Simulating urban mobility and the role of public policies: the challenges of Agent Based Models

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ABSTRACT

The paper provides a critical review of research on agent-based models (ABMs) focusing on passengers and/or freight urban mobility. The work analyses also the contribution of ABM in simulating the impacts on urban actors' behaviour of the public policies aiming at improving the sustainability of city systems. Traffic in towns in fact is responsible for a high share of greenhouse gas emissions and congestion. The empirical studies included in this survey have been classified, according to some relevant dimensions. The following conclusions can be derived. ABMs present important advantages for analysing urban transport, but the literature is still lacking. On the one hand, attempts of using ABMs for investigating urban mobility are more numerous in the domain of passengers transport than in the one of freight transport, but they are still limited in the number. On the other hand there is a relative high number of ABMs dealing with freight mobility in broader geographical areas, but few that are focused on urban areas. It emerges that the most promising field is the integration of passengers and freight domains of urban mobility in the same model, in order to simulate and evaluate policies that would influence both at the same time.

Keywords: urban mobility, agent-based models, city logistics, passengers transport, policy simulation

JEL: O18, R41, R15

1. INTRODUCTION

Recently the role of agent-based modelling for studying city logistics and passenger mobility in urban areas is highly debated in the academic literature. However, the emphasis given at a theoretical level to the potential advantages of this type of models has not yet been translated in an intensive production of agent-based models addressing urban mobility (Tamagawa et al., 2010). The aim of this paper is providing a review of the existing works which utilize this tool for analysing either freight transport, or passengers mobility, or both at the same time, in cities and for predicting the impact of the different urban public policies on the agent behaviours and, as a consequence, on climate change goals.

The paper focuses on the urban environment because in the practice freight and passengers flows coexist and share the same physical scarce spaces. Public policies have an impact at the same time on the whole urban dimension, affecting the entire transport system. Moreover, the majority of world population lives in urban areas and continues to increase, supporting the negative externalities (pollution, noise, vibration, energy consumption, congestion, etc.) coming from transport and other social and economic activities.

In the European Union, over 60% of the population lives in urban areas and a car runs 75% of its mileage in and around cities. According to a recent opinion poll, 90% of Europeans think that the traffic situation in their area should be improved (European Commission, 2007). In Europe increasing traffic in the city centres is leading to permanent congestion. The delays and other damages caused by traffic jams cost the European Union 1% of its Gross Domestic Product. Many European citizens are exposed to high levels of air pollution, especially from the concentration of PM10, NOx and SOx (European Commission 2009). The combustion of gasoline and diesel from people and goods transport accounts for 31% of total U.S. CO_2 emissions and 26% of total U.S. greenhouse gas emissions in 2013 (United States Environmental Protection Agency 2015). In particular, the domination of oil as a transport fuel generates CO_2 and air pollutant emissions in towns. In fact, urban mobility accounts for 40% of all CO_2 emissions of road transport and up to 70% of other pollutants from road transport (European Commission, 2007).These kind of phenomena contribute to the wider and highly debated process of climate change. However, in turn, climate change has consequences on the transport sector itself. For example global warming producing a rising in the sea level may amplify the vulnerability of coastal infrastructures. Extreme weather occurrences may affect the safety of all modes (European Commission 2009). There is urgency for the transport sector to mitigate its negative impact on the environment. The EU adopted a package that sets a target of reducing greenhouse gas emissions within its area by 20 % with respect to 1990 (European Commission 2009)Within this framework it is clear that the urban sustainability is one of the most important challenges of the present and future societies.

The contribution of the paper to the transport economics literature is to develop a critical review and a classification, according to specific features, of the works focused on the use of agent-based models for the analysis of urban systems, considering one or both the dimensions of passengers and freight flows. Therefore the intention of the work is to identify a space in the academic literature and to provide the basis for agent-based modelling having the aim of integrating the whole system of mobility in cities and evaluating the effectiveness of public policies in terms of climate change goals.

The paper is structured as follows. In the next section an overview of the characteristics of agent-based models (ABMs) and of their potential role in analysing the complex issues of both freight and passengers flows in cities is provided. Moreover, the possibility to integrate ABMs with Geographical Information Systems (GIS) in order to better describe the actors' spatial interactions is underlined. In section 3 an useful framework for the creation of a taxonomy of existing researches about ABMs and urban systems is presented. Section 4 is dedicated to the analysis of the surveyed literature according to this taxonomy, while in the last section some conclusions are drawn and further research needs are suggested.

2. THE URBAN SYSTEM AND THE AGENT-BASED MODELS

Agent-based models (ABMs) can be a valuable tool among urban mobility researchers for its strong capability of capturing the dynamic behaviour of individual stakeholders and their interconnections. ABMs attempt to model the complexity of social systems with individual level representations of interacting autonomous agents (Gilbert, 2008; Gilbert and Troitzsch, 2005, Shafiei et al., 2013). An ABM is "a computational method that enables a researcher to create, analyse, and experiment with models composed of agents that interact within an environment" (Gilbert, 2008, p. 98). Four elements uniquely characterize ABMs: (1) an environment, i.e., a set of objects the agents can interact with; (2) a set of interactive agents; (3) a set of relationships linking objects and/or agents; and (4) a set of operators that allow the interaction between the agents and the objects. In particular, ABMs implement a generative approach, which allows the investigation of social patterns using a bottom-up technique (Natalini & Bravo, 2014). Agent based models assume each stakeholder is an autonomous agent with certain attributes and states. In the simulated environment, agents interact with other agents and the environment to make autonomous rational decisions, proact or react given previous experiences and communications with other agents (Gilbert & Troitzsch, 2005; Woolridge & Jennings, 1995). Over time, these agents evolve continuously based on their interactions and time-based feedbacks.

A key characteristic of the urban mobility domain is the high number of stakeholders and, especially as concern freight transport, the heterogeneity of the actors along the different supply chains which distribute their goods to the final customers. The different roles generate different kinds of needs and interests for each stakeholder group. Therefore, each group has particular decision making processes (Anand et al., 2011-2012; Buliung & Kanaroglou, 2007). Accordingly, there is a strong need for a systematic and analytical approach to grasp decision making among different stakeholders in order to understand urban freight and passengers mobility (Anand et al., 2011-2012). ABMs allow to attach different features, decision processes and objectives to each agent or group of agents.

ABMs offer the advantage of bottom-up modelling (Shafiei et al., 2013). The researcher shape the agents with heterogeneous behavioural rules, goals that must be reached and criteria for satisfaction levels. Agents will be embedded in networks, which will influence their actions. By modelling components rather than the entire system, the structure of the system is not pre-defined and one may observe the emergent properties. Moreover, by modifying the variables of interest, the modeller may explore different kinds of scenarios. Different options for a transport system can be tested in a simulated environment (Sirikijpanichkul et al., 2007). ABMs can be calibrated with real data (Squazzoni, 2012). This allow both to test ex ante the effect of potential policies, or to evaluate ex post the effect of actual policies that have been implemented in reality. For example one may consider the impact of the actual transport mobility of a specific area on the total greenhouse gas emissions of that zone, and, in turn, the potential contribution to these emissions to climate change. One may also observe the impact of policy changes on these aspects, considering their capabilities to meet the climate change goals.

Some insights about the usefulness of agent-based models for the investigation of urban transportation systems, both in the field of freight transport and of passengers mobility, are discussed in the next section.

2.1 ABM and Urban Freight Mobility

A fundamental characteristic of the urban freight mobility domain, also called city logistics, is the high number of stakeholders and the heterogeneity of their needs. Therefore, the economic services offered are fragmented in a high number of small activities. In the cities different Urban Supply Chains (UBCs), i.e. the last mile of the supply chains in charge of delivering the goods to an urban areas, interact (Danielis et al., 2013). They have a very complex nature and can assume different profiles according to the characteristics of the urban area and of the other economic activities and to the product and the structure and organisation of the whole system. Also from the demand side there is high fragmentation, since citizens often derive high benefits by buying items in small local shops or ordering the goods on the internet. The level of demand fragmentation is higher in some countries such as in Italy, where the large-scale retail trade in the cities is less widespread while the urban sprawl is great (Maggi, 2007). As summarized in Table I, the actors involved in city logistics domain have their own interests, often conflicting and consequently act following their own goals without any centralized control. For example, local administrators impose rules such as weight restrictions to mitigate the disturbance from commercial vehicles. However, these limits may damage the profit and the quality of services supplied by the carriers. Shopkeepers order small but frequent deliveries, because they have very small or any space of warehousing in order to contain the total logistics costs. By this way they reduce the inventory cost, but at the same time they limits the capacity of operators delivering the goods to maximize the vehicle loading factor. As a consequence the number of vehicles per day increases and more negative externalities are generated.

This framework makes urban freight transport a decision making system which is highly distributed. This, in turn, leads to the well-known problems in urban freight transport, which consist mainly in low economic and environmental sustainability. For these reasons there is a need for an analytical approach to investigate decision making processes among different stakeholders in order to address systematically the organization of urban freight transportation (Anand et al., 2011).

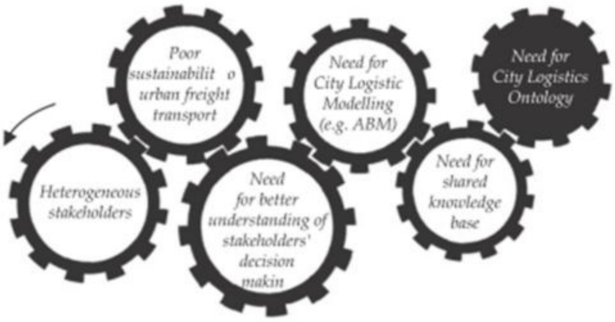
Table I - Interests of stakeholders involved (Macário et al. 2008)

Stakeholders	**Interests**
Residents	Product and Services
	Negative environmental impact
Retailers	Competitiveness and Profitability
Authorities and Public Service	Accessibility
	Governance and Legislation
	Negative environmental impact
Suppliers	Market growth
	Profitability
Carriers	Congestion
	Cost effectiveness

The research run in the city logistics domain has the goal to facilitate an efficient urban freight delivery system and to boost solutions that sustain economic growth. More in details, city logistics can be defined as “the process for totally optimizing the logistics and transport activities by private companies in urban areas while considering the traffic conditions, congestion issues and combustible consumption, with a view to reduce the number of vehicles on the cities, through the rationalization of its operations" (Institute for City Logistics). The city logistics modelling works above all helps to create a knowledge base about freight flows and behavioural issues of the different stakeholder (Taniguchi et al., 2013). Moreover, it is regarded as a forecasting tool to gain insight about freight vehicles, commodity flows, infrastructure and information needs. The final goal is to design possible policy measures to improve the efficiency of the total urban freight transportation system, without creating inefficiencies in the remaining part of the whole supply chain. The main problems related to city logistics are clearly channelled into city traffic, but their roots are connected to the decision making processes of the different actors. The work of Anand et al. (2011) is useful since it focuses on the need of a shared ontology serving as the basis for research and policy making in the field of city logistics. In order to get an efficient communication many actors should interact with each other and share a common knowledge, starting from the terminology until the types of decision they are making. From the point of view of semantics, a common language is needed in order to have coordination among users and sub-systems, and between researchers and policy makers.

Agent-based modelling (ABM) can be an effective instrument able to describe in a dynamic way the behaviour of each stakeholder or group of homogenous stakeholders and their relations. Nevertheless, the use of ABMs for the analysis of city logistics issues is at relatively initial stage. Some attempts for ABMs in city logistics domain are in the works of Donnelly (2007), van Duin et al. (2012), Tamagawa et al. (2010). These models share the goal of testing and evaluating the potential impact of different policy measures in city logistics domain. Anand et al. (2012) insist on the fact that today ABMs knowledge bases are still built with little sharing or reuse. Almost each author starts from a sort of blank slate. The introduction of a city logistics ontology may improve this situation. An ontology is a formal specification of the concepts and relationships that can exist for an agent or a community of agents. The development of an ontology may create a shared and standardized template that specifies the data structure within the models. This possibility would decrease working time and improve the robustness and reliability of the resulting knowledge bases. The diagram by Anand et al. (2012), represented in Figure 1, is – in our opinion - particularly useful and intuitive in order to give a graphical representation of problems forming mechanism in urban freight mobility.

Figure 1. Problems forming mechanism in city logistics (Anand et al. 2012)



2.2 ABM and Urban Passengers Mobility

Regarding passengers mobility, it must be highlighted that urban structures have complex transportation networks. The performance of each network is influenced by individuals and choice behaviours. The complexity of the system is influenced on the one hand by interactions among heterogeneous kinds of agents, and on the other hand between agents and their environment. Over time specific behavioural patterns emerge and, in turn, they will influence the environment itself. Given these complexities, agent-based models are an useful tool to simulate this kind of interactions (Shukla et al., 2013).

As we explained in the previous section, ABMs implement a generative approach, which allows the investigation of social patterns to use a bottom-up technique (Natalini & Bravo, 2014). The use of bottom-up approaches instead of top-down approaches, like for example the System Dynamics, gives different advantages. One of the most important is the consideration of emerging properties. The behaviour of any system is a result of the interactions amongst its components. Indeed, ABMs are useful to analyse the non-linearity of aggregated behaviours with respect to individual ones. A macro-behaviour may be something different then the simple aggregation of several micro-behaviours. The value of this kind of models lies in the prediction of emergent system behaviour that would be difficult (if not impossible) to elicit with analytical methods (Gilbert & Troitzsch, 2005).

Transport networks fit perfectly this description, since their global performance is a product of the interactions of the network components. ABMs assume each commuter is an autonomous agent with specific attributes and states. In the simulated environment, agents interact with other agents and with the environment itself in order to make autonomous travel decisions and proact or react given previous experiences and communications with other agents (Gilbert & Troitzsch, 2005; Woolridge & Jennings, 1995). Over time, these agents evolve continuously based on their interactions and time-based feedbacks.

Methods different than ABMs which have been utilized to study travel behaviour are discrete choice models (Koppelman & Wen, 1998; McFadden, 1973). They include probit model (Gaudry, 1980), multinomial logit (MNL) model (McFadden, 1973) and nested logit model (Daly & Zachary, 1979). These approaches have some limitations such as i) the strict model structure needs to be specified in advance; ii) they are unable to model non-linear systems; and iii) they consider only conditions that hold across an entire population of observations. These limitations can be overcome by using machine learning based methods such as Decision Trees (DT) and Artificial Neural Networks (ANN) (Cantarella et al., 2003; Reggiani & Tritapepe 1998; Shmueli et al., 1996; Xie et al., 2003). However, crucial issues remain unexplored, such as; (i) decision whether to implement a centralized or non-centralized learning approach, and (ii) choosing a learning algorithm. For instance, even if ANN are useful at classifying large amounts of data, it is difficult to determine how classification decisions are made. This happens because they are black box type of models, without the possibility of tracing the mechanisms leading to the outputs. DT models provide structure to how decisions are made but are not good at classifying continuous data.

Another method for simulating the travel of individuals in the transport network of an urban area is micro-simulation models (Balmer et al., 2008). These models are useful for the representation of the structure of transport systems. However ABMs are usually better suited to capture the impact of agents behaviours on the transport network (Shukla et al., 2013).

2.3 ABM and Geographical Information Systems

Cities are complex systems, with many dynamically changing parameters and large numbers of actors. The heterogeneous nature of cities makes it difficult to distinguish between localized problems and city-wide problems. Najlis and North (2004) argue that there is a growing interest in the integration of Geographical Information Systems (GIS) and agent-based modelling systems (Brown et al., 2005; Parker, 2004; Torrens & Benenson, 2005). Examples of interesting applications include pedestrian dynamics, urban growth models and land use models (Crooks, 2006). This integration provides the ability to have agents that are related to real geographic locations. In an agent based model agents often have some spatial relationships to each other and are situated in an environment and the use of GIS allows a useful representation of this kind of relationship. A GIS can contain multiple layers, such as for example a housing layer, a road network layer, or a population layer. The combination of layers allows one to model different kinds of agents situated at the same time in a geographical environment. The use of GIS in ABM, specifically its use of polygons for representation of space, represents a step forward from the regular lattice structures used in previous urban models (Wu, 1998). Since cities do not have regular spatial patterns, the use of GIS allows one to model cities using a variety of different land parcel shapes and sizes. One can deal with objects, such as people or houses, either as fixed or not fixed objects. Fixed objects are things which have transition rules and cannot move, such for example a park, while non-fixed objects have transition rules and can move, like individuals or firms. Area changes are normally associated with interactions taking place between agents and their environment (O’Sullivan & Torrens, 2000). Fixed and non-fixed objects have close relationships and dependences. Therefore a change in variables of either type will have immediate changes on the other variables. This change can be detected by geo-referencing the objects and agents simply using x and y coordinates (Crooks, 2006).

3. FRAMEWORK FOR EVALUATING THE LITERATURE ON AGENT-BASED MODELS ON URBAN TRANSPORT

In order to provide a critical classification of the literature containing ABMs on urban mobility, the analysis has been largely inspired to the taxonomy developed by Davidsson et al. (2005). These authors in their useful literature review apply the taxonomy to the works dealing with transport logistics in general. They consider every domain of transportation: air, rail, road, sea and intermodal situations. On the contrary, as it has been explained before, the present paper focuses on urban mobility only.

As indicated in Tables II and III, the reviewed works on ABMs in urban mobility have been classified according to different features. The following dimensions are derived from the work of Davidsson et al. (2005) and explained below: the *time horizon*, the *structure*, the *agents attitude*, the *maturity level* and the *usage*. The dimensions that have been added for their importance are: *intention of the model*, kind of *variables* utilized and *calibration on actual data*. Moreover, in the passengers domain it has been added also the dimension of *category of people*, since often the ABMs used in this domain address specific sub-groups of city inhabitants, while in the freight domain the whole system of city logistic is usually considered.

Time horizon

The dimension time horizon refers to what stage, in the decision-making process, the application is used, or is intended to be used. The stage could be strategic, tactical or operational. Strategic decision-making concerns long-term decisions, determining the action line. The tactical level involves medium-term issues, while the operational level is about short-time issues. Of course the time horizon for these levels is dependent on the domain of research. As an example, a simulation regarding the location of a distribution centre would be classified as strategic in its time horizon. A tactical approach would be to plan the vehicle fleet to satisfy the customer demand, while an operational issue would be the scheduling of every delivery with the controlling function.

Structure

The structure of the model may be either static or dynamic. Static means that the whole structure is predetermined and the set of agents, their roles, or their decision-making processes do not change during the execution of the simulation. Dynamic means that such mechanisms may change during the simulation according to specific criteria or to random elements.

Attitude

In many cases agents of the models interact among themselves in order to accomplish their tasks. They can do it either through a cooperative attitude or a competitive one. In the first case, as an example, they may be supposed to comply with social laws or collective aims. Therefore they may act following criteria which are more heterogeneous than only pure individual profit maximization, like for example, adapting the own behaviour to the majority of behaviours of the neighbourhood agents or seeking the social welfare maximisation. In the second case, actors act following only the principle of maximizing their own profit or utility.

Maturity

The degree of maturity of a model indicates how complete and validated an application is. The lowest degree of maturity in this taxonomy is the conceptual proposal. In this case the idea of the proposed application is described with its general characteristics. The second maturity degree concerns simulation experiments: the model runs in a simulation environment. The data used in simulation can either be real, that is to say they are taken from existing systems in the real world, or not real, which means that they may be artificial, synthetic or generated. The further maturity stage is the field experiment, which means that the model has been experimented in the environment where the application is supposed to be applied. In the final stage, deployed system, the system has been implemented in the real world. This is the most mature type of agent-based models.

Usage of the agent system

The agent-based models can be classified as either serving as an automation system, or as a decision-support system. An automation system should have a mechanism that self-acts a required performance at a certain time or in case of occurrence of defined conditions. In this context the system influences directly the controlled environment and no human is involved. On the contrary, a decision-support system (DSS) may provide important elements that help the policy-making in taking decisions. Indeed, in this last case the final decision is taken by a person and not by the application itself. As all the revised papers are developed as DSS, this dimension has been excluded from Table II and III.

4 APPLICATION OF ABM TO URBAN MOBILITY ANALYSIS

4.1 ABM and City Logistics

The literature review on specific applications of agent-based models to transportation issues has highlighted that few of them focus on freight transport in urban areas. Most of these few works aim to develop models that represent the whole city logistic systems, considering the different stakeholders involved in the decision making processes and their respective priorities and needs. Therefore, the authors of these works declare that the main advantages of adopting an agent-based approach are: the possibility of representing heterogeneous types of agents that form various and coexisting decisions centres, ability to deal with partial data and possibility to model complex problems (Roorda et al., 2010; Tamagawa et al., 2010). The researchers utilise this tool in order to go beyond the simple modelling of transport scheduling. The models included in this review contain the broad categories of actors which have been introduced in section 2.1, with differences and specificities in each work.

In the reviewed papers, negotiations among actors normally take place through contracts and market-based operations (Taniguchi & Tamagawa, 2005; van Duin et al., 2012). The agent based models have different specific aims.

The work of Anand et al. (2012) develops from a theoretical point of view only an ontology on city logistics ABM, while the others are more applied. In the paper of Donnelly (2007) a microsimulation approach was developed in order to estimate the urban freight demand in Oregon and the related supply organisation. The overall simulation environment provides information on global exchange, travel times, vehicle availability, the regional economy, and the characteristics of transportation networks.

The research of Van Duin et al. (2012) aims at providing insight in the urban distribution centre (UDC) success by investigating dynamic price settings and cost-valued choices by individual agents. In the work of Tamagawa et al. (2010) a model for vehicle routing and scheduling, in case of time-windows policy application, has been developed. Taniguchi and Tamagawa (2005) perform a simulation of the impacts on the stakeholders behaviours of implemented truck ban and tolling of urban expressway as city logistics measures on test road network. They used a model which determines the optimal solution by minimizing total transportation costs.

Roorda et al. (2010) develop an agent-based microsimulation framework that represents the different roles and functions of actors in the freight system and their interactions in markets through contracts. Finally, Teo et al. (2014) describe the use of the multi-agent systems (MAS) modelling approach, to solve the vehicle routing problem of carriers’ delivery jobs and to evaluate the short-term impact of distance-based road pricing and a load factor control scheme on the major stakeholders (carriers, shippers, administrators and customers). They experiment the model on the real network of Osaka (Japan), showing that the joint scheme is able to reduce the cost of shippers and carriers as compared to the higher cost experienced when only the distance-base road pricing is implemented. The variables or components of the models in the papers vary according to the specific objective of the simulation (for details see Table II).

Concerning the data used by the model, the work of Donnelly (2007) is calibrated on actual data and the conceptual proposal of Roorda et al. (2010) also plans to calibrate the proposed model on real data on Toronto. Indeed the other models of this review do not utilize real data.

Regarding the time horizon, the models considered address strategic decision-making, which involves long-term decisions about the whole city logistic system of an urban area. They try to go beyond the scheduling of single transports. Only the works of Donnelly (2007) have also an operational component, by modelling discrete daily shipments carried by specific vehicles, with specific departure and dwell times.

Referring to the structure of the models, most of them are dynamic. Agents change their behavioural rules according to their reactions to policies. Negotiations take place among and new rules are therefore established. When city logistics measures are implemented and their living environments are changed, the behaviour of the agents will change to adapt to the new environment.

Regarding the attitude of the agents, most of the time they have both cooperative and competitive behavioural rules.

As far as the maturity level of the model is concerned, two of the works analysed are at the stage of a conceptual proposal (Anand et al., 2012; Roorda et al., 2010). This kind of works are extremely useful, since they try to highlight trends and critical issues that are common in different situations. Therefore, one researcher who is willing to develop an ABM on urban logistics may utilise these kinds of framework, and their ontology and taxonomy. These works summarize the main types of actors involved in urban freight transport, the kinds of interactions and contracts they have, the kinds of output variables which are relevant for the urban system and the kinds of policies which are likely to influence the variables of interest. The other papers describe complete models, which run either on simulated experiment only, or use some partial real data. In this last case they may be labelled as field experiment (Donnelly, 2007).

As regards the last dimension, all the works considered can be classified as Decision Support Systems (DSS), since they provide useful insights for decision makers in the measures evaluation process ex-ante, in itinere or ex post, but they are not linked to real concrete operations on their own.

Finally, concerning the software used by the works reviewed in this paper, which deal with city logistics, Van Duin et al. (2012) utilizes Netlogo, while in the others it is not specified. Tamagawa et al. (2010) use also the method of Q-learning, a technique of reinforcement learning, in constructing a learning model for stakeholders which evaluates their behaviour, learns the value of them and selects the behaviour considering their value.

4.2 ABM and urban passengers mobility

The tool of agent-based modelling is utilized for the investigation of passenger behaviour in urban areas more often than for the analysis of freight transportation. Most of the works that are considered in this paper deal with a sub-category of citizens, such as, for example, university commuters, work commuters or pedestrians. Only a minority of models address the whole category of the inhabitants of an urban area.

At a first glance, it is possible to divide the models into two groups. First, the ABMs that aim to test the effectiveness of policies that improve some specific services in the domain considered, such as for example the location of schools or parking areas (Benenson et al., 2009). Second, the models testing policies that provide incentives for the agents to modify their behaviour in a desired way (for example, Natalini & Bravo, 2004). Specifically, the intentions of the models are mixed and the categories of people and of variables used vary as a consequence. The model ILUTE (Integrated Land Use, Transportation, Environment) developed by Salvini and Miller (2005) simulates the evolution of an integrated urban system over an extended period of time with the aim to support the analysis of transportation, housing and other urban policies. The modelled activities are land use, location choice, auto ownership, economic activity and daily travel.

The paper of Shukla et al. (2013), focusing on an University campus, presents a methodology for developing a hybrid agent-based micro-simulation model to individuate the impacts of commuter travel mode choices on the transport network. University land use, commuter demographics, and socioeconomic conditions are considered.

Benenson et al. (2008) develop an agent-based, spatially explicit model for parking in the city, called PARKAGENT, which simulates the behaviour of each driver, capturing the complex dynamics of the parking agents within a non-homogeneous road space. The model has been applied to Tel Aviv in order to study the impact of additional parking supply in a residential area with a shortage of parking places.

Harland and Stillwell (2007), analysing the daily pupil movements between schools and residences in Leeds, develop a framework for a planning support system and policy formulation, which is based on Spatial Interaction Models or Agent Based Models.

The paper of Lu et al. (2008) uses an agent-based model to study the effect of six land use regulations on travel behaviour in a hypothetical urban area loosely based on the Chicago, Illinois, metropolitan area.

Schelhorm et al. (1999) develop the STREETS model for investigating by a dynamic way the pedestrian behaviour in urban centres. The ABM and GIS-based socio-economic data permit to integrate the configuration and the location of attractions, both of which influence the pedestrian movements.

The TRansportation ANalysis and SIMulation System (TRANSIMS) Project by Smith et al. (1995), integrating the regional transportation systems and the analysis on the environment, simulates a regional population of individual travelers and freight loads with travel activities and plans, the individual interactions and the environmental impacts.

Natalini and Bravo (2014) develop an Agent-Based Model called Mobility USA which reproduces the transport choices of a sample of citizens and the corresponding GHG emissions of their daily commutes in the USA. They aim at testing ex ante the impact of public policies willing to foster commuting choices with lower GHG emissions. The focus is on the effects of two sets of policies: market-based and preference-change ones.

The variables and the types of agents of the models in the revised works vary according to the specific aim of modelling (for more details see Table III).

Usually, the variables included in the models concern features of the agents (such as demographic characteristics, information on their activities and their choices on transportation patterns), monetary aspects (such as for example parking fees or travel costs in term of ticket price for the public transportation or gasoline price) and information related to travel time. In the cases in which the model is geographically located, it includes information on the distribution of relevant points, accordingly to the scope of the model.

Referring to the time horizon indicator, all the works analysed can be considered strategic, in the sense that they address the question of interest from a broad point of view and consider each component as a part of the whole urban area, without restricting the simulation to sub-dimensions of the problem. They build the complex interactions of a high number of variables belonging to different domains.

The structure is usually dynamic, since the behavioural rules of the agents change according to various criteria during the simulation, like for example the feedback given by the behaviour of the previous time step. In the work of Salvini and Miller (2005) higher level decisions (e.g. residential mobility) influence lower-level decisions (daily travel behaviour). In Natalini and Bravo (2014) work agents adopt one out of four possible decision rules according to the level of social and material satisfaction of each commute. In Lu et al. (2008) the choices of the mode of transport and the one on the relocation of the residence are interdependent.

Regarding the attitude of the agents, in one of the works analysed agents have both cooperative and competitive behaviour, depending on their tasks. In Lu et al. (2008) paper agents compete over the use of land, while in Benenson et al. (2008) compete for the parking areas. In Natalini and Bravo (2014) we can say that agents have a cooperative behaviour, in the sense that social influence and imitation mechanisms play an important role in the decision processes. In the other papers of this survey the distinction between competitive or cooperative behaviour do not really apply, since each agent decides for itself and there is almost no interaction.

Concerning the maturity level of the models, two works are at the stage of a conceptual framework, although they plan to calibrate the future model on actual data from specific cities. The model of Schelhorn et al. (1999) utilises agents whose behaviour and features are informed by GIS-based data. However, the model itself remains at the stage of a simulation experiment. The other papers concern models which are field experiment, that is to say the application has been conducted in an environment reproducing actual cities. None of the works concern a deployed system. All the works considered are calibrated on actual data or, in the case of the conceptual frameworks, are planned to be calibrated on real data. The majority of them uses the support of GIS.

Finally, as regards the final indicator, all the models considered in this review are conceived to be decision support systems for decision makers and policy makers.

To the best of our knowledge, the only model addressing both passengers and freight transportation is the Transportation Analysis and Simulation System (TRANSIMS), which is an integrated set of tools developed to conduct regional transportation system analyses (Smith et al., 1995). The simulation environment includes a population of individuals with travel activities and plans and a transport freight system. The environmental impacts of these activities is as well determined by the model. TRANSIMS is based on a cellular automata microsimulator. Traffic network data and population data usually must be compiled from several independent sources, such as public or private census. The model has been applied to the Dallas and to the Portland case studies. In Dallas researchers developed a microsimulation in TRANSIMS that executed the travel itinerary of each individual in an urban region, limiting the focus on automobile trips. In the Portland case researchers explored a wider range of actors and their impact on the sensitivity of TRANSIMS. Large vehicles, transit vehicles and transit passengers were included.

The reviewed models utilise different kind of software. Benenson et al. (2008) use ArcGIS. Shukla et al. (2013) design a customized software platform, which in turn uses different tools: Java, used to implement algorithms managing the synthetic population; PostgreSQL, an opensource object-relational database system; Transims, that receives information from the Java and Postgres database to simulate agents' travel patterns and their multi-modal transportation activities; YellowFin, a data visualisation software used to represent congestion profile. Natalini and Bravo (2014) and Lu et al. (2008) use NetLogo, an open-source software for agent-based modelling. Schelhorn et al. (1999) use the SWARM simulation environment and the GIS and Salvini and Miller (2005) the software C++.

5. CONCLUSIONS

Mainly in the last five-six years the efforts to develop agent based models for people and passenger transport analysis have strongly increased. Their success is due to the capability of these models to represent the complex interactions, the diversity and the inherent variability which characterise the transport systems (Donnel, 2009). Nevertheless, in literature there is still a gap in urban transport AB modelling.

The present literature review has indeed highlighted that few ABMs on freight transport are focused on urban areas only. Most of the existing works in this field consider rather broader regions, but the specificities or freight transport in urban areas and its crucial role in terms of sustainable development require to focus the analysis on the flows in and to/from the cities, even if in connection with the mobility of other more extended areas. The ABMs dealing with passengers mobility in urban areas are more numerous than those dealing with city logistics but their number is still limited. They are usually focused on sub-categories of city inhabitants, such as for example school pupils, students, pedestrian or car owners, without a systemic view. As far as the authors know, only one model tries to integrate freight and passengers issues in the same application: the TRANSIMS one (Smith et al., 1995) but it mainly focuses on passenger transport (commuters).

The maturity level which can be labelled as field experiment is reached more often in the passengers domain than in the freight one. In general, it would be extremely interesting and useful to implement real surveys in order to calibrate the ABMs on first-hand data. This would be true particularly for data on the needs and problems of the stakeholders involved in the city logistics, even if it is clear that this kind of survey would be extremely complicated and expensive, given the heterogeneity of categories of actors involved. Any work is located at the stage of deployed system. Indeed in the opinion of the authors the main role for ABMs in this field should be that of external support for public decision making.

Most of the models analyses their respective issue from a strategic point of view, in the sense that they consider it as a whole system and aim to provide policy recommendations that address the problem at its roots, and not only in some sub-parts of it.

Until now urban planners and policymakers have often failed to capture some of the key dynamics of urban passenger and freight mobility and to understand and predict the interactions and the policies' impact on the urban transportation actors. Agent based models can give a strong contribution to fill in this gap.

The analysis suggests that the most useful frontier that needs scientific advances in the field of urban studies is the development of ABMs that integrate the passengers and freight dimensions. The reasons for this recommendation is that any public policy having the aim of improving one of the two dimensions, inevitably influences at the same time the other one as well. The tool of ABM would provide the important possibility of considering the two dimensions as integrated. Such a research should exploit the expertise matured, on the one side in the works about freight mobility in the cities and also in broader areas than urban one, and on the other side, in the few models dealing with passengers commuting behaviours in towns. The main challenge of such an integrated model would be the coordination among all the activities of the different domains and the consistency between passenger behaviour and requirements of the freight mobility system in the town. The conceptual work of Roorda et al.

(2010) only plans to try this integration, starting from a model on urban passengers mobility and extending it to urban freight transport. They indicate, for example, that jobs modelled for the passengers system are coincident with the necessity of labour in the freight system or the travel times of commercial vehicles are consistent with the flows of passengers means of transportation.

The major criticism that emerged is the coordination among the different stakeholders and the development of the model in a way that it results of practical utility for policy purposes.

The present literature review is the first step of a wider research, which have the final intention to develop a model able to consider the greenhouse gas emissions of the whole urban mobility and the capability of public policies to meet the climate change goals. As second step, an agent-based model will be develop to consider firstly only the passenger mobility and secondly also the freight flows. The model will be calibrated on Varese area (North West of Italy). The total greenhouse gas emissions derived from commuting patterns and from city logistics decisions will be estimated with different transport modes and under the influence of different kinds of policies.

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Table II. Literature containing agent-based models on freight transportation in urban areas

Author(s)	**Intention of the model**	**Variables**	**Geographic dimension**	**Calibrated on actual data**	**Time horizon**	**Structure**	**Attitude**	**Maturity level**
Anand et al. 2012	Design of an ontology				Strategic	Dynamic	Both	Conceptual proposal
Donnelly 2007	Urban freight demand estimation and supply design	Economic drivers; Modal alternatives; Trans-shipment; Exports & Imports, Shipment generation, Destination choice, Carrier and vehicle choice, Tour optimization	Oregon	Yes	Strategic & operational	Static		Field experiment
Van Duin et al. 2012	Investigation on the impact of policy measures for the success or urban distribution centres	1 Type of trucks and freight carriers; 1 type of goods; 1 UDC operator; Retailers; Municipality;-Roads; Streets; Nodes	-	No	Strategic	Dynamic	Cooperative	Simulation experiment
Tamagawa et al. 2010	Model for vehicle routing and scheduling problem with time window-forecasted	5 kinds of actors with different objectives: Freight carriers; Shippers; Residents; Administrators; Motorway operators	-	No	Strategic	Dynamic	Both	Simulation experiment
Taniguchi and Tamagawa 2005	Evaluation of city logistics measures impacts on the stakeholders behaviour	Administrators; Residents; Shippers; Freight carriers; Urban expressway operators	-	No	Strategic	Dynamic	Both	Simulation experiment
Roorda et al. 2010	Development of a framework for a description of actor heterogeneity and interaction in freight system	Business establishments, firms and facilities; commodity production and business service facilities; logistics service facilities; End consumers Contracts; Commodity contracts; Business service contract; Logistics service contract; Shipments Time	Toronto Area	Yes 2006	Strategic	Dynamic	Both	Conceptual proposal
Teo et al. 2014	Evaluation of the	Carriers’ profit and cost, shippers’ cost, distance travelled	Osaka road network	No	Strategic and	Dynamic	Both	Simulation experiment

	short-term impact of distance-based road pricing on the major urban stakeholders	by trucks, n. of trucks, n. of customer complaints, nitrogen oxide, NOx, carbon dioxide, CO2, suspended particulate matter			operational			

Table III. Literature containing agent-based models on passenger transportation in urban areas

Author(s)	**Intention of the model**	**Variables**	**Categories of people**	**Geographical dimension**	**Calibrated on actual data**	**Time horizon**	**Structure**	**Attitude**	**Maturity level**
Salvini and Miller 2005	Simulation of the evolution of an integrated urban system over an extended period of time.	Demographic features; Transportation nodes and links; Travel times; Buildings; Location; Monetary values	City inhabitants	Greater Toronto Area, 5,700,200 inhabitants	Yes-Year not specified	Strategic	Dynamic	Both	Field experiment
Shukla et al. 2013	Predict university commuter behaviour and its impact on the transportation system	Demographic features; Info on the role in the Campus; Travel info	University commuters (students and staff)	Wollongong Campus, New South Wales, Australia	Yes 2011	Strategic	Dynamic	-	Conceptual framework
Benenson et al. 2008	Development of a model for parking space supply	Destination of the drivers; Search time; Walking distance; Parking costs	Inhabitants searching for parking	District of Tel Aviv, Israel	Yes 2005-2006 GIS	Strategic	Static	Competitive	Field experiment
Harland and Stillwell 2007	Simulation of daily pupil movements between schools and residences for planning support system	To be defined. Data are about school rolls; commuting distances; pupil mobility; residential migration; pupil	Commuting to school, residential migration and movement between schools	Leeds, England, 700,000 Ihnabitants	Yes 2002-2007	Strategic	-	-	Conceptual proposal

		gender; pupil ethnicity							
Lu et al. 2008	Development of a simulation model to study the impact of six land use regulation scenarios on transit use for work and urban form	Metropolitan rail lines; Employment distribution; Residential location; Household income; Household size; Car ownership; Age; Gender	Work travel behaviour and Urban Form	Inspired to the Cook, DuPage, Kane, Lake, McHenry, Will Counties of Chicago, USA	YES 1995 GIS	Strategic	Dynamic	Competitive	Field experiment
Schelhorn et al. 1999	Investigating pedestrian behaviour in urban centres. Pedestrian movement is influenced by attractions' configuration and location	Socio-economic characteristics: income, gender Behavioural characteristics; speed; visual range; fixation on the schedule	Pedestrian behaviour in the city	None (simulated data)	YES GIS-based socio-economic data	Strategic	Dynamic	-	Simulation experiment
Smith et al. 1995	TRansportation ANalysis SIMulation System (TRANSIMS) as integration of transport system with environmental analysis	Socio-economic characteristics; Economic activities	Commuting choices	Dallas, USA, 1,200,000 inhabitants Albuquerque, USA, 555,417 inhabitants	Yes From 1995	Strategic	Dynamic	Competitive	Field experiment
Natalini and Bravo 2014	Testing ex ante the impact of public policies willing to foster commuting choices with lower GHG emissions	Transport mode choice by the agent; price of the transport mode	Commuting choices of Inhabitants	USA: various cities	Yes 2009	Strategic	Dynamic	Cooperative	Field experiment