UNDERSTANDING PASSENGER AND FREIGHT URBAN MOBILITY TO IMPROVE THE EFFECTIVENESS OF URBAN TRANSPORT POLICIES: THE ROLE OF AGENT-BASED MODELS

Elena Maggi, Associate Professor, University of Insubria, Varese, Italy

Elena Vallino, Post-doc fellow, University of Insubria, Varese, Italy
OUTLINE OF THE PRESENTATION

- Aim and methodology of the paper
- Characteristics of ABMs
- Potential role of ABMs for urban mobility simulation
- Results and taxonomy of the reviewed works on urban freight mobility and urban passenger mobility
- Conclusions
- Further research needs
- Next steps of our research
AIM OF THE PAPER

To provide a critical review of the existing works which use Agent-Based Models (ABM)

- for analysing urban freight transport, or urban passengers mobility, or both at the same time, and

- for predicting the impacts of the different urban public (or private) policies on the agent behaviours.

To provide the basis for agent-based modelling having the aim of integrating the whole system of mobility in cities.
METHODOLOGY: THE TAXONOMY

- Development of a **taxonomy** (partially inspired by Davidsson et al., 2005), i.e. classification of the studies according to the following features:
  1. **model intention**, 
  2. **main variables** used: stakeholders and elements of the environment represented by the variables, 
  3. **geographical dimension**: restricted or large urban area, 
  4. **data calibration** on actual data, 
  5. **time horizon**: stage of the decision-making process (strategic, tactical or operational), 
  6. **dynamical or static structure**, 
  7. **agents attitudes**: kind of interactions among the agents (cooperative or competitive), 
  8. **model maturity level**: (i) conceptual proposal, (ii) simulation experiment, (iii) field experiment, (iv) deployed system, 
  9. **type of use of the agent system**: Automation system (self-acting mechanism) or Decision-Support System (support for the policy makers)
METHODOLOGY: Why focus on Urban Environment?

- Urban sustainability is crucial for present and future societies.
- Urban mobility accounts for 40% of all CO2 emissions and up to 70% of other pollutants from road transport.
- In urban areas freight and passengers flows are consistent and coexist, sharing the same scarce space.
- Public policies have an impact at the same time on the whole urban dimension.
- The majority of world population lives in urban areas (EU 60%; European Commission, 2007).
- 90% of Europeans think that the urban traffic is a problem.
AGENT-BASED MODELS

- ABM: a **computational method that attempts to model the complexity of social systems**. «It enables a researcher to create, analyse and experiment with models composed of agents that interact within an environment» (Gilbert 2008, p. 98).

- **Four elements:**
  - 1) an environment: set of objects
  - 2) a set of interactive agents
  - 3) a set of relationships linking objects and agents
  - 4) a set of operators that allow the interaction between the agents and the objects.

- **Bottom-up technique**: from the interactions of agents at individual level it is possible to observe the emergent properties of the whole system.

- **Possible application**: evaluation ex-ante or ex-post of the effects of possible or actual policies on the agents behaviour.
ABMs may be an effective tool

- to consider an **high number of stakeholders** with **heterogeneity of needs and interests**
- to investigate the agents’ interactions,
- to **simulate the complex system of urban mobility** and
- to **model complex planning problems**

Also considering the **heterogeneity of cities** in terms of geographical and urbanistic characteristics (possible integration of ABMs with GIS tool)
As regards **urban freight mobility**:  
- high fragmentation both of demand and supply of city logistics services  
- different Urban Supply Chains interact  
  => stakeholders act following their own goals, without any centralized control => often conflict arises  
  => low economic sustainability  
  => low environmental sustainability  
- Need to address systematically the organization of urban freight transportation
As regards **urban passenger mobility**:  
- Urban structures have complex transportation networks  
- The performance of each network is influenced by interactions among heterogeneous agents and interactions between agents and their environment  
- Each commuter is an autonomous agent with specific attributes and states  
- Overtime behavioural patterns emerge

Passenger and freight mobility strongly interact in urban areas on the same space and in the same time
RESULTS AND TAXONOMY OF THE REVIEWED WORKS – URBAN FREIGHT MOBILITY/1

- Few works focus on freight transport in urban areas.
- Authors agree on the validity of ABM to simulate the complexity of city logistics, trying to consider the single components as a part of a whole system.
- Some of them test policy measures, such as road pricing or urban distribution centres; others use the model in order to estimate transport demand and supply or to solve logistics problems (e.g. routing, scheduling).
Referring to the taxonomy, the main results are:

1. **Intention of the model**: different aims
2. **Variables**: stakeholders from the supply and demand sides of city logistics
3. **Geographic dimension**: mainly large urban areas
4. **Calibration on actual data**: the majority no
5. **Time horizon**: almost all strategic (in 2 cases also operational)
6. **Structure**: the majority dynamic
7. **Attitude**: all both cooperative and competitive (only 1 exception: cooperative)
8. **Maturity level**: conceptual proposals and simulated or field experiment
9. **Type of use of the agent system**: all decision support systems
<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Intention of the model</th>
<th>Variables</th>
<th>Geographic dimension</th>
<th>Calibrated on actual data</th>
<th>Time horizon</th>
<th>Structure</th>
<th>Attitude</th>
<th>Maturity level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anand et al. 2012</td>
<td>Design of an ontology</td>
<td>Economic drivers; Modal alternatives; Trans-shipment; Exports &amp; Imports, Shipment generation, Destination choice, Carrier and vehicle choice, Tour optimization</td>
<td>Oregon</td>
<td>Yes</td>
<td>Strategic &amp; operational</td>
<td>Dynamic</td>
<td>Both</td>
<td>Conceptual proposal</td>
</tr>
<tr>
<td>Donnelly 2007</td>
<td>Urban freight demand estimation and supply design</td>
<td>-</td>
<td>-</td>
<td>No</td>
<td>Strategic</td>
<td>Dynamic</td>
<td>Cooperative</td>
<td>Simulation experiment</td>
</tr>
<tr>
<td>Van Duin et al. 2012</td>
<td>Investigation on the impact of policy measures for the success or urban distribution centres</td>
<td>1 Type of trucks and freight carriers; 1 type of goods; 1 UDC operator; Retailers; Municipality; Roads; Streets; Nodes</td>
<td>-</td>
<td>No</td>
<td>Strategic</td>
<td>Dynamic</td>
<td>Both</td>
<td>Simulation experiment</td>
</tr>
<tr>
<td>Tamagawa et al. 2010</td>
<td>Model for vehicle routing and scheduling problem with time window-forecasted</td>
<td>5 kinds of actors with different objectives: Freight carriers; Shippers; Residents; Administrators; Motorway operators</td>
<td>-</td>
<td>No</td>
<td>Strategic</td>
<td>Dynamic</td>
<td>Both</td>
<td>Simulation experiment</td>
</tr>
<tr>
<td>Taniguchi and Tamagawa 2005</td>
<td>Evaluation of city logistics measures impacts on the stakeholders behaviour</td>
<td>Administrators; Residents; Shippers; Freight carriers; Urban expressway operators</td>
<td>-</td>
<td>No</td>
<td>Strategic</td>
<td>Dynamic</td>
<td>Both</td>
<td>Simulation experiment</td>
</tr>
<tr>
<td>Roorda et al. 2010</td>
<td>Development of a framework for a description of actor heterogeneity and interaction in freight system</td>
<td>Business establishments, firms and facilities; commodity production and business service facilities; logistics service facilities; End consumers Contracts; Commodity contracts</td>
<td>Toronto Area</td>
<td>Yes 2006</td>
<td>Strategic</td>
<td>Dynamic</td>
<td>Both</td>
<td>Conceptual proposal</td>
</tr>
<tr>
<td>Teo et al. 2014</td>
<td>Evaluation of the short-term impact of distance-based road pricing on the major urban stakeholders</td>
<td>Carriers’ profit and cost, shippers’ cost, distance travelled by trucks, n. of trucks, n. of customer complaints, nitrogen oxide, NOx, carbon dioxide, CO2, suspended particulate matter</td>
<td>Osaka road network</td>
<td>No</td>
<td>Strategic and operational</td>
<td>Dynamic</td>
<td>Both</td>
<td>Simulation experiment</td>
</tr>
</tbody>
</table>
RESULTS AND TAXONOMY OF THE REVIEWED WORKS – URBAN PASSENGER MOBILITY/1

- Higher number of works with respect to freight transport domain, but still few
- Most of them deal with a specific sub-category of citizens (university commuters, work commuters, pedestrian)
- Some ABMs test policies that improve services
- Other ABMs test policies that provide incentives for the agents to modify their behaviour
Referring to the taxonomy, the main results are:

1. **Intention of the model**: different aims
2. **Variables**: features of the agents, monetary aspects, information on travel time
3. **Geographic dimension**: whole cities or some neighborhood only
4. **Calibration on actual data**: the majority yes. Use of GIS.
5. **Time horizon**: all strategic
6. **Structure**: dynamic with two exceptions
7. **Attitude**: the majority only competitive (1 only cooperative and 1 both)
8. **Maturity level**: conceptual framework and field experiment
9. **Type of use of the agent system**: all decision support systems
<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Intention of the model</th>
<th>Variables</th>
<th>Categories of people</th>
<th>Geographical dimensions</th>
<th>Calibrated on actual data</th>
<th>Time horizon</th>
<th>Structure</th>
<th>Attitude</th>
<th>Maturity level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maggi and Miller 2005</td>
<td>Simulation of the evolution of an integrated urban system over an extended period of time.</td>
<td>Demographic features; Transportation nodes and links; Travel times; Buildings; Location; Monetary values.</td>
<td>City inhabitants</td>
<td>Greater Toronto Area, 5,700,200 inhabitants</td>
<td>Yes-Year not specified</td>
<td>Strategic</td>
<td>Dynamic</td>
<td>Both</td>
<td>Field experiment</td>
</tr>
<tr>
<td>Shulda et al. 2013</td>
<td>Predict university commuter behaviour and its impact on the transportation system.</td>
<td>Demographic features; Info on the role in the campus; Travel time.</td>
<td>University commuters (students and staff)</td>
<td>Wollongong Campus, New South Wales, Australia</td>
<td>Yes 2011</td>
<td>Strategic</td>
<td>Dynamic</td>
<td>-</td>
<td>Conceptual framework</td>
</tr>
<tr>
<td>Benenson et al. 2008</td>
<td>Development of a model for parking space supply.</td>
<td>Destination of the drivers; Search time; Walking distance; Parking costs.</td>
<td>Inhabitants searching for parking</td>
<td>District of Tel Aviv, Israel</td>
<td>Yes 2005-2006 GIS</td>
<td>Strategic</td>
<td>Static</td>
<td>Competitive</td>
<td>Field experiment</td>
</tr>
<tr>
<td>Henderson and Stillwell 2007</td>
<td>Simulation of daily pupil movements between schools and residences for planning support systems.</td>
<td>To be defined. Data are about school rolls; commuting distances; pupil mobility; residential migration; pupil gender, pupil ethnicity.</td>
<td>Commuting to school, residential migration and movement between schools</td>
<td>Leeds, England, 700,000 Inhabitants</td>
<td>Yes 2002-2007</td>
<td>Strategic</td>
<td>-</td>
<td>-</td>
<td>Conceptual proposal</td>
</tr>
<tr>
<td>Lu et al. 2008</td>
<td>Development of a simulation model to study the impact of land use regulation scenarios on transit use for work and</td>
<td>Metropolitan rail lines, Employment distribution; Residential location; Household income;</td>
<td>Work travel behaviour and Urban Form</td>
<td>Inspired to the Cook, DuPage, Kane, Lake, McHenry, Will Counties of Chicago, USA</td>
<td>YES GIS</td>
<td>Strategic</td>
<td>Dynamic</td>
<td>Competitive</td>
<td>Field experiment</td>
</tr>
</tbody>
</table>

| urban form                        | Household size; Car ownership; Age; Gender | 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 |
| Schelhorn et al. 1999             | Investigating pedestrian behaviour in urban centres. Pedestrian movement is influenced by attractions' configuration and location | 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 |
| Smith et al. 1995                 | TRansportation ANalysis SIIsulation System (TRANSIMS) as integration of transport system with environmental analysis | Socio-economic characteristics; Economic activities | Commuting choices | USA: various cities | Yes 2009 | Strategic    | Dynamic   | Cooperative | 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 |
**Conclusions**

- Effort to develop ABMs for people or freight transport analysis increased in the last years.
- Their success is due to their capability to represent complex interactions, the diversity and the variability of urban transport mobility and system.
- Policy makers often fail in capturing problems at the roots of passengers and freight mobility. ABM can give an important contribution to fill in this gap.
- However, there is still a gap in ABM urban transport modelling.
- Most of ABMs dealing with freight consider regions broader than urban areas only.
- ABMs dealing with passengers mobility in urban areas are more numerous, but their number is still limited. Focused on sub groups of citizens.
FURTHER RESEARCH NEEDS

- Few papers calibrate the model on real data. The heterogeneity of categories of actors makes difficult and expensive real surveys for calibration of the ABM on first-hand data.
- Only an empirical work (TRANSIMS model) tries to integrate freight and passengers mobility (Smith et al 1995).
- The most useful frontier is the development of ABMs that integrate passengers and freight dimensions. => any public policy inevitably influences both spheres.
**NEXT STEPS OF OUR RESEARCH**

1. To develop an agent-based model for simulating urban passenger mobility
2. To extend this model to include the urban freight flows
3. To study the interaction between passenger and freight mobility in urban areas and text some public policies
THANK YOU FOR THE ATTENTION!

elena.maggi@uninsubria.it