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Reviewing Software for Agent-based Bicycle Flow Models

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Abstract

Agent-based models are able to simulate traffic flows and reveal emergent phenomena which tend to remain hidden in traditional traffic modelling frameworks. Until now Agent-Based Modelling has primarily been employed to simulate bicycle traffic flows at a local level, but hardly ever at a regional level. The present review examines the suitability of available agent-based platforms for modelling bicycle traffic flows at regional level, outlining the requirements for doing this. From a wide range of available tools, we considered GAMA, NetLogo and MATSim for an in-depth evaluation.

Keywords:

bicycle traffic flow, agent-based modelling and simulation, agent-based platforms

1 Introduction

Although cycling accounts for a growing share of (urban) traffic, data on origins and destinations as well as on flows are sparse, and it is not currently possible to derive valid cycling flow data at the level of road segments from existing data. Consequently, although cycling is heavily promoted in many cities and regions, we do not know how many cyclists are on the roads, where or when (Steenberghen, Tavares, Richardson, Himpe, & Crabbe, 2017). Until recently, detailed cycling flow models did not exist for cities and regions. Major reasons for the lack of models are the heterogeneity of cyclists and the difficulties in predicting mobility and cycling behaviour (Damant-Sirois, Grimsrud, & El-Geneidy, 2014).

Agent-based simulation models (ABM) offer a unique opportunity to consider individual agents with their own demands, preferences, activity schedules and behaviour (Bazzan & Klügl, 2013). By instructing the model with simple movement rules at agent level, the model is able to explain phenomena at a higher system level (Manzo, 2014). Thus, an ABM produces emergent traffic flows based on relationships between numerous heterogeneous agents, and on individual choices made by travellers that rely on probabilistic decision rules (Manzo, 2014). Although the ABM approach seems to be advantageous in transport modelling, there are still limitations. Bazzan and Klügl (2013) identified scalability as a major challenge for agent-based software, which has difficulties handling large-scale traffic flow scenarios. Additionally, there are limited ways to test the cycling model for credibility due to insufficient validation data (Bazzan & Klügl, 2013). Another challenge is computational power, since cycling models may include heavy spatial data (Crooks & Castle, 2012). Lastly, due to a lack of adequate input data, ABM has rarely been employed for modelling cycling flows at the city or regional scale. Exceptions are Wallentin & Loidl (2015), Leao & Pettit (2017), and Ziemke, Metzler, & Nagel (2017). In the near future, with the increasing demand for high-quality traffic flow data, thanks to the growing availability of input data and computational improvements, it can be expected that more agent-based simulation models for cycling flows will appear.

In this paper we aim to provide guidance for the choice of suitable platforms for modelling cycling flows and to establish the criteria for a future benchmarking test. The objectives of this study are to examine the most important ABM platforms and to define quantitative evaluation criteria, in order to identify a set of not more than three candidate platforms for further analysis. In future research, we plan to implement a reference model using these platforms to compare in detail their suitability for bicycle flow modelling using the defined list of criteria.

2 Evaluation of ABM platforms

To assess the suitability of different ABM software tools for bicycle flow modelling, we identified a set of nine evaluation criteria and drew up an evaluation scheme (Table **1**). The selection of these criteria was based on the requirements of bicycle flow modelling, and on findings in the literature on lessons learned in applied research projects (Abar, Theodoropoulos, Lemarinier, & O'Hare, 2017; Berryman, 2008; Braubach, Pokahr, & Lamersdorf, 2008; Kravari & Bassiliades, 2015; Nikolai & Madey, 2009; Railsback, Lytinen, & Jackson, 2006).

Adapting the comprehensive list of evaluation criteria for ABM modelling platforms offered by Abar et al. (2017) and Kravari and Bassiliades (2015), we picked the following criteria for our study: platform purpose, licence, integrated development environment (IDE), performance, language and user support. We also added spatial capabilities, visualization and platform maintenance to our final list. These criteria are briefly discussed below:

- Platform purpose – ensures general and domain-specific functionalities and flexibility;
- Licence – ensures availability, transparency, extensibility;
- Model development effort – a decisive feasibility factor in terms of the effort needed for developing a new model;
- Integrated development environment (IDE) – provides functionalities of coding, debugging and running models;
- Performance – high performance is particularly important in transport models to represent an agent's complex, adaptive behaviour during daily activities, their choice

of transport mode, and route preferences during a simulation. This micro-level behaviour of individual cyclists depends on the one hand on the agent's response to environmental conditions (e.g. season, weather, quality of road surface), and on the other hand on the presence and behaviour of other road users;

- Spatial capabilities – ensure the implementation of cycling behaviour, which requires spatially explicit representation of networks (Batty, Desyllas, & Duxbury, 2003);
- Output visualization – facilitates verification of output and understanding of model behaviour;
- Platform maintenance – regular software updates beyond mere bug-fixing, that constantly enhance functionality and usability.

Table 1: Evaluation criteria of ABM software

Evaluation criteria	Parameter values	Minimum requirements
Purpose of platform	Single- and multipurpose	Single- and multipurpose
Spatial capabilities	Support for loading common vector and raster formats and graphs, spatial database support, support for geovisual analytics	Essential asset
Performance	Initialization and simulation execution time, maximum size of model	Platform needs to support realistic scenarios in virtual world
Model development effort	Days needed to implement the benchmark model	Easy-to-learn modelling languages preferred
Software licence	Open-source/closed-source, free/proprietary	Restricted to open-source licences
IDE	Error tracking, code colouring	Essential asset
Output visualization	Maps, graphs	Advanced data visualization functionality preferred
Platform maintenance	Number of active developers, frequency of software updates, size and activity of user community	Only platforms under active development considered
User support	Code documentation, tutorials, model library, user forum	Must-haves: code documentation, tutorials, model library, user forum

Following the minimum requirements stated in Table **1**, we reviewed 85 agent-based modelling tools recently addressed by Abar et al. (2017). The first criterion, *purpose of platform*, identifies almost all tools as potentially relevant for traffic flow models. As an essential criterion, *spatial capabilities* reduces the number of potentially relevant tools significantly. To the list of twelve geospatial ABM tools (Cormas, Envision, GAMA (2D/3D), Insight Maker, MATSim, OBEUS, Pandora, Repast-J/Repast-3, Repast HPC, Repast Simphony (2D/3D), SOARS and TerraME) examined by Abar et al. (2017), we added NetLogo, because of its built-in GIS extension. However, based on our nine evaluation criteria (as described in Table 1), we excluded ten of Abar's software tools, thus narrowing the potential modelling tools down to GAMA, NetLogo and MATSim. So far NetLogo (Wallentin & Loidl, 2015) and MATSim (Ziemke et al., 2017) are the only agent-based platforms that have been used for modelling bicycle traffic flow. In addition, we have developed a bicycle traffic flow model using the GAMA platform in the context of a research project that is ongoing.

NetLogo

NetLogo (Wilensky, 1999) is an open-source modelling environment for the implementation of agent-based models and cellular automata. Aimed at students and researchers without prior programming skills, NetLogo follows Logo's vision of providing a language with a 'low threshold' for novice users and 'no ceiling' for expert modellers (Papert, 1980). Russell and Wilensky (2008) developed a GIS extension based on the software My World GIS (https://myworldgis.org/) that offers core capabilities for spatial data handling and analysis, including reading and writing of vector and raster data, conversion between multiple coordinate systems, spatial analysis and geovisualization. The GIS functionality is complemented by a network extension that provides a large set of network analysis tools. However, NetLogo does not natively support geospatial objects, but handles the vertices of the street network as agents, a process which uses an excessive amount of memory space and thus greatly impacts network models.

MATSim

MATSim (Multi-Agent Transport Simulation) is an open-source framework for modelling agent-based transport simulations. It is able to simulate large transport systems with millions of agents. In MATSim, agents are aware of the environment. They learn from their experience and re-plan their routes, departure times and modes to an optimum (Horni, Nagel, & Axhausen, 2016). Furthermore, this platform aims at high computational performance by implementing parallel computing (Dobler, 2013); it uses the Java language and thus requires programming experience. Since standard Java IDEs do not visualize data, MATSim uses extensions and stand-alone software for output visualization.

GAMA

GAMA (GIS & Agent-based Modelling Architecture) is an ABM platform that is designed to simulate models in a geographic environment (Taillandier, Vo, Amouroux, & Drogoul, 2012). The comprehensive spatial data handling capabilities are provided by using GIS software libraries, which allow the software to natively operate with geographic data formats. Models are designed in an Eclipse-based IDE with the help of the relatively simple, domain-specific language GAML. GAMA's data visualization capabilities allow planar and oblique map views, as well as the dynamic display of variable values, graphs and charts (Grignard et al., 2013).

3 Discussion and conclusions

This paper provides an overview of existing agent-based platforms in order to support mobility researchers in the selection of ABM software. Three potentially adequate software environments were identified according to a set of nine evaluation criteria: MATSim, GAMA and NetLogo. Each of these has its strongpoints and disadvantages with respect to the given purpose.

- Modellers who are experienced Java programmers and who want to use established frameworks of activity schedules will probably be best supported by the single-purpose tool MATSim.
- Modelling novices who want to gain initial experiences in model development will find NetLogo to be a useful platform for developing medium-sized models. Especially if aspects beyond simple movement from A to B are to be included, this general-purpose software is a reasonable choice. However, as it does not natively support graph data formats, large street networks will soon push the software to its performance limits.
- Modellers who aim to work with geographic data of different formats and want the flexibility of a general-purpose software will enjoy the extensive capabilities for spatial data handling of the GAMA modelling platform. This spatial focus makes it a recommendation for transport modellers with a background in geography especially.

In order to be able to provide conclusive software recommendations, further research, based on a single reference model, will be directed towards a more comprehensive and quantitative comparison of the potentially suitable software environments. Such an investigation in the context of a research project on modelling bicycle traffic flows for an entire city and its surrounding municipalities is planned. The reference model will implement spatial data handling, spatial operations, interactions with the environment, and the dynamic visualization of the model's outputs.

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