Contributi di ricerca
Contributo LabSIMQ n. 1

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EXPERIMENTING A MULTI-AGENT MODEL: THE SIMAC MODEL

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Indice

PREMESSA

La simulazione multi-agente rappresenta oggi uno degli approcci più promettenti per lo studio teorico e per l'analisi empirica dell'evoluzione dei sistemi territoriali. Essa nasce dalla convergenza di diversi campi di ricerca, quali quelli dell'intelligenza artificiale distribuita, delle scienze cognitive e delle teorie della decisione, resa possibile dai recenti sviluppi dei computer e delle capacità computazionali. Grazie anche alla crescente disponibilità di piattaforme standardizzate per la simulazione multi-agente, l'uso dei MAS (Multi-Agent Systems) si sta diffondendo rapidamente in tutta la comunità delle scienze sociali.

Anche se, in campo territoriale, le applicazioni dei MAS sono, per ora, ancora limitate, la loro introduzione solleva numerosi interrogativi, teorici e metodologici, circa gli avanzamenti stessi degli studi territoriali in un'epoca, quale l'attuale, nella quale gli sviluppi delle nuove tecnologie dell'informazione e della comunicazione, non solo influenzano l'organizzazione spaziale dei fenomeni ma stanno profondamente modificando anche i modi attraverso i quali percepiamo, osserviamo ed impariamo a conoscere i fenomeni stessi.

Questo lavoro presenta l'esperienza di applicazione di un MAS, il modello SimAC (Simulating ACcessibility) sviluppato all'IRES, per lo studio di fenomeni connessi all'accessibilità, alla pendolarità ed all'adozione del tele-lavoro.

La sperimentazione di SimAC è stato motivata da uno studio sull'accessibilità per l'area metropolitana di Torino condotto dall'IRES alla fine degli anni '90.

Essa si colloca a pieno titolo fra le attività di ricerca promosse dal LabSIMQ.

Seguendo le finalità del Laboratorio, pertanto, si auspica che le indicazioni che emergono da questo lavoro di ricerca possano fornire contributi di riflessioni inediti per approfondire l'analisi di quei fenomeni.

ABSTRACT

This paper illustrates some results of the application of a Multi-Agent System (MAS) approach to explore new model capabilities for dealing with commuting, accessibility and telecommuting adoption. SimAC, which has been implemented at IRES on the SWARM simulation platform, makes it possible to investigate changes in the urban routines engaged by individuals for partaking to work as a result of the introduction of telecommunication possibilities. As simulation by agents is rapidly diffusing in social sciences, it is also gaining an increasing popularity for modelling geographical phenomena, although so far the full range of possible advancements is still unforeseen. It is argued that the new model possibilities are not simply methodological. Adopting a MAS approach in fact entails a fresh look to the very core of modelling activity, i.e. examining the kind of urban issues to be addressed and the use of models in planning and decision-making. The development of the SimAC (Simulation Accessibility) model can be regarded as a contribution to sharp these questions.

Key words: physical versus virtual accessibility, multi-agent approach, emerging urban phenomena, social simulation, telecommuting, SWARM simulation platform.

1. INTRODUCTION

Simulation by Multi-Agent System (MAS) is attracting an increasing interest in many domains of social sciences (Axtell, 2000; Ballot and Weisbuch eds. 2000; Conte, Hegselmann, and Terna, eds., 1997; Kohler and Gumerman eds., 2000; Marney and Talbert, 2000). Technological progress, diffusion of computer skill and more easily accessible software platforms are contributing to this success.

As simulation is becoming familiar to a wider and diversified public, it affects in the process the core activity of many domains. This is also evident in geography, where a number of questions are raised about the future advancement of the field, in an era in which the introduction of new communication technologies not only affects the spatial deployment of phenomena but also modify the ways we learn about them as well as the means we have to cope with them (see for example the Project Varenius).

This paper reports the results of an ongoing research activity carried out at IRES, in which a Multi-Agent System (MAS) approach is used to explore new model capabilities for dealing with commuting, accessibility and telecommuting[1] adoption.

The research strategy develops along three directions.

- The first is an exploration of some major urban phenomena associated with mandatory mobility, such as accessibility, commuting and telecommuting by means of computer simulation. In this context, one major scope of a multi-agent model is to spur revising the approaches commonly held to tackle these issues.
- The second direction concentrates on the model possibilities in providing novel premises to support policy decision-making. Simulation experiments by a MAS model, in fact, allow us to explore those elusive and often hidden links between individual spatio-temporal behavioural options, and their global outcome (i.e. the emergent properties) observable at a 'system level'. This is becoming an increasingly relevant issue for devising socially acceptable policy measures for urban sustainability.
- The last direction is a contribution to the more general debate concerning the role of model-based knowledge for innovating planning thinking and practice. A MAS approach endows modelling activity with new potentials. These result from the enhanced role of cognitive mediation that models can play as artefacts, i.e. in linking the components of an abstraction process and the domains of the external environment in which modelling activity takes place (see Occelli, 2001a, 2001b, 2003; Occelli and Rabino, 1999).

The paper is organized in three main sections.

The first hints at the more general debate about the role of model-based knowledge for innovating planning thinking and practice. In this context, a kind of model taxonomy is suggested which allows us to emphasize the potentials of a MAS approach compared with other model types.

The second and more extensive section presents the conceptual and methodological development of the SimAC (Simulating ACcessibility) model. This is a multi-agent model, which has been developed using the SWARM simulation platform. Underlying this model development are two lines of reasoning: a) that accessibility implies a notion of *performance* associated with an agent's action space (the better the performance the greater is the agent's accessibility) and b) that there exits a further notion of accessibility which results from the interaction of individual behaviours.

Finally, the last part of the paper illustrates the results of some simulation experiments. A few remarks about this experience with a MAS model conclude the paper.

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[1] Although tele-work and tele-commuting does not exactly indicate the same phenomenon, in this paper the distinction is not relevant.

2. PUTTING THE SIMAC MODEL IN PERSPECTIVE

As in any modelling activity, the development of SimAC raised some fundamental modelling questions (see Occelli and Rabino, 2003), which would certainly deserve a deeper attention in future applications of the model. Broadly, this questioning refers to two general sets of questions:

a. Which kind of city is addressed by the modelling application, i.e. which view of city we are adopting in designing the model?
b. Which type of model approach we aim to implement, i.e. what is the model distinctive profile?

2.1 The view of city underlying the SimAC Model

The well-established idea of self-organizing city is at the basis of the SimAC's world (see Bertuglia and Staricco, 2000, Portugali, 2000, Pumain, Sanders and Saint-Julien, 1989). Whilst conceptually sharing several features of the IRN (Inter Representation Network) cities posited by Portugali (2000, p. 15), the city dealt with by SimAC is the city of everyday life, where ordinary people live and operate. The daily routines people follow in partaking to urban activities set up the SimAC's world. Its inhabitants, in addition, are not blind avatars, but possess a kind of cognitive ability, i.e. they have certain perceptions of their urban environment and these guide their spatial behaviour.

This view of city, therefore, maintains that there is a responsibility of urban routines in affecting the spatio-temporal processes taking place in cities. Indeed, their importance has been lately recognized in devising strategies for the management of travel demand (see Garling and Axhausen, 2003). Not only the greater variability of urban routines is accounted for, but also their behavioural determinants underpinning them are scrutinized, as it is increasingly evident that personality traits, attitudinal factors and environmental knowledge play a crucial role in individuals' action spaces, travel pattern behaviours and acceptance of policy measures such as traffic restrictions as well (see Nilsson and Kuller, 2000; Schwanen and Dijst, 2003). This was also at the basis of our claim that agents could actively construe their accessibility (see Occelli, 2000).

This view is also sensitive to the institutional, socio-economic, and cultural changes now occurring in most developed countries (see Castells, 1989, 1996). Space-adjusting technologies (the so-called New Information and Communication Technologies), in particular, are deeply influencing both the range and temporal organisation of activities offered in an urban setting and the ways individuals participate in them (Janelle and Hodge, eds. 2000, Graham and Martin, 1996, 2002).

As a result, at an individual level, the spatial behaviour of households and businesses is becoming more heterogeneous and diversified, while, at the meso-level, more complex patterns of interaction and timing of activities are emerging. One major consequence, which is also particularly crucial from a planning perspective, is that several time-dependent urban phenomena, such as traffic congestion and the temporal ordering of activities are increasingly difficult to control (Occelli, 2000).

2.2 *The model approach*

To better appreciate the type of model approach used in SimAC, it is worth recalling a taxonomy of model approaches, which has been recently elaborated as a result of more general reflection about modelling, the modelling activity, and the role of simulation (Occelli and Rabino, 1999, Occelli, 2001a, 2001b, 2002, 2003).
In particular, two main views of modelling underlie the taxonomy:
a. the first sees modelling as an activity through which an understanding of the organizational structure of an urban system is obtained. According to this view (which has been called *structural perspective)* a model is a (simplified) representation of certain urban phenomena and of their changes to exogenous or controlled induced perturbations;
b. the second considers modeling as an activity for testing, exploring, creating and communicating knowledge about certain urban phenomena. For this view (also referred to as *cognitive perspective*) models therefore are means for representing the working of our knowledge hypotheses and their outcome.

The proposed taxonomy of model approaches and their salient features as far as simulation is concerned are summarized in Tables 1 and 2 respectively.

	Intelligent Package	*Decision Support System*	*Cognitive models*
Socially relevant geographical phenomena	Urban costs and benefits	Efficiency and effectiveness of urban dynamics	Human decision making in a spatial environment and formation of collectives
Action domain	Geographical variables to be used as a leverage for change	Reasoning about socio-economic scenarios in a spatial framework	Awareness of action spaces in a spatial environment
Observable	City as a mix of urban functions	City as a system of interacting activities	City as a self-organized system, inhabited by social, autonomous, cognitive agents
Abstractions (theoretical bases)	Spatial equilibrium and utility maximisation approaches	Integration of input-output and spatial interaction approaches in a multi-level framework	Activity space of agents in a time-space framework, complexity approach
Mental models	NA	Implicitly included	Included
Knowledge levels (*)	Low granularity and high formalization	Medium granularity and medium formalization	High granularity, low formalization
Model of the observable	Regional system model, urban sector partial equilibrium models	Stock-flows models, operational urban system models	Multi-agent models of spatial movements and behaviour in an (artificial) environment

(*) As defined by Moss (1999)

Table 1 Profiles of the model types dealing with urban phenomena[2]

[2] For the sake of clarity it should be kept in mind that the keys in Tab. 1 are based on the modelling steps belonging to the two main loops involved in a modelling activity, i.e.:
- the internal loop (the modelling process loop) consisting of the conventional steps underlying a process of abstraction. This has its roots in the positivistic assumptions held in the mainstream of social sciences. It proceeds from observation to the formulation of concepts and their formal models

	Main features of the model	Role of simulation
Intelligent Package	A model is an analytic device to duplicate in a simplified way an urban phenomenon	It allows the functioning of the computer object
Decision Support System	A model is an analytic device by which a (simplified) duplication of urban phenomena permits replications of our knowledge hypotheses about them	It links the functioning of the computer object with the external world
Cognitive model	A model is an artefact allowing us to duplicate how we replicate the learning process of urban phenomena	The external world is made functioning within a computer program

Table 2 Types of models and role of simulation

The model approaches mentioned in Tabs. 1 and 2 can be briefly outlined as follows.

- Intelligent packages: they address specific well-defined urban questions. They exploit consolidated modelling methodologies, which thank to the advances in information and computing technologies are being incorporated in user friendly packages and diffused to a large public. The structural perspective to modelling largely predominates. Simulation is mainly restricted to the internal loop. It plays a major role as an analytic dimension supporting algorithmic procedures and making it possible the operational implementation of the model.
- Decision support systems: they are primarily aimed at assisting analysts for policy making. Both the structural and cognitive modelling perspectives are involved although to a various extent. In particular, a 'what if' perspective is adopted, where attention is turned not just on the 'what' but also on the 'if'. They typically are hybrid systems integrating three types of components: a core system describing the urban structure, an information component for data retrieval and output evaluation and a graphical interface for output visualization. In these system models the role of simulation is not limited to the internal functioning of a component but, because of the 'what if perspective', a set of links with the model external domain are established, although mainly associated with the technological backcloth characterizing the information system architecture.
- Cognitive models: the knowledge of human decision-making and action in an uncertain and changing environment is the main purpose of these models. Whereas underlying any modelling activity, cognitive mediation has here an enlarged role acting both as an activator of simulation potentials and as a recipient of the latter.

(the so called enc*oding process*), and terminates referring back the latter to the observed reality (through the so called *decoding process*);

- the external loop (the modelling domain loop) representing the general context of modelling. This takes into account the historical and socio-cultural domains hosting the process of abstraction. It reminds us that any modeling activity has to confront itself with the urban issues it aims to address, the resource availability, as well as with the socio-cultural context in which it takes place.

Simulation is an intrinsic dimension underpinning this type of models. Its novel features are co-determined by the cognitive mediation role.

The SimAC (Simulating ACcessibility) model belongs to the last type of models.

Building a MAS model for dealing with urban routines and their related features reveals a number of fundamental advantages.

First, it makes it possible to give a fresh look to the concept of accessibility, and to its relationships with urban routines, in an urban environment which is more sensitive to the introduction of NICT. In particular, it makes it possible to question the commonly held view that accessibility is a kind of entity derived from transportation demand (Couclelis, 2000, Occelli, 2000). On a conceptual level, a MAS approach provides arguments to view accessibility as: a) a resource for human settlements depending on individual's action spaces and cognitive abilities, and b) a collective outcome resulting from the interaction of individuals' behaviours.

Re-interpreting urban accessibility in terms of agents' behavioural profiles, i.e. considering their goals, cognitive abilities, and their rules of interaction is a challenging task, but one we cannot avoid if we want to harness the complexities of a sustainable urban development.

Second, on an analytic level, it allows analysts to explicitly treat the time dimension and recognise the different temporal scales on which urban dynamics unfold. Many critical situations we observe in urban areas today are caused by this intertwined deployment of events in certain places and times.

Finally, a MAS model provides an exploratory context in which experimentation with a model can yield substantial contributions for policy making, i.e. reasoning about how to cope with the novel features of the various correlates of urban routines.

3. THE SIMAC MODEL: A GENERAL OVERVIEW

3.1 Accessibility, mobility and NICT in the SimAC model

The SimAC (Simulating ACcessibility) model is a multi-agent model, which has been developed using the SWARM simulation platform, in order to deal with major urban phenomena associated with accessibility, mandatory mobility and the introduction of NICT.

Accessibility is a hybrid entity sharing features of the two fundamental components of any spatial system, the spatio-temporal pattern of activities, and the spatio-temporal pattern of interdependences. It therefore provides a junction between them. Apart from being responsible for a certain elusiveness of the concept, it is this 'junction role', which explains the longstanding debate on accessibility in the geographic and planning literature (Occelli, 2000).

Recently, a new interest for accessibility is emerging, as there is a need to revise its currently used notions. A number of reasons motivate this upsurge in interest, i.e. the appearance of new urban phenomena and processes marking the transition to a Post-Fordist society (see Amin ed., 1994); the shifts occurring in land-use and transportation policy in relation to the sustainability issues (see Banister, 1994; Hanson, 1998) and the introduction of NICT which modifies the organisation of activity, role of distance and pattern of interactions (see Bertuglia and Occelli, 1995; Couclelis ed., 1996; Graham and Marvin, 1996, 2000, Moss, 1998).

Both a micro and macro view of urban systems is considered in the SimAC model, see Bellomo and Occelli (2000), Occelli and Bellomo (2000). In addition, two lines of reasoning underpin the model development.

- That accessibility implies a notion of *performance* associated with an agent's action space (the better the performance the greater is the agent's accessibility). This means that agents are keen to assess this performance and modify their action space accordingly.
- That there exits a further notion of accessibility which results from the interaction of individual behaviours. Accessibility at a system (macro) level, therefore, *emerges* from the interaction of individual action spaces at the micro-level. This statement of emergency is based on a few presumptions: a) that there exist certain collectively recognised and agreed upon representations of accessibility, b) that some of these are likely to forge the *cultural fingerprints* of accessibility and become part of the prior information available to individuals, and c) that new views can result from a negotiation of already existing representations. These may affect policy norms and planning and ultimately modify individual action spaces.

SimAC does not purport to give a complete description of urban routines. Only work related daily routines are considered. An artificial world is set up which is populated by a number of agents whose behaviour in mandatory mobility obeys certain rules, and is constrained by the features of the urban environment, i.e. the transport and telecommunication networks, the kind of access demand to work, the types of job accommodations.

Re-interpreting urban accessibility in terms of agents' behavioural profiles, i.e. considering their goals, cognitive abilities, and their rules of interaction, is a challenging task, but one we cannot avoid if we want to harness the complexities of sustainable urban evolution (see, for example Couclelis, 2000).

Notwithstanding the noticeable insights provided by the recent literature on urban systems (see for example, Bertuglia, Bianchi and Mela eds. 1998; Otter, van der Veen

and de Vriend, 2001), we sustain that alternative views about accessibility should be investigated[3].
The modelling experience with SimAC represents one possibility.
In designing the SimAC model we have been confronted with a few questions concerning the definition of:

1) the kind of agency we aim to reproduce in the model;
2) the types of agents (i.e. cognitive abilities driving the agents' behaviour);
3) the kind of interactions in which agents are involved.

3.2 *Designing the agency profiles*

To make our agents look as much human as possible, we would like them be endowed with as much cognitive abilities (i.e. conative functions and representational capacity, Ferber, 1999) as people, living in a urban environment commonly have (or, at least, are supposed to have). In particular, we need to understand how (Golledge and Stimson, 1997; Mark et al., 1999):

1) humans process spatial information;
2) spatial information is collected, memorized and retrieved;
3) spatial decisions are undertaken.

To fully address these aspects would require a model architecture capable of explicitly dealing with the cognitive attitudes and decision-making processes of distributed agents (see Rao and Georgeff, 1995, Broersen et al., 2001). Given the limited scope of this study, we can only make a few assumptions about the general principles. We hold that these abilities are rooted in a fundamental characteristic of any living systems and namely in their capability to derive measures from the external environment and making sense from them (i.e. the so called operational closure in Pattee, 1986).

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[3] In this regard, a few major themes pointed out by the ongoing debate can be summarised in the following (see Occelli, 1998, 2000).
First, that accessibility is an intrinsically complex notion, likely to encompass various aspects which can co-exist although not easily be reducible to each other. On this ground, the questions involved are both conceptual, i.e. formulating an appropriate time-space framework of reference according to which relevant notions should be conceived, and empirical, i.e. defining both the kind of process or outcome indicators and data to be used to measure accessibility. Although this observation may appear trivial on theoretical and methodological grounds, it is certainly not from a policy point of view. Most policy measures of accessibility currently implemented overlook those questions. They consider a certain definition of accessibility (i.e. a given indicator), failing to acknowledge that its implications can be very different (and even contrasting) in different areas (i.e. planning contexts).
Second, that the 'junction role of accessibility' is the most sensitive to the introduction of NICT. Their impact acts at two fundamental levels (Occelli, 1999): a) at a substantial level on the determinants of accessibility, i.e. enabling certain socio-economic opportunity or reducing the spatio-temporal constraints in participating in urban activities; and b) at a conceptual level on our ways to represent accessibility and its relationships with the city (think of the use of the new information tools, such as GIS).
Third, that we assist at a shaking of both conventional planning wisdom (i.e. dispersed vs. compact cities, substitutions of commuting trips by virtual communication in order to reduce traffic) and planning practices (i.e. such as those reflected in a further lessening of planning controls on locations). In many contexts, system responses able to act through bottom up rules of behaviour rather than top-down controls are recognised to play an increasingly important role. In this respect, the recent surge of interest in spatio-temporal planning (see Mey and ter Heide, 1997) and travel management strategies (Bonnel, 1995; Salomon and Mokhtarian, 1998; Arentze and Timmermans, 2002, 2003), are further aspects of the quest for new system responses.

On this premise, we assume that two main drives underlie agents' cognitive abilities:

- Self-evaluation. Urban agents regularly make an assessment of the urban routines they engage in and may change their behaviors accordingly. This evaluative activity can be considered as a kind of internal goal, associated with the intrinsic nature of urban agents (similar to the more general feature of self-preservation which characterizes all kinds of living agents).
- Communication. Besides the various signals produced by agents' interactions and mediating role of the environment, communication between agents has a role in stirring agents' behaviors. It, therefore, influences their decision-making, as it provides additional information about choice alternatives, reinforcing certain determinants of choice, and makes it possible to anticipate or postpone an action. A corollary assumption is that a communication is likely to be related to an evaluation activity.

SimAC does not possess a complete architecture of agents' cognitive abilities. It however maintains the idea that agents' actions are *deliberative* in the sense that they are based on certain *agents' internal (or mental) models* of the action spaces they are able to set up in the simulated urban environment. As mentioned above, some of these internal models depend on the evaluation activities (and communication acts) undertaken by agents. In addition, they are endowed with a kind of memory, making it possible for agents to recall, although to a limited extent, past experiences in their evaluation activity[4].

Although SimAC architecture does not belong to any of the well defined classes of agents, i.e. logic based, reactive, belief-desire-intention, layered architectures (Wooldridge, 2000), its operational structure can be considered hybrid. In fact, it has its roots in both the symbolic representations underpinning logical approaches i.e. agents minimize their travels and have a performance function, and reactive architecture, i.e. the activation of certain agents' actions depend on accomplishing certain modules taking the form of rules.

3.3 Types of agents, cognitive abilities and behaviors

SimAC addresses issues concerning work related urban routines, i.e. commuting, accessibility and telecommuting. Given the goals of the model application, three types of agents populate the artificial world simulated by the model.

INHABITANTS: These agents mimic certain features of mandatory mobility behaviour of individuals in an urban setting. Inhabitants daily commute in order to get to their workplace. The job related urban routine shapes their action space and determines their accessibility. Inhabitants are able to make an evaluation of their accessibility and modify their travel path accordingly. They also have the possibility to telecommute. This decision depends on both drives and constraints, acting at individual and system levels. The drives depend on the individuals' action spaces. The constraints are both external, i.e. the availability of telecommunication networks and labour regulations, and internal, i.e. the psychological factors related to the need of face-to-face contacts. Inhabitants' overall dynamics unfolds on two different time scales. Accessibility changes occur on a relatively short time span, while the decision to telecommute is supposed to be taken on a relatively longer one.

[4] Besides memory, also the ability to anticipate future events is a major characteristic to be accounted for in agents' internal models (see Rosen, 1985; Ferber, 1999). This aspect, however, is not dealt with in the present version of the model.

LOCALITIES: These agents embody features related to work activity and urban places. In the current version of SimAC, Localities refer to workplaces, which are spatially ‘fixed’. Besides providing jobs to Inhabitants, Localities have to supply a bundle of job accommodations, i.e. car parking availability, office floor space, telecommunication infrastructure, etc. Localities are able to monitor the behaviours of their own employees as they access their workplace, i.e. they can measure the traffic congestion produced in the surrounding areas. Consequently, they can introduce more flexibility into working times to contrast the observed negative effects. In evaluating their performance, Localities take into account their overall revenues and costs. We suppose that these depend on a relatively slow changing set of structural determinants, i.e. costs of labour, rents and facilities and a relatively faster changing set of factors, i.e. congestion, road price, adoption of new information technologies, which are more sensitive to the dynamics of the SimAC world.
WHISPER: This agent does not represent any given physical entity. Broadly speaking, he can be understood as a kind of repository of the tangible and intangible *information pool* existing in a city. On a more practical ground, he may represent an external observer, who is able to observe certain outcome of the behaviours of both Inhabitants and Localities. As he collects and processes, information for policy purposes, he also computes a set of diagnostic indicators of the overall performance of the system. Some of these are used by the Whisper to undertake certain actions, i.e. increase capacity of certain roads, introduce traffic calming and road price, and favour the diffusion of new information technologies. Others may be used to give prescriptions or recommendations to Inhabitants and Localities.

3.4 Defining the interactions among agents

Two main types of relationships are at the basis of the agents’ interactions.

- The so-called *structural relationships*. These are the social, functional and physical relationships pertaining to the different activity spaces of a city, i.e. those associated with the participation of individuals to urban activities (work, school, leisure, retailing, etc.) and their movements in the urban environment (see Bertuglia, Bianchi and Mela eds., 1998; Golledge and Stimson, 1997; Janelle and Hodge eds., 2000). This kind of relationships, which underpins the majority of current urban models, also underlies the general structure of relationships in the SimAC world.
- The so-called *informational relationships*. These are associated with the communications established in the artificial world (i.e. among the agents and between agents and the environment). Communication is a fundamental feature of a multi-agent world and can deploy itself in many forms (see Ferber, 1999; Nilsson, 1998; Woldridge, 1992). In this model application a communication act is broadly understood as a kind of speech act associated with agents’ conative functions. As the architecture of the agents’ internal models is not fully developed, the major role of communication acts is simply to accompany agents’ evaluative activities, i.e. reinforcing, constraining or inhibiting certain determinants of agents’ actions, and thus affecting their final outcome[5].

[5] The architecture should also consider the agents’ capability to establish links among their internal models, and namely reason about other agents’ behaviours (goals, resources, actions and plans), see Sichman, Demezeau, Conte and Castelfranchi (1994).

4. MODEL BUILDING: THE AGENT PROFILES

The present model builds on a preliminary version of SimAC (Bellomo and Occelli, 2000). Although the original structure has been maintained, having its straightforward counterpart in the basic components of the SWARM simulation platform (Terna, 2002), both the profiles and behaviours of the agents have been substantially developed. In the following, we briefly describe the agents' capabilities which have been recently implemented.

4.1 The Inhabitant agents

As mentioned earlier, these agents mimic certain features of (mandatory) mobility. Inhabitants daily commute in order to get to their workplace but can decide to telecommute thus substituting their physical travel with virtual contacts.
Inhabitants' behaviour is guided by the following intentions:

- they communicate with the agents they come in contact with;
- they have to work;
- they value time, have a time budget and are sensitive to time constraints. They are, therefore, motivated to reach their workplace as soon and easily as possible. They also make an assessment of their travel time relative to other uses of time (leisure time);
- they move in the urban environment;
- they are aware of the spatial and environmental characteristics of the city;
- they have to travel in order to participate to an activity (i.e. work);
- they can substitute physical movement with virtual contacts in order to participate to an activity (i.e. work).

Inhabitants live and work in different zones of the urban environment. Each zone corresponds to (i.e. coincides with) a node of the urban spatial network.
In evaluating their urban routines, Inhabitants consider two main aspects each of which is associated with a communication act:

- the first relates to their journey-to-work. Evaluation, therefore, addresses processes occurring on a short time period and typically on a daily basis;
- the second concerns the decision to telecommute. In this case evaluation deals with processes which may take place on variable time spans, which are however longer than those considered in assessing the journey-to-work.

4.1.1 The journey-to-work

The main strategy underlying Inhabitants' journey-to-work is based on the minimization of travel time, as this is perceived as a disutility, which can also negatively affect the time budget for ther activities (Bellomo and Occelli, 2000). Journeys-to-work therefore are based on the conventional rule of time path minimization. In moving on the urban network, agents follow the sequence of links with the lowest travel times. (Their computation is based on the Dijstra algorithm, see Car, 1997). Everyday, on their way to work, they update the time of each link as they pass it. To carry out this task, the following formula is used:

$w(t) = S_f a * s(f, t) + c*g(f, t)$ (1)

where,

w (t) is the perceived travel time

s (f, t) is the number of time steps necessary to pass a link, f, connecting two nodes of the grid; to distinguish it from the *w* travel times, we will call it observed travel time

a is a weight representing the importance of the observed travel time

g (f,t) is a function of congestion (number of Inhabitants on each link of the transportation network)

c is a parameter weighting the importance of congestion.

These travel times (eq.1) are then used for computing a new minimum path in the following day. A similar approach is used to calculate travel times in their way back to their residence zones[6].

Each Inhabitant has two matrices of travel times. The first is obtained from the *s(f, t)* times and accounts for those components of urban environment (i.e. transport network, location patterns of activities, social values of time) affecting individual travel times at a system level. The second is given by the *w (t)* times and can be considered an element of the *mental map* of individuals' action space.

Evaluation of the journey-to-work also extends to the arrival time. When reaching their place of work, Inhabitants compare their arrival time with the work starting time. If they are late, they will leave home earlier in the following day. Otherwise, if they arrive too early, they will leave later. The following expressions are used to update their departure time from home:

if $AT(t) > WS(t)*z$ then $DT(t+1)=DT(t) - 1$

if $AT(t) < WS(t)*z$ then $DT(t+1)=DT(t) + 1$ (2)

where

t is the simulation interval (one day)

AT is the arrival time

WS is the time at which work starts

DT is the departure time from home

z is the flexibility interval of working time start.

The complaints of late arrivals will be reported to the Locality by communication acts.

4.1.2 The decision to telecommute

Inhabitants have the possibility to telecommute. This decision, TEL, results from both drives and constraints acting at individual and system levels (Mokhtarian and Salomon, 1994). The drives, DRIVE, relate to various aspects of an individual's action space, i.e. job environment, family life, leisure time and the negative perceptions of commuting. The constraints, CONS, are both external, i.e. the availability of telecommunication networks and labour regulations, and internal, i.e. the need of having face-to-face contacts or separating work from family sphere. Whereas constraints determine the possibility to telecommute, drives can modulate the preferences to undertake it. For each Inhabitant, therefore, there exists an evaluation function given by:

TEL = [CONS * DRIVE] (3)

with

CONS = ext*int (4).

[6] As a result, Inhabitants' matrices of travel times (s and w) are not symmetrical.

Ext and *int* are the external and internal constraining factors, respectively. They can be represented by binary variables. If *ext* or int = 0, therefore, CONS = 0 and TEL = 0.
We suppose that *ext* will depend on:

- the decision of the Locality agent to introduce telecommunication technologies and give employees the possibility to telecommute (i.e. provide both access to internet and computer assistance);
- and the availability of communication services in a residential zone, i.e. as a result of the telecommunication policy undertaken by Whisper.

Therefore:

ext = 1 (5)

if the Locality where an Inhabitant is employed innovates and if telecommunication services are available in Inhabitant's residential zone.
We also make the hypothesis that the internal factor, *int*, is influenced by the diffusion of tele-work and information about its adoption (the more inhabitants know about telecommuting the more likely they will adopt it):

int =1 if (NTEL*INFOTEL) > NMET*p (6),

where

NTEL	is the number of telecommuters met or known in the agent's action space (in his residential or workplace zone)
INFOTEL	is the information about telecommuting provided by the Whisper agent
NMET	is the number of agents met or known in the agent's action space (in his residential or workplace zone)
P	is a weighting factor.

The DRIVE component is defined as:

DRIVE = (F1, F2, F3, F4) (7),

where

F1 = d1*JOB	is the component representing the job milieu
F2 = d2*HOUSE	is the component representing the residential milieu
F3 = d3*LEISURE	is a factor reflecting the importance of leisure time, within the overall Inhabitant's time budget
F4 = d4*w	is the component associated with the perceived travel time as defined by eq (1).

D1,., d4 are weights reflecting both the measurement scale and relative importance of the various factors. Some of them may be reinforced or constrained by the information provided by agents.
If there are no constraints (CONS=1) and the drives to telecommute reinforce significantly in a period, Inhabitants will decide to telecommute.
For each Inhabitant therefore, TEL= 1
If evalD (t, t+Dt) = {[(DRIVE (t+Dt)–DRIVE (t)]/ DRIVE (t)]+ [sIN*INF]}> sSY (8),
where

sIN	is the sensitivity to modifications in the DRIVE function as perceived by each Inhabitant agent
INF	is the information sent by the Locality
sSY	is a threshold reflecting the overall system sensitivity to changes in the drive function as perceived by all the Inhabitants.

If Inhabitants continue to travel, the outcome of their evaluation activity can have an influence on the weights in the DRIVE function (eq.7), and the information made available by the Locality and Whisper agents.

4.2 The Locality agents

In this version of SimAC, a Locality stands for a work activity and is regarded as a bundle of jobs, employment, office facilities and workplace access.
The following features characterize the behaviour of this type of agents:

- they communicate with the agents they come in contact with;
- they provide work to Inhabitants;
- they are compelled to maintain (improve) a certain performance level in their production activity;
- they are aware of their urban milieu (i.e. the spatial, economic and social characteristics of the area in which they are situated);
- they have to provide job accommodations for their employees (i.e. offices, working equipment and infrastructures).

Localities have a fixed location in certain nodes of the urban network and do not relocate during the simulation period[7].
In performing their self-evaluation, PERF, they take into account two terms, PROD and COST, i.e. PERF (t)= {PROD (t)/COST (t)}, which accunt for the Localities' gains and costs, respectively.
PROD is defined as:

PROD(t) = [NE(j)*q] (9),

where

NE (j) is the total number of Inhabitants employed in a Locality j
Q is the output for each employee, expressed in term of time availability, q = leisure - w (i, j).

COST depends on a slow changing structural component, STRUCT, and a faster changing trend, FEXT:

COST(t) = [STRUCT(t), FEXT(t)] (10),

where

STRUCT(t) = (C1, C2, C3) (11),

with

C1 = s1*labour*NE, is the component representing the total labour cost. Labour represents the unitary cost for employee
C2 = s2*rent*office*NEC, is the component accounting for the office running costs. Rent and office are the unitary rent and office floor cost, respectively, and NEC is the number of employees not telecommuting
C3 = s3*cct*facilities*NEC, is the cost of equipment, i.e. size of parking lots (facilities) and unitary costs (cct)
s1, s2, s3 are weights taking into account both the scale dimension and relative importance of the various factors. They may be updated depending on the information provided by the other agents.

FEXT = (C4, C5, C6) (12),

with

C4 = s4*enviext, is the component accounting for the environmental externality caused by congestion in a Locality zone. We assume that *enviext* is given by =H * NEC, where H is entropy of the employee distribution, arriving in a locality during a certain time interval, it, H = [$-\Sigma_{it}$ n(it)*Log n (it)], with n (it)=NEC

[7] In developing this part of the SimAC model we took advantage of previous studies we carried out about the introduction of new information and communication technologies in urban systems, see Bertuglia, Lombardo, Occelli and Rabino (1995); Bertuglia, Lombardo and Occelli (1998); Bertuglia. and Occelli (2000).

(it)/S_{it} NEC(it), and NEC is the total number of inhabitants commuting to a locality

C5 =s5*roadprice*NEC, is the component accounting for the fare that Inhabitants may have to pay in order to access certain zones

C6 = s6*technology, is the component representing the net gain of adopting a technological innovation as a result of the introduction of new telecommunication infrastructures and services

s4, s5, s6 are weights similar to the s1-s3 above.

Evaluation of a Locality's own performance is carried out taking into account the components and total value of the COST production function (eq. 10). Depending on the observed types of change, different actions can be undertaken and accompanied by communication acts sent to the Inhabitant and Whisper agents.

4.3 The Whisper agent

This is a kind of super-agent, who plays the role of both observer and planner of the system. The main scopes of Whisper are:

- monitoring the behaviour of both Inhabitant and Locality agents at a system level;
- giving prescriptions and recommendations for action to both Inhabitants and Localities.

As an observer, Whisper is able to analyse the situation in the urban system, by computing a set of diagnostic indicators, EVAL, such as the following:

EVAL1, Crent = rent (j)* office (j) (13)

EVAL2, Cfacility = cost (j)* facility (j) (14)

EVAL3, Totalcomp = number of complaints sent by Inhabitants and Localities (15).

As a planner, however, his actions, in this version of the model, are rather limited. They can be defined exogenously, in terms of target values for certain variables, described by means of scenarios of the system's future likely changes, i.e. modifications in the transportation network, introduction of access restrictions to certain areas of the city, desired rent levels and facility provision in the localities.

In this version of SimAC, only the last diagnostic indicator, EVAL3, plays an active role. When reaching a certain level, in fact, Wisper is supposed to make investments in telecommunication infrastructure and services in the most populated residential zones.

5. THE MODEL ARCHITECTURE

5.1 General outline

Although SimAC is built upon the standard SWARM simulation platform, two aspects in its implementation are worth being underlined, and namely, the management of the informational relationships and treatment of the time dynamics in the agents' behaviour.

5.1.1 The architecture of the SimAC model

The architecture of the SimAC model consists of two main layers, see Fig.1a.
The upper layer contains the model general manager, Model Swarm. Besides accounting for the structural relationships and their implementation, i.e. input-output operations, time schedules, Model Swarm also manages the informational relationships. It collects all the messages sent by the agents, through their communication acts, processes them and make their result available to the agents. Whereas agents of different type can exchange information, communication among agents of the same type has to be managed by Model Swarm.

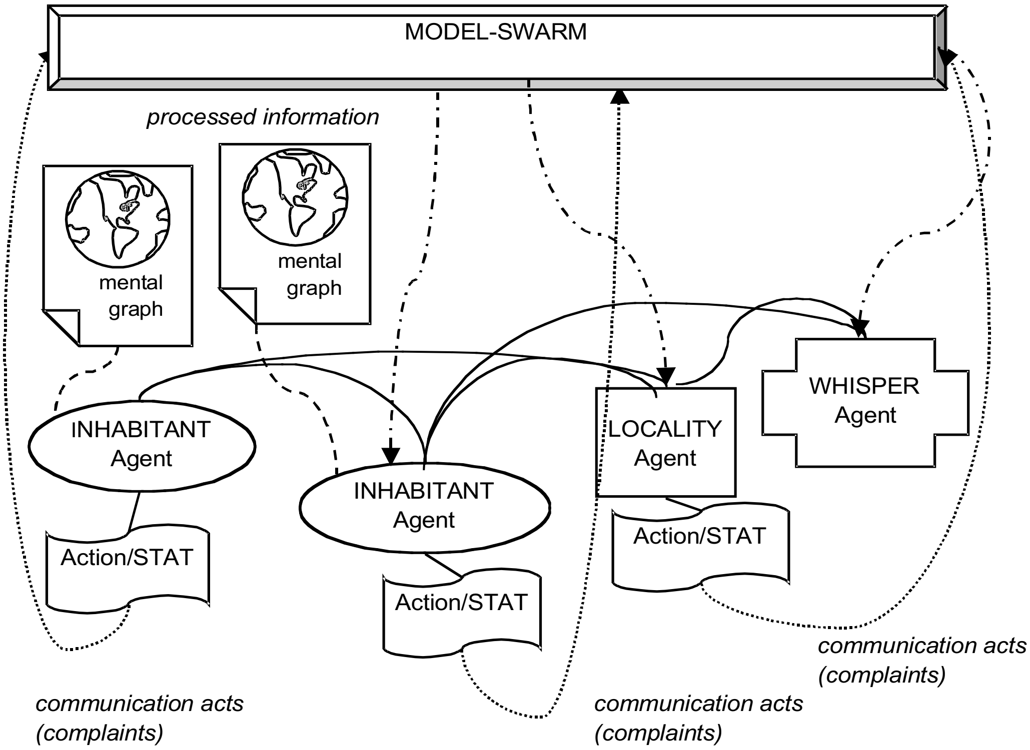


Figure 1a The overall architecture of the SimAC model

The latter therefore, acts as an intermediary of the informational flows among the agents. Although this intermediary role may limit the range of communication possibilities in the system it proved the only way to deal with communicating agents with scarce cognitive abilities.
At the lower layer are the Inhabitant, Locality and Whisper agent types. For each of them there is a module, which describes their cognitive abilities, the list of actions and

their outcome (action/STAT module in Fig. 1). In addition, Inhabitant agents have a module accounting for their mental representations of the spatial network, i.e. the mental graph, which is daily updated as agents travel on the network (see eq. 1).
Table 3 summarizes the main features of behavioural profile for each type of agent.

	Inhabitant agents	*Locality agents*	*Whisper*
Main goal within the artificial world	They have to work. To reach their workplace they have to travel, but can substitute physical movement with virtual contacts	They have to provide employment to Inhabitants and job accommodations for their employees	He gives prescriptions and recommendations for action to Inhabitants and Localities
Role in the artificial world	As they value time, have a time budget and are sensitive to time constraints, they are motivated to reach their workplace as soon and easily as possible.	They have to maintain (improve) a certain performance level in their production activity	He monitors the behaviours of both Inhabitants and Localities at a system level
Drives to action	Changes in the commuting time and in the factors underlying their drive to telecommute	Changes in the environmental and socioeconomic factors	Variations in the system diagnostic indicators
Communication	They send complaints to the Swarm Manager and receive information from Localities and Whisper	They send complaints to the Swarm Manager and receive information from Inhabitants and Whisper	He collects complaints (signals) from the Swarm Manager and give information to Inhabitants and Localities

Table 3 General features of the behaviours of the agent types

To implement the consequences of the evaluation activities undertaken by agents a kind of behavioural agenda is defined which is based on the more formal descriptions of agents' behaviours given in section 3.
For the sake of simplicity, an IF THEN format has been specified which defines a set of behavioural rules for each type of agent. Its general expression is as follows:

> "IF the temporal variation in a component and /or variable (see eqs. 7, 11, 12) is greater or less than a certain threshold value
>
> > THEN makes an action, i.e. update certain variables and/or their relative weights, and/or send a message (a complaint) to Inhabitants and/or Localities and/or Whisper".

The threshold values can be updated in each simulation experiment.

5.1.2 The treatment of time dynamics

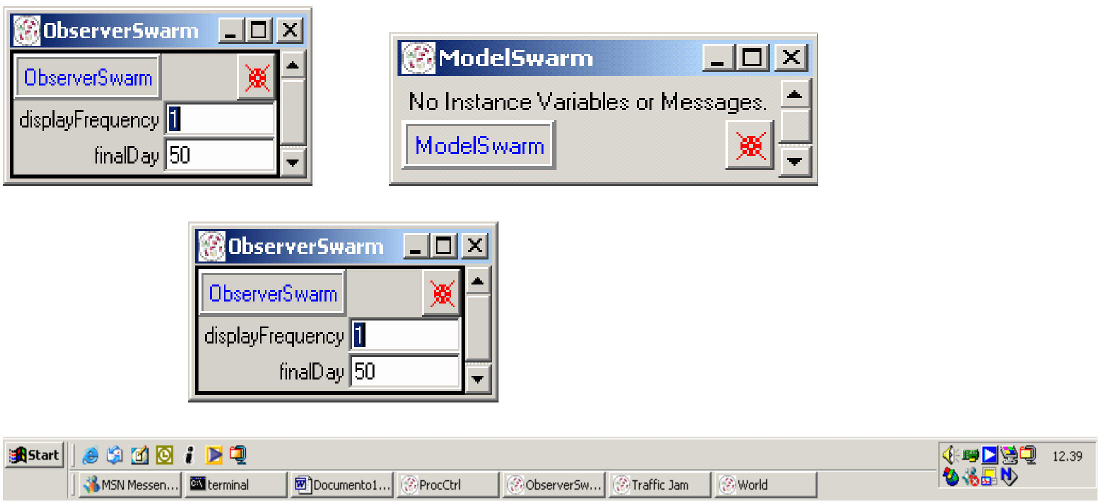
In SimAC an effort is made to account for the co-existence of different dynamics in agents' behaviours. Agents are able to put into perspective the changes occurring in their surrounding environment.

This means that they have certain *windows of observation* of these changes, i.e. their decision-making and decision to act therefore may refer to different time horizons.These can also vary by agent types or across a certain population of agents.
To address this aspect, in SimAC we introduce the possibility that each type of agent can undertake their evaluation activities considering different time intervals. As a result, the decisions to act, by agent type, does not necessarily occur simultaneously, but may be shifted in time. Although the implemented approach is still a group centred view, it nonetheless allows us to investigate how different time scales in agents' decision-making can affect their outcome in the urban evolution.

5.2 The SimAC computer modules

For the implementation of SimAC three types of computer modules have been developed.

- The first deals with the 'Inhabitants' mental graph'. It accounts for the description of the urban network as perceived by individuals, in moving on it. Each Inhabitant has his/her own mental graph (see eq.1) which is updated every time step of the simulation.
- The second consists of a set of files making it possible to configure a simulation experiment, see Fig. 1b. Besides defining the features of the artificial world, i.e. number of agents and extension of the spatial network, these files also specify:
  - the characteristics of the profiles of the Inhabitant, and Locality agents (i.e. the initial values of the variables used in eqs. 7, 11, 12). As these profiles are individual based, heterogeneous groups of agents and different jobs and work milieu can exist in the artificial world;
  - the structure of the spatial network. Although the grid represents the default spatial configuration, the structure of the network (i.e. number of links and associated travel time) can be specified exogenously;
  - the width of the observation window, considered by Inhabitants, Localities and Whisper in their evaluation activity.
- The last module reports the outputs of the simulation experiment, i.e. the data describing the changes in agents' behaviour, and computes some system indicators (i.e. indices of accessibility potentials and travel times as discussed in Bellomo and Occelli, 2000). The changes occurring in the artificial environment can also be



visualized as the simulations run, see Fig. 1c.

Figure 1b The interface for managing the simulation experiments

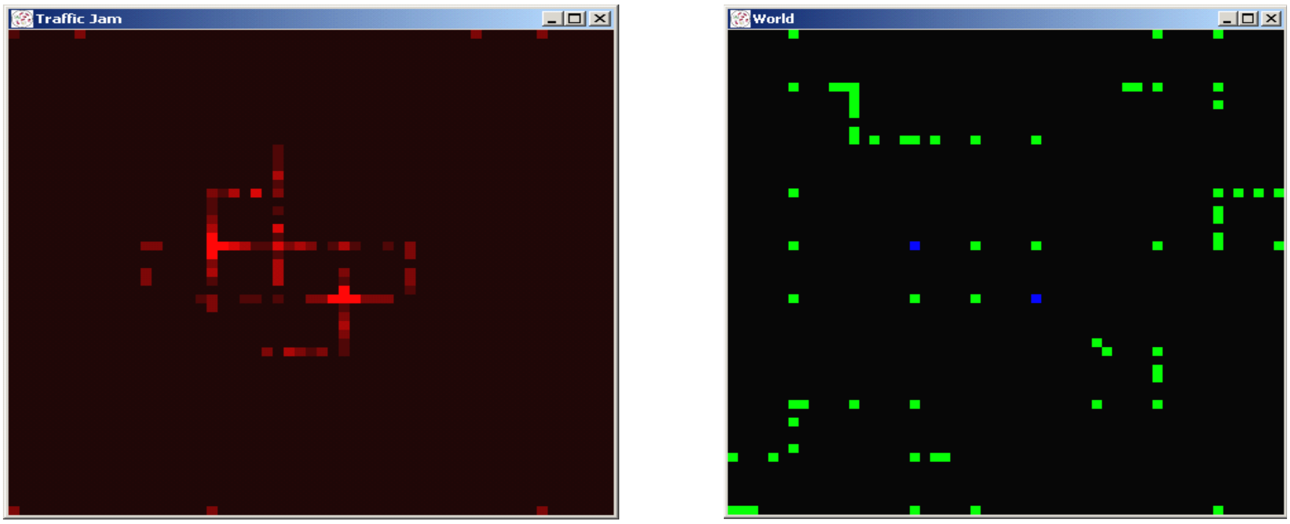


Figure 1c **The maps of the artificial worlds, which are visualized during the simulation**

6. SIMAC IN ACTION: SOME RESULTS OF SIMULATION

6.1 Configuration of the experiments

A number of simulation experiments have been run and allowed us to carry out some preliminary testing of the model capability (Bellomo and Occelli, 2003; Occelli and Bellomo, 2003).
Unlikely the earlier ones which referred to an undifferentiated urban environment consisting of uniformly spaced residential zones, in the current experiments the spatial network, although still grid shaped can be irregular, i.e. it can consist of links having different (time) length, see Fig. 2[8].

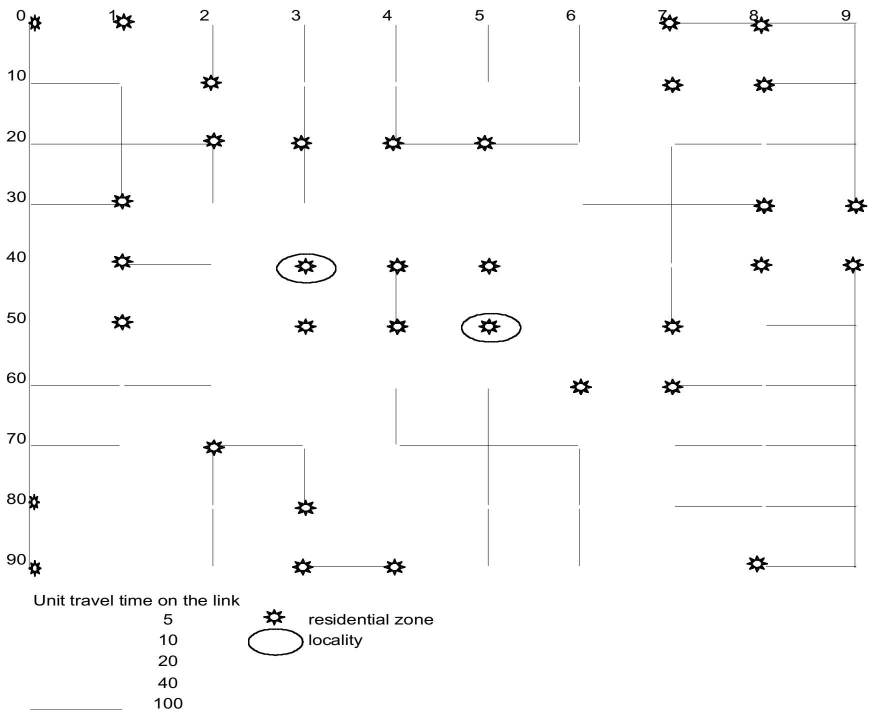


Figure 2 The spatial structure of the urban environment simulated by SimAC

As shown in the figure, the artificial environment approximates a metropolitan area, and its spatial pattern is characterized by:

a. a central urban core, consisting of six very close residential zones (i.e. the travel times of their connecting network are the lowest). These are surrounded by a transportation ring linking the core area it to the outer zones;
b. a group of suburban residential areas situated on the fringe of the urban core;
c. a few sparsely distributed residential areas located in the outer parts of the area.

In all the experiments there are 349 Inhabitant agents, which are almost uniformly distributed over the 35 residential zones. There are 2 Locality agents located in the core of the area. They both employ the same number of Inhabitants.

[8] The default environment in the Swarm simulation platform is grid-shaped. Although this may be a poor description of a real urban environment, it is nonetheless possible to define a very close knit grid which would better approximate a city spatial structure.

Each experiment simulation has a fixed time period consisting of 100 time units (days). All the results of simulations are referred to periods consisting of 10 time units.
Two main sets of experiments have been carried out:

- the first compares the results of the adoption of tele-work resulting from different widths of observation windows, for an urban environment with a regular and an irregular spatial network;
- the second focuses on the non-homogenous urban environment and investigates the effect on the adoption of tele-work and travel times for different sensitivities to tele-work adoption.

6.2 Tele-work adoption for different widths of agents' observation windows

Agents' width of observation does significantly affect the deployment of urban routines and their outcome. In effect, the narrower the width, the more attentive agents are to their action spaces. This greater awareness also means that agents are more willing to undertake their evaluation activity, which may result in a higher propensity to modify their behaviour. Too narrow observation widths however may let trends of change go unnoticed and produce no variation in agents' behaviour. In the simulation experiments carried out so far this did happen for Inhabitant agents when their observation width was set to a value equal to the unit simulation period (Occelli and Bellomo, 2003).
In the current experiments only certain combinations of observation widths are taken into account. These resulted in three main configurations of the simulation experiments:

- an experiment in which the width is relatively wide (10 time units) and equal for the three types of agents, experiment w101010;
- an experiment where the width has been halved for all the agent types, w555;
- an experiment in which the Whisper's observation window has been narrowed further and its width set to the smallest value, w551.

All the above experiments have then been run for an urban environment with a regular spatial network (a w***grid experiment) and an irregular one (w*** experiment).
A general result, already noticed in previous experiments, is that the number of adopting agents increases as the agents' observation window narrows. This increase is particularly significant in those cases in which the width of the observation window for the Whisper agent is relatively smaller, see Fig. 3.

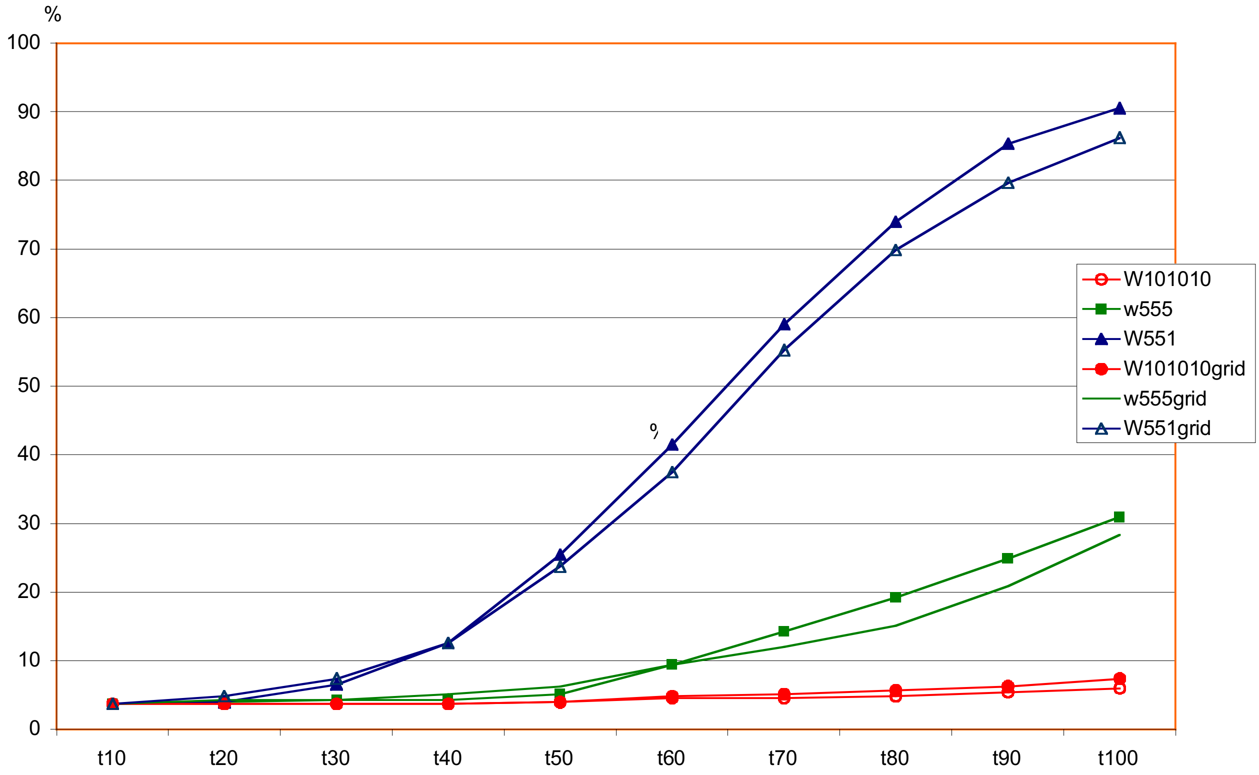


Figure 3 Tele-work adoption in an urban environment with regular (grid) and irregular spatial network for different widths of the observation window

In these cases, in fact, the constraining factors to adoption tend to be weaker as a result of a greater availability of telecommunication services in residential zones. The Whisper agent, infact, is able to make telecommunication investments in a greater numbers of zones.

This happens in both urban environments with regular and irregular spatial networks. Figure 3 also shows that the less performing results are observed in the experiment W101010, in which the width of the observation window, for all types of agents is the largest, i.e. the agents' awareness to the changes of the urban area is relatively lower.

A major aspect worth being emphasized is that the increase in tele-work adoption tends to be higher for the urban environment with an irregular spatial network. Although this result may depend on the particular configuration of these simulation experiments, a plausible explanation is that, in a more highly constrained spatial environment, agents' drives to improve their accessibility is likely to be higher.

A partial support to this explanation can be found comparing the values of the number of nodes Inhabitants cross in moving on the spatial network and of the observed total travel times, at the end (t100) and beginning (t10) of the simulation periods, see Fig. 4.

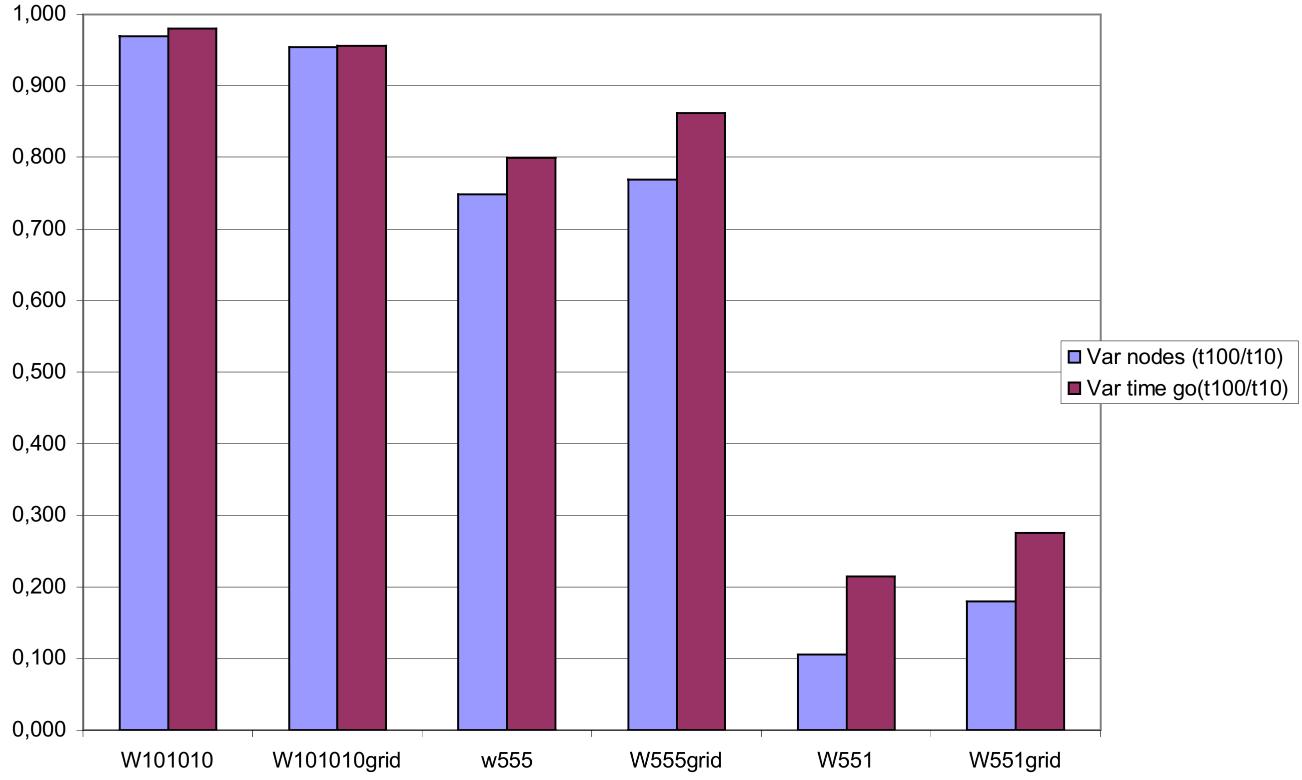


Figure 4 Variation in the number of nodes and total travel time and during the simulation period in an urban environment with regular (grid) and irregular spatial network for different widths of the observation window

As introduced earlier, these are some of the descriptive statistics that SimAC computes. Their variation in a simulation period yields a measure of the reduction of the mobility impact on the urban environment. For a certain experiment, therefore, the greater their variation, the higher the reduction o f the pressure of mobility.
What Fig. 4 suggests is that, the variations in these indices depend on the width of the observation windows and spatial configuration as well. The wider is the observation window the greater is the imposrtance of a non homogenous spatial configuration.

6.3 Impact on the tele-work adoption and travel times for different sensitivities to tele-working

In this second set of experiments we concentrate on the w555 experiment for the non-homogenous urban environment and investigate the effects of varying the sensitivity to tele-work adoption for those Inhabitants living in certain zones of the system.
As previously introduced, in SimAC there are two types of parameters modulating this sensitivity (see eq. 8):

- a parameter, sSY, which applies to the system as a whole and accounts for the overall propensity of the urban system to adopt an innovation. This is kept constant in these experiments;
- a parameter, sINF, acting at the individual level, influencing the internal drives of the Inhabitant agents to tele-work. In particular, this modulates the information received from the Locality agents to tele-work, which on their turn, affect the internal drives.

The W555 experiment was run a number of times assuming that the sINF parameter has a higher value for those Inhabitants living in certain areas of the urban system. More precisely in a first experiment we raise sINF only in those zones belonging the central part of the area (W555core). In a second one, we assume that the increase involves six zones at the outskirts of the area (W555periphery). Finally, in a last run we investigate the case in which sINF is increased in the zones situated in an intermediate area between the core and periphery (W555core-periphery).

In all the experiments a total of six zones (about 60 Inhabitant agents) are affected by changes in the sINF parameter.

As could be expected, raising sINF has a positive impact on the adoption of tele-work and we observe an increase, though moderate, in the total number of tele-work adopters in the system, see Fig. 5.

The number of final adopters is the lowest when the changes in sINF involve the Inhabitant agents living in the periphery of the area (W555periphery). It is even lower than that observed in the W555 experiment where no variation in the sensitivity parameter is introduced.

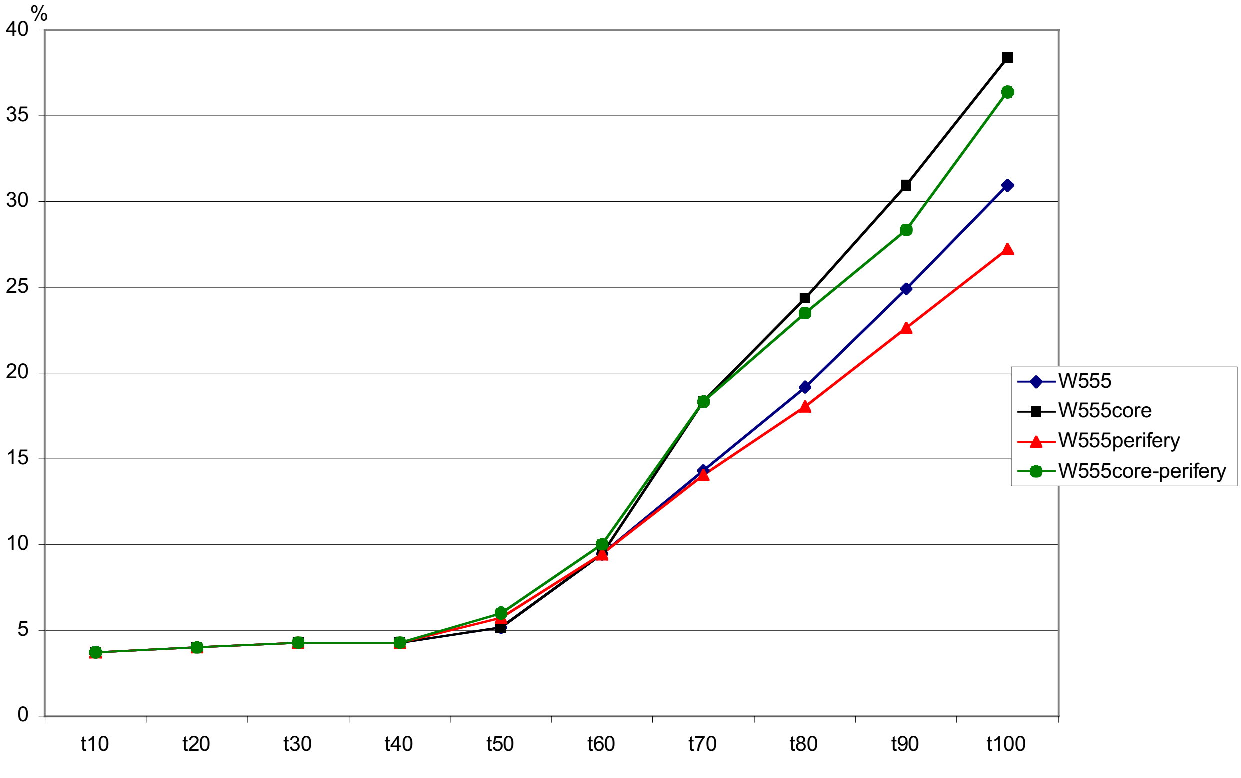


Figure 5 Tele-work adoption for different values of the sensitivity parameter sINF in the core, periphery and core-periphery residential zones

The increase in total number of adopters , however, and this was not entirely expected, is slightly more significant when the changes in the sINF parameter involve the central zones (W555core). These are also the zones of the urban environment most significantly affected.
This result can be best appreciated in Fig. 6, which depicts the overall changes occurring in the residential zones at the end of the simulation period. For the sake of comparison, the results of the W101010 and W551 experiments are also shown.

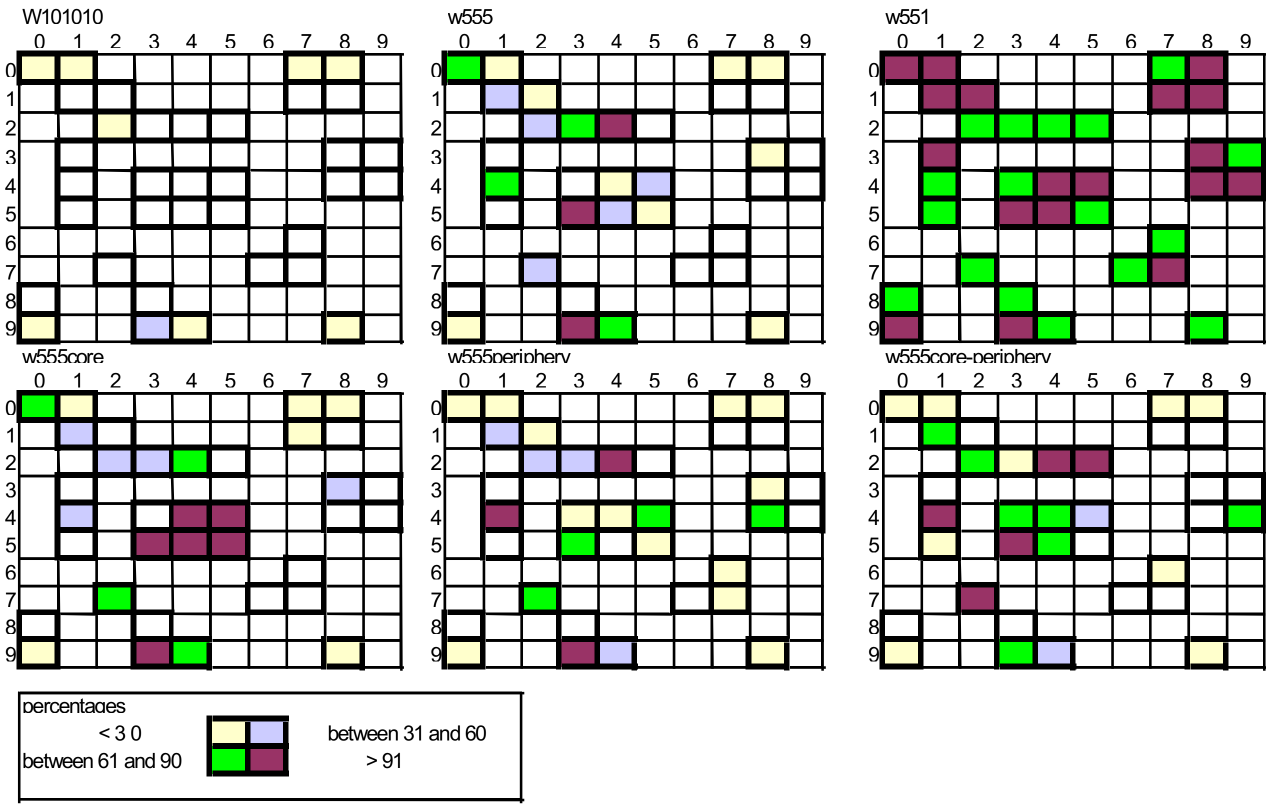


Figure 6 Percentage adopters in the residential zones at the end of the simulation period in the different experiments

The number of final adopters is the lowest when the changes in sINF involve the Inhabitant agents living in the periphery of the area (W555periphery). It is even lower than that resulting in the W555 experiment where no variation in the sensitivity parameter is introduced.
In the W555periphery experiment, in addition, their spatial distribution at the end of the simulation period is also more scattered than in the W555core (see Fig. 6).
An intermediate result is obtained when sINF is increased for those Inhabitants living in semi-central areas (W555core-periphery experiment).
These results therefore indicate that spatially different distributions in the initial conditions of the sensitivity to adoption can yield different results in both the total numbers of adopters and their spatial pattern. In this respect, they provide some evidence to the general founding that both the process of adoption, i.e. the formation of a critical mass of adopters and level of information, and the spatial features of the urban

environment play a role in determining the observed rate of adoption of tele-work in the various areas.
To better appreciate the influence of the spatial features on the final outcome, the W555core experiment was run once again for the urban environment with a regular spatial pattern (W555coreGRID).
Figs. 7 and 8 compare the results observed in these two experiments.

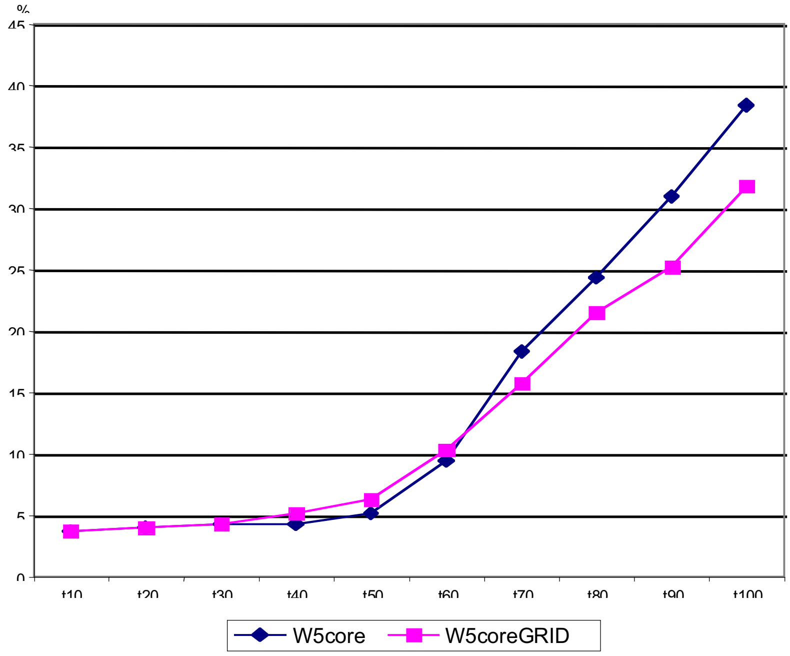


Figure 7 Percentage adopters in an urban environment with regular and irregular spatial network, for higher values of the sensitivity parameter in the core areas

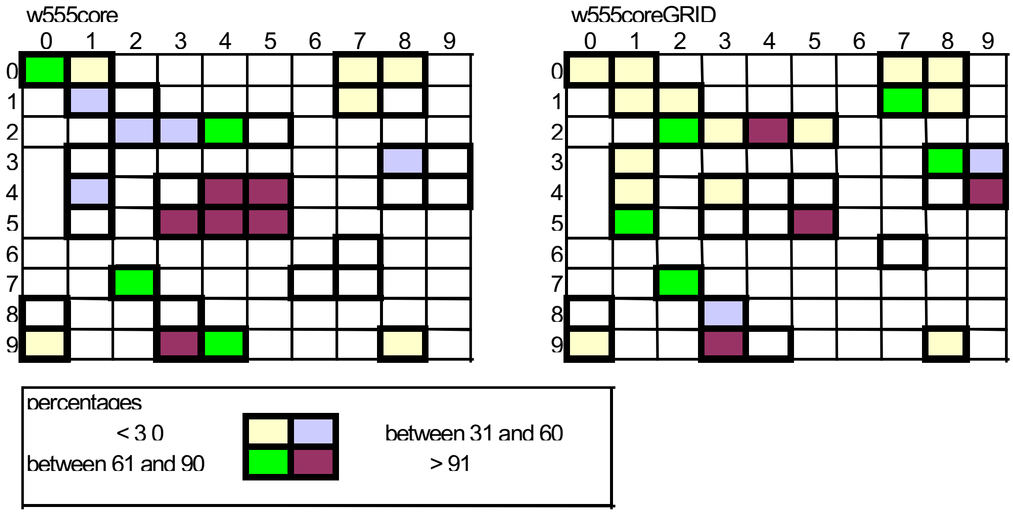


Figure 8 Percentage adopters in the residential zones at the end of the simulation period in an urban environment with regular and irregular spatial network, for higher values of the sensitivity parameter in the core areas

The results show that whereas in the urban environment with an irregular network the increase in the tele-work adoption significantly concentrates in the core of the urban area, this does not happen with a regular network, see Fig. 8.

7. CONCLUDING REMARKS

This paper illustrated an application of a MAS approach to explore new model capabilities for dealing with commuting, accessibility and the adoption of tele-work.

A few interesting features of the SimAC model are:

- a tentative to account for features of urban interactions which depend on the communication between agents,
- the acknowledgement of the need to explicitly address agents' cognitive abilities to deal with their decision-making in an urban environment;
- the possibility to explore novel ways to treat the coexistence of different time dynamics and the relationships between micro-macro system levels.

Although further experiments will be necessary to fully test the overall capabilities of this model, the experience we gained so far suggests that this type of model raises a number of interesting questions likely to challenge future research work in urban analysis.

On a theoretical ground, for instance, they point out that there is a need to concentrate on the development of a suitable operational cognitive architecture of the (spatial) behaviour of agents in an urban environment. In this respect, some topics to be addressed concern both the definition of the agents' cognitive abilities and level of tractability which the model architecture should possess for implementing the desired cognitive abilities (see, Rao and Georgeff, 1995).

While acknowledged in the model, the communication between agents is an aspect to be detailed more deeply in future research. This would require to make it explicit how communication affects the cognitive abilities of individual agents, and influences their perceptions and mental models. This is likely to open new lines of enquiry about how the outcome of agents' communications consolidate and may inscribe in the knowledge repository of the city collective agent.

The latter, in fact, was at the basis of our meta view of an accessible city, as accessibility was viewed as a kind of emerging property resulting from the intertwining of agents' internal models.

On an operational ground, a number of questions are raised about the impact that simulation approaches will have in the field of urban modelling and quantitative geography. In this regard, two general aspects can be mentioned:

- the first is the integration of the new MAS approaches, under the general umbrella provided by GIS, with the existing fields of spatial analysis, transportation and urban modelling as well as with the emerging fields of computer vision and scientific visualisation. Description of agents' behaviour in an evolving urban environment will greatly benefit from this integration;
- the second deals with the enhancement in our capacity of perceiving, understanding and managing urban phenomena, also in the current practice of policymaking and application. In this respect, we maintain that MAS models will play an increasingly relevant role because of a) the greater capacity of cognitive mediation underlying the modelling activity and b) enhanced possibilities offered by the computer artefact.

This last point takes to the fore a final observation concerning the deeper relationships between simulation and modelling in dealing with spatial phenomena. It has already been emphasized that simulation is not only involved with the operational realization of a modelling activity, but it is co-determined by it (Occelli, 2003). As the progress in technological and information backcloths make simulation and the computer artefact more powerful, the role of a modelling activity is likely to be progressively accrued. As a consequence, the knowledge gains and action capabilities to deal with urban complexities might be considerably improved. The effectiveness of this enhancement, however, will depend on how the cognitive mediation role of a modelling activity will actually benefit from this progress. In addition, a number of ways would exist by means of which this enhancement may benefit the current practice of policy making and application, and these are further aspects to probe.

Acknowledgement
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