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"SENSING" MOBILITY: AN OUTLINE OF A MAS MODEL FOR URBAN MOBILITY

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PRESENTAZIONE

La simulazione Multi-Agente rappresenta oggi uno degli approcci più promettenti per lo studio teorico e l'analisi empirica di molti fenomeni di evoluzione urbana. 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.

Proseguendo le riflessioni già sviluppate in occasione di altri studi del LabSIMQ, il presente lavoro è volto ad offrire una presentazione introduttiva circa la rilevanza che l'adozione di questi approcci può avere per gli studi di mobilità delle persone e la simulazione del comportamento di viaggio.
Il contributo ha natura essenzialmente concettuale e teorica.
Esso ha lo scopo di segnalare come l'adozione di una prospettiva di analisi multi-agente possa portare benefici considerevoli non solo dal punto di vista analitico, nella direzione di fornire descrizioni maggiormente realistiche del comportamento di viaggio degli utenti, ma anche in termini di policy, nella direzione di pensare agli utenti dei trasporti non come semplici destinatari/utenti di interventi inerenti i trasporti e la mobilità, ma come soggetti attivi degli interventi stessi.
Naturalmente, lo studio va inteso come passo preliminare di un percorso di riflessione che dovrà essere adeguatamente approfondito sia per quanto riguarda gli aspetti metodologici sia con riferimento all'analisi empirica dei comportamenti di viaggio.
Le applicazioni finora effettuate, peraltro, suggeriscono come gli approcci multi-agenti rappresentino, oggi, una vera e propria sfida per la costruzione di modelli di mobilità e, più in generale, di molte delle dinamiche urbane. Da un punto di vista metodologico, infatti, essi mettono a disposizione nuovi apparati di analisi capaci di tener conto dei micro-comportamenti e strumenti computazionali sempre più efficaci e potenti per il loro trattamento e per lo studio dei loro effetti collettivi. Lo sviluppo operativo di tali apparati metodologici costituisce esso stesso un tema di ricerca di indubbio interesse
È, però, soprattutto, da un punto di vista teorico-concettuale che la sfida per la modellizzazione si rivela più ardua, – ma, forse proprio per questo, più interessante – poiché stimola alla formulazione di nuovi contributi teorici circa l'evoluzione delle città e degli insediamenti territoriali

Nonostante il carattere introduttivo, il presente lavoro può offrire un contributo utile alla Regione Piemonte per la definizione di politiche di trasporto che sappiano fronteggiare l'articolazione crescente dei bisogni di mobilità, anticiparne le modalità future e controllarne gli effetti indesiderati sull'ambiente e sulla sicurezza dei cittadini.
Da questo punto di vista, esso si colloca a tutti gli effetti tra i contributi di studio che l'IRES sta realizzando nell'ambito dell'Osservatorio Regionale della Mobilità.

Il Presidente
Avv. Mario Santoro

ABSTRACT

In order to develop a MAS approach to mobility phenomena a strong notion of agency is required. This implies to articulate both an analytical-epistemological and a conceptual-ontological dimension. While increasing attention is being given to the former, the latter dimension is to date still largely unexplored. The salient features which distinguish a MAS approach to mobility phenomena are emphasized. It is claimed that the possibility to take into account agents' mental worlds is both a potential and challenge of MAS approaches. Elements of a conceptual framework which may serve as a reference for designing a MAS model for urban mobility are outlined.

1. NTRODUCTION[1]

The acknowledgement that mobility, the physical movements of people (and goods) in a geographical environment, is a complex phenomenon has been lately recognized in both academic and management fields. This has stimulated an increasing interest in the factors and processes making up that complexity, i.e. the features of human personalities guiding individual behaviours and intrinsic emergent nature of mobility phenomena, while questioning the ways to cope with them, see [4], [7], [11], [25], [30], and [34].
As recently popularised also in the social science literature see [9], [12], [20], and [38] most of these topics are at the core of the so called Multi Agent System approach, which is being developed in the overlapping fields of IA, DIA and expert systems, see [14], [33], [52], and [53].
This paper looks into the possibilities of applying a MAS approach for dealing with mobility phenomena. It builds upon a previous work which contended that in order to take advantage of MAS potentials to model urban processes, a strong notion of agency is needed, i.e. a notion capable of accounting for both the analytical-epistemological and conceptual-ontological dimensions see [38].
The discussion of the former dimension suggested that a number of epistemological, technological and cultural changes are occurring in the ways we apprehend urban phenomena. They concoct new potentials, which are associated with the cognitive mediation role underpinning today modelling activity. This role, in fact, calls for a greater attention to innovative ways of addressing the modelling steps. In this light, it was argued that interpreting the different aspects of model building in a MAS perspective would make it available a new valuable methodological and operational framework for urban modelling.
The discussion of the latter dimension emphasized that a major advancement of a MAS approach is the possibility to account for the cognitive abilities of urban agents. These provide the missing link between those worlds of human experience, i.e. the physical and cultural, conventionally considered in urban models. Their full acknowledgement, however, requires devising novel views of the city.
The coupling of the physical, cultural and mental worlds, therefore, turns out to be a challenging task, not only on the methodological-operational ground, i.e. implementing more effective and realistic cognitive architectures of urban agents, but also on the conceptual-theoretical one, i.e. developing conceptual constructs for agent based city evolution.
A general claim of that discussion was that, as far as urban analysis is concerned, we are entering a period of conceptual revolutions whose impact is likely to be as much impressive as the so-called quantitative revolution has been [49].
In this paper, an effort is made to take the discussion a step further, by focussing on the mobility phenomena. Addressing this topic is not an unconcerned choice.
First, from a substantial point-of-view, the negative externalities of mobility are among the most critical factors making at stake the environment and quality of life in today cities. In this respect, insights into mobility issues likely to result from the application of a MAS approach would be helpful in devising more effective and socially acceptable mobility policies, see [5], [45], and [46].
Second, from a conceptual perspective, mobility phenomena do represent a challenging subject for applying the complexity paradigm to urban analysis. The possibility to deepen

[1] La versione originale di questo testo è stata presentata alla Conferenza Internazionale di Simulazione Sociale, ESSA2004, di Vallamolid, settembre 16-19, 2004.

the notion of emergence by experimenting with a MAS model represents an opportunity for bridging the gap which so far has parted theoretical and operational analysis to city evolution.

Finally, in transportation analysis, increasing efforts are recently being undertaken to link individual mobility with urban activity space, while taking into account the uncertainty and constraints of urban environments, see [1], [2], [16], [18], and [28]. They are calling attention to the requirement to explicitly include in modelling approaches new entities, i.e. agents' psychological attitudes and learning abilities, while revising old notions, i.e. to view urban activities as entities resulting from the consolidation of agent engagements.

The paper proceeds as follows. In the next section, some introductory remarks are presented aiming to point out the salient features which distinguish a MAS approach to mobility phenomena from other modelling approaches. A claim is made that the possibility to take into account agents' mental worlds is both a potential and challenge of MAS approaches. Then, attention is turned to frame some conceptual elements which may inspire the development of a MAS model for urban mobility. Some summarizing comments and suggestions for future research conclude the paper.

2. PREMISES OF A MAS APPROACH FOR THE ANALYSIS OF URBAN MOBILITY

As mentioned in the introduction to develop a MAS approach to urban mobility a strong notion of urban agency is needed. This requires taking into account and properly articulating both the analytical-epistemological and conceptual-ontological dimensions underlying a modelling endeavour. For the sake of the subsequent discussion, in the following, some major features associated with these arguments are briefly recalled.

2.1 A MAS approach as a cognitive mediator

In geography and regional science, urban modelling forms a well defined, although increasingly expanding field. Today, due to a number of epistemological, technological and socio-cultural changes, modelling activity has new potentials, see [35], [36], and [40].
They provide a refreshed view of the mediation role of modelling, i.e. strengthening the possibilities the connections between the abstraction process (i.e. the encoding-decoding process underlying a modelling activity) and the external environment in which a modelling is embedded (i.e. the domain of application of the model), see Fig. 1. Besides being an interface between the two loops, a modelling activity plays a role of cognitive mediator between them. This takes advantage of one fundamental feature of models, and namely their intrinsic autonomy from an analyst's ability to conceptualise and perceive urban phenomena, see [32]. In addition, as models increasingly rely on computing technology, which like any technology reveals its strength as it is used, that role is further enhanced.
Models as cognitive mediators, therefore, are active complex artefacts having their own hardware and software identity. In a geographical domain, in particular, models as cognitive mediators are confronted with three main components see [36]:

a. a syntactic component, concerning the methodological aspects of modelling. Modelling in fact requires a method of analysis (i.e. a coherent set of steps of enquire) which by means of an abstraction process (the encoding and decoding process) yields an explanation of observed urban phenomena. This component also presupposes to make it explicit the underlying epistemological background;
b. representational (semantic) component, related to the sense associated with the representations of the urban phenomena provided by the model. The kind of system structure we refer to in our view of city and the meaningfulness of the descriptions conveyed by the model are crucial aspects of this component, i.e. the range of prototypical images produced by our perceptions and categorization of cities;
c. knowledge project component, associated with the purports of the investigation underlying a model application (i.e. aims of the model, data and computing requirements, expected results, etc.). This component plays a crucial function in both instantiating the model application and steering the accompanying learning process.

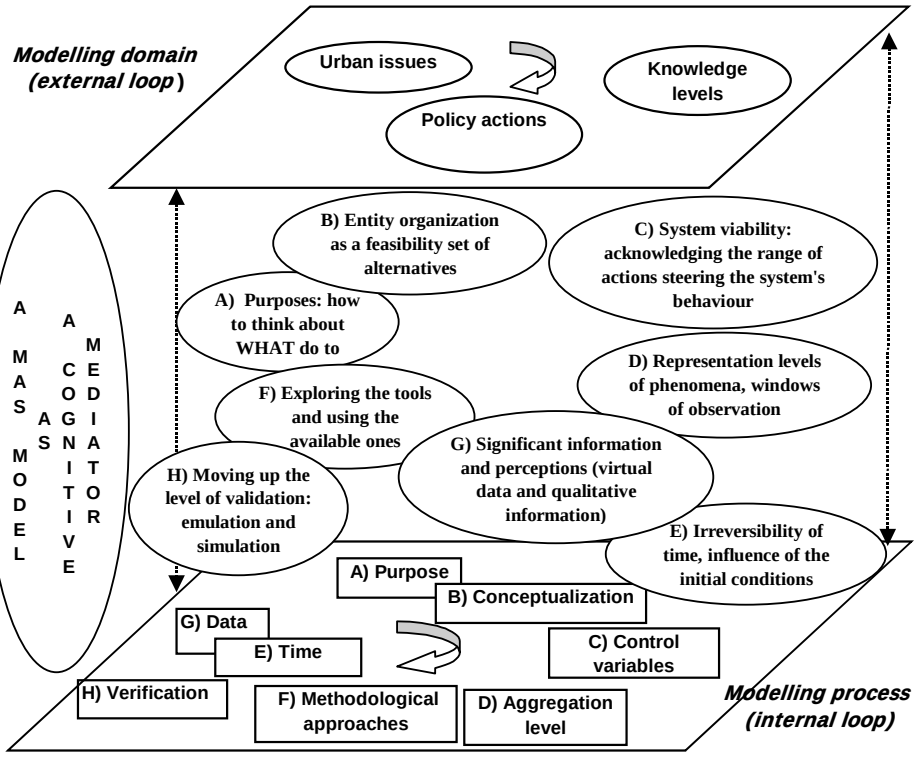

Fig. 1. A MAS model as a cognitive mediator

To epitomise this novel role, the role of models has been assimilated to that of an ACL agent, i.e. an entity making it possible to instantiate the evolving relationships among the syntactic, semantic and knowledge project components and capable of:

- undertaking a course of Action, thus enabling the realization of a certain project of urban analysis. This reminds us that a multiplicity of views of the urban phenomena exist to be apprehended in a coordinated way. Such a view involves what has been indicated by Zeleny [54] as "relating descriptions of objects into coherent complexes. The relationships among objects are not simply out there to be captured, but are being continually constructed and reconstructed and re-established by the knower" [p. 212]. The model, therefore, is an active entity to be operated on in order to build these coherent complexes;
- communicating with other kinds of agents (other models), thereby affecting them and/or modifying itself in the process. Communication is spurred by a need to reconcile those contrasting views conventionally held when relating human experience and the external worlds, i.e. subjective and objective approach, tacit and explicit knowledge, local and global knowledge, hard and soft sciences, common sense and scientific knowledge. Underlying communication is a drive a get at meaning. This is obtained through a learning process in which knowledge of cities is permanently fuelled and opened to confrontation and critical revision. Several representations of urban phenomena can be derived, updated and progressively enriched;
- enabling users with a certain Learning ability, thus generating stimuli in critical revising both the external and internal loops of the modelling activity likely to trigger new quest of investigations.

Several facets of the ALC-agent role are made apparent in the recent development of simulation models and its unprecedented diffusion in the social sciences, see [9], [12], [20], [37] and [41]. It should not be come unexpected, therefore, that MAS approaches can be regarded as specific instances of an ALC agent entity.
One major outcome of this cognitive mediation role of modelling, or at least of the strengthening of that role, is the fact that the classical aspects of model building as originally introduced for designing urban models in the early seventies, are significantly modified, see [50]. These aspects refer to the internal loop of modelling and form a kind of checklist ensuring consistency of the model building, see the bottom part of Fig. 1. Whereas this consistency requirement still holds for an ALC modelling activity, all the mentioned aspects are considerably enriched in so far as they can be transformed from simple items of a checklist into more active autonomous objects, see the intermediate part of Fig. 1.

2.2 Distinctive features of a MAS approach to urban and mobility phenomena

Mobility as many most urban phenomena are the results of agents' participation in three worlds of human experience:

- the physical/natural world, consisting of physical entities like processes, forces, fields, matter and energy;
- the psychic world, that is the mental states, including consciousness, experience of conception, thinking, emotions, intentions, memories;
- the cultural world, represented by the human mental products, in arts, technique, literature, philosophy and science.

If one surveys the contents of both urban modelling and mobility analysis, two major views can be identified see [36]:

a. a substantial view, which mainly focuses on the issues related to the functioning and evolution of cities. Topics of interests are the features of the urban phenomena, i.e. the characteristics of the activity systems, transport network, and built environment as well as the processes steering the overall urban behaviours, i.e. the driving forces, inertia, structure of system relationships, temporal deployment. In this view, the city is a complex system sharing the properties of any other living but fundamentally physical systems. Understanding these features and processes is therefore crucial for the theoretical and methodological advancement typically belonging to the scientific domains of the cultural world;
b. a procedural view, which deals with the decision-making process underlying the behaviours of both ordinary agents (i.e. individuals, firms and organizations) and stakeholders. The profiles of choices alternatives, evaluation indicators and judgment values are a few ingredients in the procedural approaches the definition of which is rooted in the human mental products. For this view, the physical world is an object of observation/evaluation on which agents' decisions should act upon. Improving the understanding of the decision-making underlying individuals' behaviours is thus important to explain the structuring and evolution of urban phenomena.

Since the eighties, a number of efforts have been undertaken to better integrate the two views. The growth in desktop computing and the diffusion of communication and information technologies, i.e. information systems and GIS, played a significant role in this respect, see [15] and [27]. A confident view was held that a clever linking of the components pertaining to he physical and cultural worlds would enable analysts (and

planners) to yield a sounder understanding of the novel or unexpected kind of phenomena taking place in today cities.
Although acknowledged on a conceptual ground, the fact that mental states could not only affect those worlds, but also be generative in constructing them, has been rarely accounted for in urban modelling except in behavioural approaches see [21].
The above mentioned views are also discernable in the fundamental approaches underlying transport modelling and mobility analysis, and notably, the earlier Four Step Model (4SM) and more recent Activity Based Approach (ABA), see [30].
Their overall profiles are compared in Tab. 1, and articulated according to the features and critics which have been addressed to each of the approach, because of their conceptual inadequacy and/or operational weaknesses.

Table 1. A comparison of the Four Step Model and Activity Based Approach

Features	*Four Step Model (4SM)*	*Activity Based Approach (ABA)*
Context of the modelling activity	Post-war economic and urban growths	Urban changes and acknowledgment of environmental crisis
Role of the modelling approach	Analytical tools allowing for a simplified account of a transport system	Analytical tools for supporting both understanding of and decision-making in an urban system
Main policy questions	Expansion of transportation infrastructure and services	Management of transportation systems and services
Views of the transport demand	Travel demand is a direct function of demographics and land-use organization	The need of travel depends on the need to perform activities. These are function of the distribution of resources among organizations and land-uses, and of social structure as well
Modelling aims	Evaluate the impact of capital-intensive infrastructure investment Trips should be forecasted in order to provide the necessary infrastructures (the who, what, where and how many trips)	Analysis of travel as daily or multi-day patterns of behaviour. Any understanding of travel behaviour is secondary to a fundamental understanding of activity behaviour (the why of activities)
Theoretical underpinnings	Utility maximisation	Space-time approach
Critics		
Theoretical shortcomings	Discrete (independent) characterization of travel behaviour	Independent descriptions of behaviours' causation.
General criticism	It does not consider the spatial and temporal inter-connectivity inherent in household travel behaviour	Lacking of a solid theoretical basis
Specific critiques	It neglects: a) linkages between trips and activities; b) temporal constraints and dependencies of activity scheduling; c) underlying activity behaviour that generates the trips	The linkages between agents and their environment are neglected. Complexity of the activity pattern. Combinatorial explosion of the potential solutions. Enormous data requirements

Central to the more recent ABA approach is the notion of action space originally introduced by the Swedish human geographers in the sixties. Compared with the earlier four-step-model, one fundamental advancement of the approach has been to recognize that there is a more complex dependence existing between the demand of travel and the pattern of urban activities. Conceptually, this resulted in the introduction of a kind of additional layer making the travel demand a function of the need of performing urban activities (work, school, shopping, leisure, etc.). As the structure and organization of activities are function of the distribution of resources among organizations and land-uses, and of social structure as well, at every moment of time, an urban activity space provides individuals with a certain opportunity field while imposing various social, spatial, institutional and temporal constraints.

The ABA approach therefore purports to accounts more realistically of mobility by providing a more detailed description of how individuals partake in activities, i.e. describing the access to urban activities (i.e. location, types of activity, opening times, and means of transport), daily scheduling, and set of family constraints individuals had to cope with in order to partake in the activities. It is held that such an increasing detailed description would yield better and more reliable insights into the determinants of mobility behaviour in urban areas and its observed variability among individuals.

The next step has been to realize that individuals do not simply partake in activities, depending on their activity space, bundle of constraints and consumer preferences. Rather they engage in activities and the decision-making process underlying this engagement, has its own causation, i.e. it depends not only on the changes in both the organization of activities but also on agents' overall states and modifications of agents' mental worlds.

Whereas, the changes in the bundle of factors influencing activity engagement, i.e. the dynamics of urban phenomena, have been accounted in several ABA approaches, the fact that agents may adapt, learn and variably react to their changing environment, has been overlooked until now, also because of the huge survey data necessary for a reliable description of these processes.

As adaptation, learning and reaction are typical features of mental worlds, however, it is evident that, on the one hand, their inclusion requires a critical revision of the categories commonly retained in describing urban activities and agents' behaviours. According to the modelling checklist mentioned in Fig. 1, for example, the consideration of agents' mental states would impinge on it from the outset, affecting in particular the modelling step labelled as conceptualization.

On the other one, it is also apparent that MAS approaches can provide a unique modelling framework making it possible their implementation. The experience recently undertaken at Ires in developing a MAS model has been instructive in this respect, see [6] and [39]. The model in fact permitted to explicitly deal with the possibility that agents had a certain cognitive ability, i.e. agents were able to put into perspective the changes occurring in their surrounding environment and evaluate them over different time windows; see Fig. 2 which shows the effects of varying time windows on the rate of adoption of tele-work.

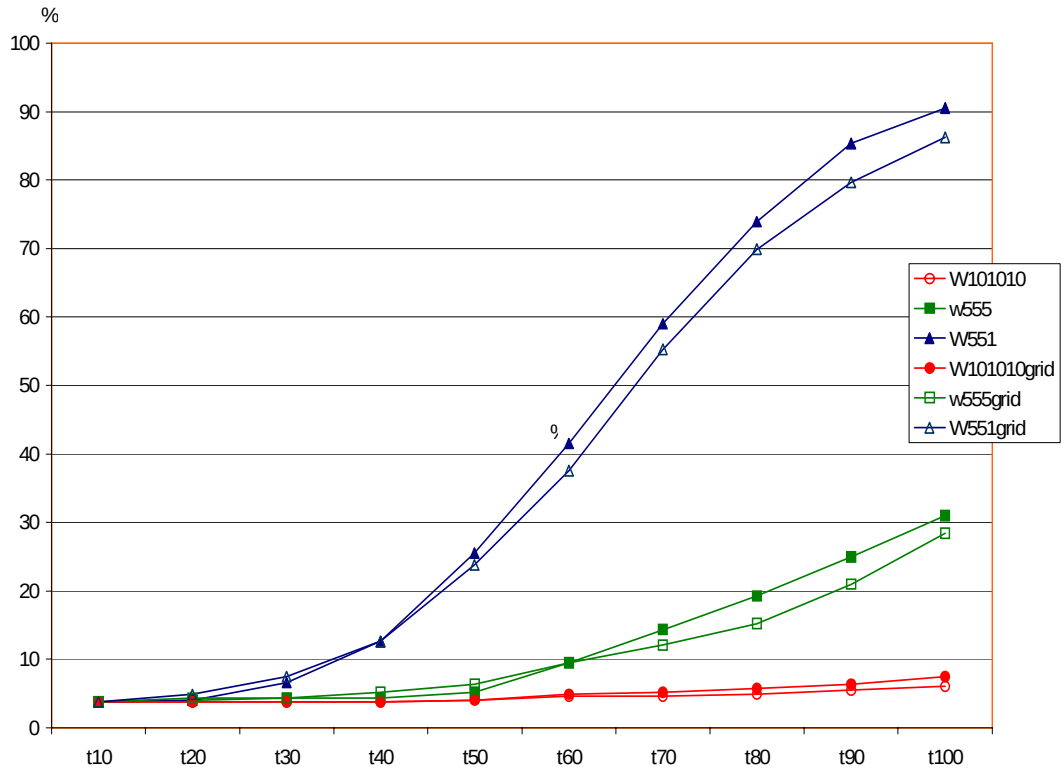

Fig. 2. Tele-work adoption in urban systems with regular (grid) and irregular spatial network for different time windows(*)

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

3. SKETCHING A MAS APPROACH FOR URBAN MOBILITY

In this section some elements of a conceptual framework for a MAS model of urban mobility are outlined. Its full development should consider all the modelling steps shown in Fig. 1. As this is still at an early stage, only a few preliminary questions are addressed. First, attention is turned to the major reasons motivating this design. Then, the development of the conceptual framework is dealt with.

3.1 Motivating the modelling endeavour

To justify the modelling endeavour the salient aspects of the complexity of today mobility should be hinted at. Notwithstanding their multiplicity, three major sources can be pointed out:

a. the spatio-temporal articulation of mobility determinants, as these involve facets of the urban systems whose dynamics deploy themselves on various spatial and temporal scales (i.e. they may combine thus producing stack factors of inertia and/or acceleration in agents behaviours, be embedded in activity routines, buried in individuals' long-term memory);
b. the recognition of the role played by individuals' mental worlds in their decision-making about mobility;
c. the impact of the New information and Communication Technologies (GIS and GPS systems, cellular phones) which can affect agents' spatial behaviour in complex ways (i.e., changing their perceptions and/or updating the information about the urban environment).

A number of aspects associated with the spatio-temporal articulation of mobility determinants have recently attracted much interest. They have been already included in a number of ABA models in order to devise more effective transport policies, i.e. collecting individual travel diary data, analysing and simulating activity based travel behaviour, see [2], [3], [5], [45] and [46].

The role of mental worlds, however, has so far received scanty attention. Although acknowledged on a conceptual ground, the fact that they could not only affect the physical and cultural worlds but also be generative in constructing them is still largely unaccounted.

It is being increasingly recognized however that the success of many transport policies depend on the ability of travelers to recognize, respond to and effectively integrate the signals from these policies into their activity/travel behaviours. Deepening the analysis of how these signals are perceived, processed and eventually incorporated in individuals' behavior is therefore important if policy responsive travel choices are to be pursued, see [19] and [34] and [45].

The ways by which NICT's can support and influence individuals' participation in urban activities and orient their travel behaviour in the medium and long terms raise also interesting questions in this respect, see [23] and [39].

For the sake of illustration, on basis of the interpretive keys of Tab. 1, the expected features of a MAS approach to urban mobility are illustrated in Tab. 2.

Table 2. Main features of a MAS approach to urban mobility see Tab. 1

Key features	*Multi-Agent-Based Approach (MABA)*
Context of the modelling activity	Multi faceted sustainable urban environment, in a global, ageing and information technology driven context
Role of the modelling approach	Artefacts for representing knowledge hypotheses about individuals' behaviours
Main policy questions	Users' responsiveness to transportation policy. Users as main enactors of policy guidelines
Views of the transport demand	Travel depends on the motivations underlying the need to participate in activities. Both individuals' and organizations' scopes are involved
Modelling aims	Understanding the process by which individuals engage in urban activities. Searching for the (stable) set of rules defining agents' behavioral processes. Urban activities as emergent entities

3.2 Elements of the framework

As mentioned earlier, a crucial point in developing a MAS approach to mobility phenomena is the possibility to include agents' mental worlds.
In the sequel some suggestions are made. They build upon the experience with a MAS model, the SimAC model, concerning commuting, accessibility and telecommuting adoption, see [6] and [39]. In designing SimAC, in fact, a number of questions were brought to the fore relating to how mental worlds are conceptualized, updated, communicated and articulated between a micro level, i.e. the level at which agents' own action spaces are perceived and set up, and others higher levels, i.e. those related to the city as a whole, and imbedded in collective entities such as social fabric, cultural milieu and planning practices.
Here attention mainly focuses on outlining a conceptual framework accounting for individuals' mental worlds.
Conceptualizing agents' mental worlds. A mental world, i.e. what is also generally referred to as a mental model, information processing mechanism, cognitive schemata, and conceptual blending, is a major challenging notion in cognition which nonetheless defeats any disciplinary bounded definitions, see [13], [23], [24] and [48].
Notwithstanding the elusiveness of the notion, it is worth noting that in the field of behavioral studies, its contribution in guiding the spatial behaviours in urban environment in not foreigner and has been acknowledged since the early seventies. Notably, these studies were mainly interested in, see [21, p. 2]: a) a focus on the individual as opposed to the aggregates; b) the development of process-oriented explanations of behaviours; c) a multidisciplinary outlook; d) the notion that an individual's behaviour is based upon his/her perception and cognition of external environment; e) the concept of an individual being an actor as well as a reactor; f) the development of dynamic models of behaviour; g) the recognition of regularities in actual, as opposed to optimal behaviour and h) the search for behavioural postulates that are independent of spatial structure.
One general aspect shared by the various notions of mental worlds is that it they are cognitive entities involving both semantic and syntactic components which are coupled to account for an individual to understand his/her urban environment. One rather straightforward application of this idea is illustrated in the scheme of Fig. 3.

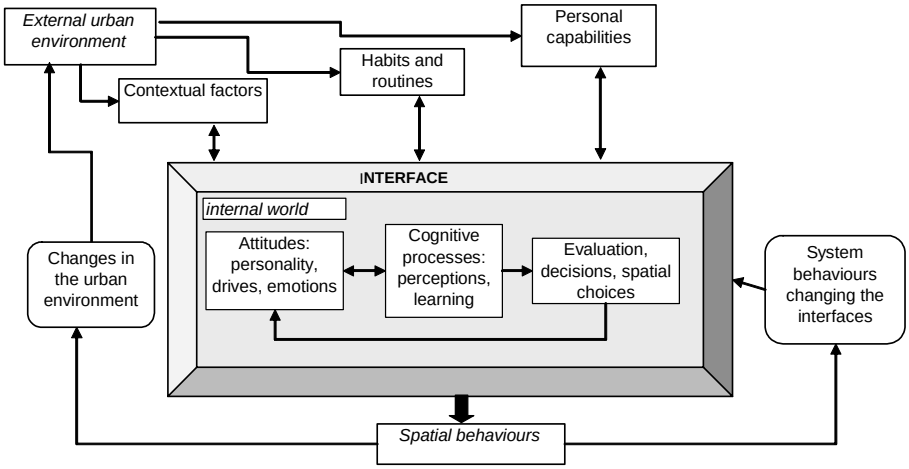

Fig. 3. An example of the application of the working of agents' mental worlds in a spatial environment

The scheme indicates the main groups of factors affecting spatial behaviour, i.e. contextual factors, habits and routines and personal capabilities, see [8]. Also shown are two further elements: a) the working of the internal world, dealing with the process linking personal attitudes, cognitive processes and decision-making, and b) the role of the interfaces which filter/mediate the internal cognition process and the external environment. The latter, in particular, hints at some facts which are increasingly important in today urban mobility:

a. the impact of the means of communication, i.e. the types of NICT affect the amount and quality of information agents can extract from their environment and these influence their spatial choice and
b. the types of travels are also increasingly dependent on the interaction means, i.e. transport modes and virtual (not physical) broadband connections, which are available in a certain area.

As for the mental worlds, we argue that these are based on intrinsic features of human beings, who live in a certain environment, and are therefore related to two main fundamental facts:

a. the fact that the drive for explanatory search for understanding (learning) is a constitutive trait in individuals, as human beings explain themselves and their circumstances while operating as observers, see [31]. This, therefore, can be considered as a kind of meta-knowledge dimension, which permanently spurs individuals to learn about themselves and their surrounding environment. This dimension can account for a wide set of situations resulting from both agents' internal and external cognition, i.e. as information can the extracted from the environment or derived from communication and interaction with other agents;
b. the fact that any living system is capable to derive measures from the external environment and makes sense from them, i.e. it is endowed with the so-called called operational closure [42]. This means that there exists a reflexivity dimension which underpins agents' behaviors in an urban environment. It can be instanced in a continuum of situations, ranging from the assessment of agents' own decision-making (rules of action) to the observation of the outcome of agents' actions (percepts of the state of the world).

While the latter dimension points out a notion of reflexivity which is commonly referred to in devising an agent's profile, see [9, cap. 5], at least in a weak definition of agency, see [29], the former adumbrates a deeper notion.
For an urban agent, in fact, knowledge is not only associated with evolutionary processes, such as learning and adaptation, but also implies a reflexive activity about the type of knowledge endeavour involved in those processes. As argued in Chavalarias [9], the ability to change that endeavour, i.e. to have some meta-rules guiding the knowledge process, turns out be one major feature that distinguishes urban agents, and more generally human social agents from other types of agents.
The joint consideration of the knowledge and reflexivity dimensions allows us to identify some stereotyped cognitive stances. They can be related to the conventional architectures of the mind, consisting of a three-fold division between perception, central processing and action and a three layered levels of functions, where each level can have a different kinds of processing (as well as functional role) and higher levels can or can not dominate or control lower ones, see Fig. 4, and [49].

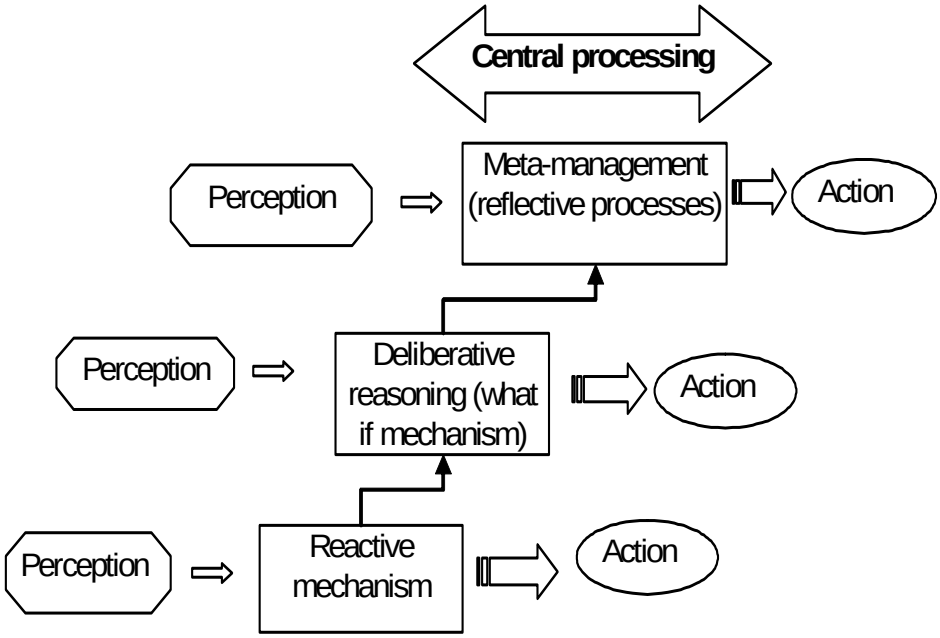

Fig. 4. A basic architecture describing the processing functions of mind

While the latter dimension points out a notion of reflexivity which is commonly referred to in devising an agent's profile, see [13, cap. 5], at least in a weak definition of agency, see [52], the former adumbrates a deeper notion. For an urban agent's, in fact, knowledge is not only associated with evolutionary processes, such as learning and adaptation, but also implies a reflexive activity about the type of knowledge endeavour involved in those processes. As argued in Chavalarias [7], the ability to change that endeavour, i.e. to have some meta-rules guiding the knowledge process, turns out be one major feature that distinguishes urban agents, and more generally human social agents form other types of agents.

The joint consideration of the knowledge and reflexivity dimensions allows us to identify some stereotyped cognitive stances. They can be related to the conventional architectures of the mind, consisting of a three-fold division between perception, central processing and action and a three layered levels of functions, where each level can have a different kinds of processing (as well as functional role) and higher levels can or can not dominate or control lower ones, see [49].
To fix the ideas, the identified types of cognitive stances have been labelled as graphically illustrated in Fig. 5 and can be briefly described as follows.

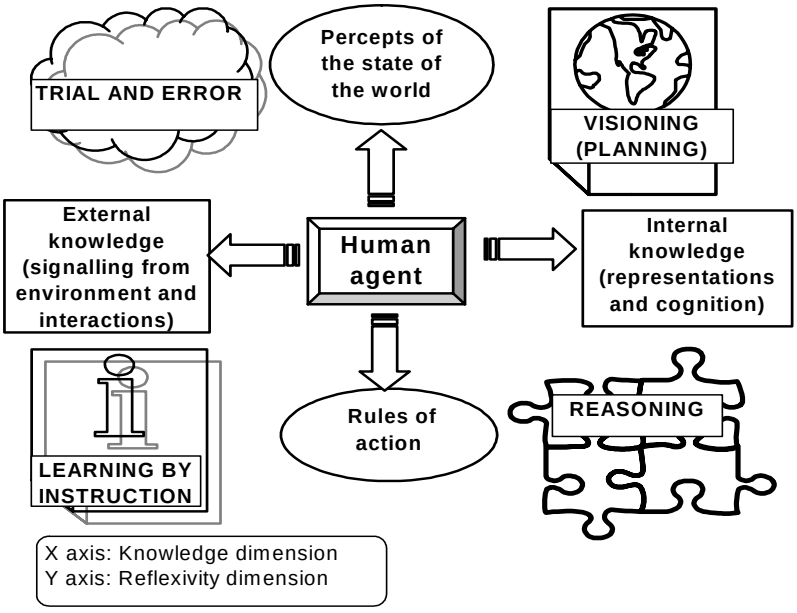

Fig. 5. Cognitive stances in agents' mental worlds

- Trial and error. This reflects the most basic kind of reactive behaviour based on stimulus action response. It typically occurs in emergence situations when unexpected events make it impossible to devise a strategy of action. This cognitive stance may also underpin those spatial behaviours which are more sensitive to established habits, i.e. those ways of acting, executed without reflections, which are developed through systematically repeating a behaviour having a positive consequence, see [18] and [19].
- Visioning. This can be related to what has been identified as the third of the mind's three I's, imagination, the others being, identity and integration, see [13]. Contrary to what is commonly held, in fact, imagination is not a character a few gifted individuals are endowed with, but a common one. It is at the basis of the anticipating attitude enabling urban agents to be pro-active, i.e. it may motivate them to take the initiative in a goal-directed behaviour and/or in thinking about agents' own goals. This cognitive stance might be also related to the higher layers of the mind's architecture in Fig. 3, where more reflective (conscious) processes of decision-making take place.
- Reasoning. It stands for the purest cognitive attitude belonging to that realm of human experience, dealing with coherence, i.e. the process by which truth is ascribed to statements which are consistent with other true statements. This is the focus of logics and forms the presuppositions on which most of conventional, and typically mathematical, approaches to urban mobility are developed.

- Learning by instruction. It underpins a whole set of processes in which episodic information are dealt with by instantiation of some generic memory structures previously created and retrieved, i.e. production rules, schemas, scripts. This cognitive stance, as the previous one, can be related to the intermediate level indicated in Fg. 4 as deliberative reasoning.

Of course, the above types of cognitive stances should be simply understood as conceptual pinpoints. In many practical situations a blend of cognitive stances is involved, although in certain cases one particular type may be prevailing, reinforced or simply activated, thus producing different behavioural outcomes.

They might however inspire more articulated descriptions as, for instance, in the case of metaphorical reasoning, where imagination and learning by instructions seem to jointly apply. The suggested typology might also serve as a reference in model implementation as in the case of the SimAC model where they allowed us to realize that the types of cognitive abilities used by agents were exclusively based on reasoning and learning by instruction, see [38] and [39].[2]

The arguments discussed so far principally focused on the syntactic components of mental worlds. It was emphasized however that semantic components exist which are coupled with the syntactic ones. It is the dynamic interlinking between syntactic and semantic components which allows individuals construe their mental models and give meaning to a certain situation, see [13]. Because of their generative nature, not a unique, but a plurality of mental worlds may therefore co-exist. For the sake of illustration, one might suppose, as in Fig. 6, that there exist two distinguishable components interlinked by a kind of activator which make it possible the generation of mental models and their integration.

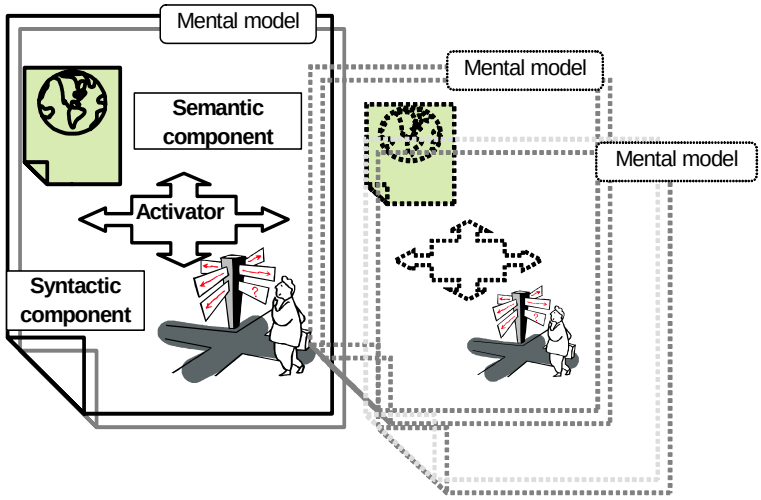

Fig. 6. A speculative representation of mental models and their components

[2] Reasoning, in particular, plays a major role in the agents' strategy for finding their travel path as they move on the spatial network to reach their workplace the strategy is based on the minimization of travel time, as this is perceived as a disutility. Its application takes into account two dimensions of travel times: a) an objective one, depending on 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; and b) a subjective one, reflecting the *mental map* of individuals' action space.
Learning by instruction is used by agents in realizing their evaluation activities. A kind of behavioral agenda of the actions to be undertaken by agents in the various situations is defined according to an IF THEN format, which can be exogenously specified, making reference to certain urban scenarios.

As for meaning, it has been posited that it involves two main aspects, sense and reference, see [48]. The former brings to the fore the notion of coherence, and, as mentioned above, it is usually associated with the cognitive stance underlying reasoning. The latter implies a more general notion of consistency with some states of the world (and agent's own states as well) as perceived and acknowledged by the agents. It is the nature of these perceptions which turns out mostly stirring for urban mobility phenomena, see Fig. 2.
As pointed out in the field of cognitive studies see [8], [13], the formation of these perceptions and the action response which in term of observable behaviours these are likely to produce raise a number of questions.
A few aspects which appear relevant also in activity and travel decision-making processes are the following.
First, the definition of the very nature of needs should be given further insights. The needs of activity engagement and related travel cannot be defined without accounting for agents' underlying goals since only teleonomic goal-oriented systems have needs. In addition, the notion of need implies not only the idea of lacking or deprivation but also that of its awareness.
As a consequence, different levels of awareness in needs are likely to entail different goals. Tab. 3 illustrates a possible articulation as far as some aspects of mobility are concerned. A three level articulation is suggested, ranging from a simple to a more conscious perception of the need of travel.

Table 3. An articulation of the needs of travel

Level of awareness	*Types of perception*	*Agents' profile*	*Likely behaviour*
A) Perceiving the need of travel	Embodied perceptions, resulting from body sensory-motors	Agents need to travel as a result of a lack of spatial movements	They make travel
B) Feeling the need of travel	Perceptions are mediated by agents' internal and external beliefs	Agents are cognitively aware of their needs of travel. They have beliefs about the reasons to travel and a certain level of information about the system opportunities and constraints	They undertake a decision-making process for identifying their travel pattern in order to satisfy their perceived travel needs, given the existing constraints and available level of information
C) Sensing the need of travel	Perceptions are modified as a result of changes in agents' internal and/or external beliefs	Agents are aware that they need to engage in activities and that these may be actively managed in their collective system	They engage in (organize) their activities and travels

Feeling the need of travel supposes that a) travel needs depend on some perceptions (or at least partially perceived) travel outcome and b) these perceptions are mediated by internal models and external information. Sensing the need of travel recognizes the possibility that deeper effects are at work as the blend between the internal ad external worlds depends, on its turn, from the cognitive stances of both individual and collective agents.
Second, owing to the intrinsic features of humans beings mentioned earlier, (at least for case B and C in Tab. 3) there should exist certain reference values which agents take into account in evaluating their perceptions and related needs. These values can belong to both the agent's internal world, being driven by his/her beliefs and desires, and external world,

being entrenched in the norms, rules, social obligations constituting the individual's cultural world. Nonetheless, as Castelfranchi [8] points out, since mental models are rooted in both cultural and material embodiment, it cannot be excluded that certain travel needs are likely to be more cogent if instantiated as bodily perceptions.
Finally, and this holds in particular for the case C, the importance of the relationships between the internal and external worlds and of their co-evolution should be acknowledged. In this regard, some questions are raised which are worth being given further attention, i.e.:

- the idea that an external cultural word is the consolidated outcome of shared individual mental worlds, see [17] and [29];
- the fact that not only the level of awareness varies among individuals, but also that it is the kind of discrepancies in these levels between the individual and collective agents which mostly matters;
- the fact that, following the Gibsonian notion of affordances, see [26], in certain context situations, the potentialities for actions held by objects, i.e. and namely by situations in which there are communicating agents, may play a role in activating the relationships between those semantic and syntactic components of Fig. 6.

Designing a scaffolding structure. As mentioned in section 2, one fundamental concern of the current agent-oriented studies concerning mobility is to include the decision-making process guiding individuals' activity and travel choices (the so-called activity agendas) see, [2], [5] and [46].
One major effort in this respect has been to account for the fact that decision-making process unfolds over time as daily activity patterns depend on both short-term and long-term decisions. Activity agendas are interpreted as a hierarchy of successive levels reflecting the different temporal stages at which decisions concerning activity participation are taken.
The scheme of Fig. 6 illustrates the identified stages. An activity pattern is then understood as the outcome of the successive realization of a long term activity calendar, a medium term activity programs and a short term activity schedules.
It is worth noting that in several models being currently developed to describe that framework, the notion of agency typically refers to the different stages of the mobility decision making process. Whereas this may be viewed as a concern for the analytical-methodological dimension characterizing an ALC model, there is the necessity to improve the articulation of the conceptual-ontological dimension in order to include agents' mental models.
A number of possibilities can be foreseeable.
A first, rather straightforward, option is to assume that the framework provides a reliable insight into an agent's decision making process, i.e. this means to suppose that there is a correspondence between the observable articulation levels of the activity pattern and the cognitive stages of the decision making process. The latter would be hierarchically ordered and the mental models associated with its various stages correspond (map) to the levels of the activity pattern, see Fig. 7. The links between these levels, then, should have to be replaced by the networks of conceptual blending likely to be activated among the various mental worlds.
While appealing in term integration with existing agent-oriented ABA approaches, this interpretation is not without flaws. A fundamental question in fact is raised concerning whether some specific mental worlds, i.e. those resulting from a blend of the cognitive stances of Fig. 2. exist which may represent the different stages, in a meaningful way. The possibility that mental worlds could evolve, by means of individual learning, communication among agents or broader cultural changes would have to be addressed too.

Even though admitting the conceptual plausibility of this option, its practical implementation in terms of data requirements and processing, however, is likely to be cumbersome, at least with the existing computing technology.

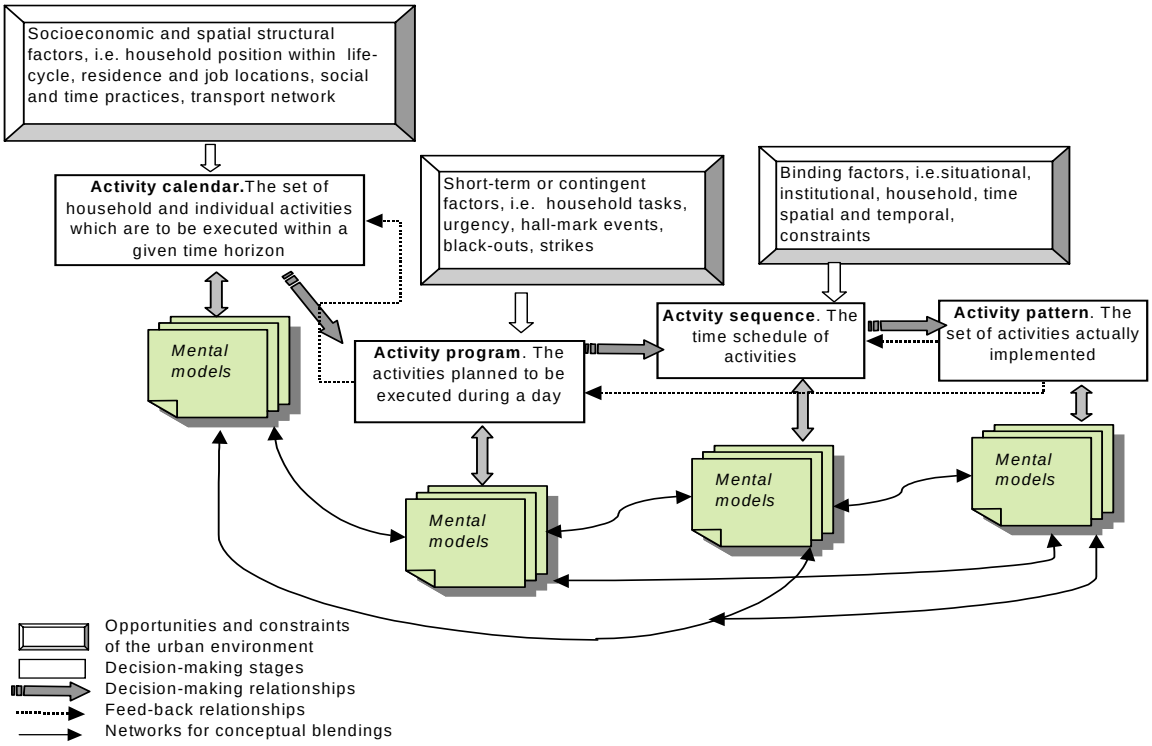

Fig. 7. A descriptive framework of the formation of activity agendas (developed upon [2])

An alternative option is to focus on the decision making process as a whole, see Fig. 3, and instead of looking for an explanation/interpretation of its relevant stages, explore the reasons behind that process and how these may evolve as a result of agents' adaptation and learning. In this vein, Rind et al [45], for example, distinguish different types of learning:

- learning about states of the world, i.e. improving an agent's ability to distinguish situations, and increase his/her familiarity with urban environment;
- learning about the opportunity space, i.e. getting information that activities meet certain requirements;
- learning about interpretations of historical trajectories, i.e. developing better knowledge about causal linkages in the environment;
- learning about the decision rules, i.e. refining the existing rules as a result of an agent's experience or new insights.

To a closer inspection, in fact, learning and adaptation turn out to be the outcome of (the functioning of) mental models, thereby producing an updating of the semantic and syntactic components of the latter, and new meanings as well.

This option actually elicits a need to extend the very function of the decision making process and recognize its twofold role of:

- prompting agents in their activity engagement, and namely, facilitating individuals' participation to activities, i.e. providing information about destinations and means of transport, making possible e-access to activities;
- motivating individuals to actively construe their own activity engagement, as they can make sense of their perceptions of travel needs.

Also in this case a temporal perspective is involved, which however appears ontologically different from the one considered in the previous option.
Of course, while acknowledging this diversity, one may suppose to embed the latter within the former, and look for some relevant overlapping which would be both valuable for interpreting mobility needs and constructive for devising mobility policy measures.

4. CONCLUDING REMARKS

This paper made an effort to frame some basic questions involved in developing a MAS approach to mobility phenomena. First, a claim was made that in order to take advantage of MAS potentials both the analytical-epistemological and conceptual-ontological dimensions should be accounted for. The discussion of the former dimension, in particular, showed that changes are occurring in the mediation role of modelling which is strengthened, i.e. it becomes more cognitive oriented.
In this respect, it was argued that a MAS approach represents a specific instance of this novel type of cognitive mediation oriented modelling.
Then, in discussing the ontological-conceptual dimension, it was emphasized that a major novelty of a MAS approach is the possibility to account for the mental worlds of urban agents.
These, however, do not simply appear as an additional feature to be plugged in the existing views of mobility phenomena. A review of the conceptual underpinnings of the current approaches to mobility analysis shows that their inclusion raises a number of questions about the very nature of agents' cognitive attitudes, their interactions and the system micro-macro relationships.
It is suggested that the notion of mental models as cognitive entities involving both semantic and syntactic components are involved, may be promising for the analysis of urban mobility. Some features of these components have been illustrated, and a few implications about the definition of travel needs put forward.
Finally, a claim was made that mental models have a crucial role in the decision making process guiding the formation of individuals' activity patterns. In this direction, the possibility to integrate them in the existing descriptions of activity patterns has been addressed and two options identified, i.e. linking the levels of the activity patterns with stages of the decision making process and motivating the role of the decision-making process.
Although far from being definitive, these options should be regarded not as contrasting alternatives, but rather as different lines of enquire each of which is likely to yield valuable insights.

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