problem (Section 3). The aim of this work was not to propose a modeling approach that improves the suitability or validity of the microeconomic model. On the contrary, we have proposed this modeling approach since it provides interesting features related to the reference scenario and to the goals of the microeconomic model. The main features of MMASS approach that can be useful in this work have been listed and some of them have been exploited in its application.

The here presented work is still ongoing and next activities will concern:

- specification of agent behavioral models: this work will be performed according to the behaviors of agents described by the microeconomic model (see households' and firms' utility functions);
- detailed specification of interactions and influences between sub-systems;
- development of a simulation system based the MMASS-based model: in performing this activity, we will exploit the tools provided by the MMASS platform [Bandini et al., 2004c] that will allow us to produce a simulation tool in the short time.

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