Data-driven agent-based model development to support human-centric TOD design*

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Abstract. This paper proposes an agent-based simulation model of an urban environment to evaluate alternative transport-oriented development (TOD) designs for infrastructure proposals prepared by urban planners. The model is tested by the students as model users, and the generated model output on the use of the city infrastructure, occupancy of public space and key data around the pedestrian and vehicle movements results can be translated to design modifications. A particular challenge with this approach is the inclusion of realistic data for the behaviour of the transport system users. To this end, an experiment was conducted in which data on the individual behaviour and activities was collected, which could be integrated in the simulation model to capture realistic responses to TOD proposals. Illustrative results are shown, demonstrating the model can produce results that are meaningful to planners, but also highlights the role of agent-based simulation models to steer the data collection process and engage with decision-makers.

Keywords: TOD, agent-based model, data collection, decision-support tool.

1 Introduction

The issue of integrated design of transit stations and affiliated urban areas such as transit-oriented development (TOD) have gained increasing attention worldwide [1]. The design of a new generation TOD emphasizes improving access to active travel and high-quality public spaces to promote human comfort [2]. To appraise whether a planning scenario achieves such improvements, there is a need for urban design support tools for studying the impact of different design scenarios and examining how people use the infrastructure and public space under different design alternatives. Agent-based

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modelling (ABM) is a suitable modelling methodology to create a heterogeneous population with activity patterns which lead to transport decisions (including mode, route, time) for a given environment and infrastructure options. Collectively, the individual decisions lead to insights on key indicators that can support planners in evaluating different alternatives and ensure new developments are attractive, efficient for users but also meet sustainability and economic targets. One of the challenges for ABM applications in this domain is how to build data-driven models and explore human behaviour.

Model development itself can help guide data collection [3] by showing what data is required to test a theory. Moreover, models can often be built as generic frameworks which are then instantiated for a specific case study by providing relevant case-specific input data. The ODD protocol specifically refers to this as "initialisation" and "input data" to describe part of the model [9]. However, there remains several methodological challenges, for example, in collecting data that matches the specification of the model, linking data sets together, analysing the data to extract significant drivers and behaviours [4], deriving agent-rules from data, and integrating human-environment models [5]. Kagho et al. highlighted that "the data collection process is one way error can be introduced into the model" and data bias (e.g. introduced by preference surveys) could cause bias in models [6].

This paper therefore aims to: 1) build a data-driven ABM decision-support tool for urban designers, especially in designing and evaluating people-centric TOD plans; and 2) discuss the role of data in the development of the urban simulation model, and the use of output data to help influence decision-making in a case study in Nanjing, China.

2 A prototype ABM

To meet these aims, we firstly developed a prototype model "Transport, Spaces, and Humans-system (TSH-system)" and implemented the model in the GAMA platform (documented in https://gama-platform.org/wiki/Projects). Fig.1 shows the model interface. The model was built as a generic framework to support students and practitioners in urban planning and design, architectural design, and other fields to analyse urban systems and to quantitatively evaluate design schemes [7, 8]. It allows the simulation of private car drivers and pedestrians for a given TOD plan to predict the usage of the space and relevant activities, as well as automobile travel demands, active travel demands, and transport mode choices.

Input data includes GIS files (land use, walking routes, and driving road network), population statistics (e.g. density), activity patterns, walking and driving speeds, mode choice parameters (e.g. weight of money cost in mode choice), personal parameters (e.g. shoulder width), and pedestrian parameters (e.g. the repulsive force in social force model). The model then outputs hourly data in terms of users over the urban space (occupancy/dwelling time), automobile traffic volumes and pedestrian population on each road segment.

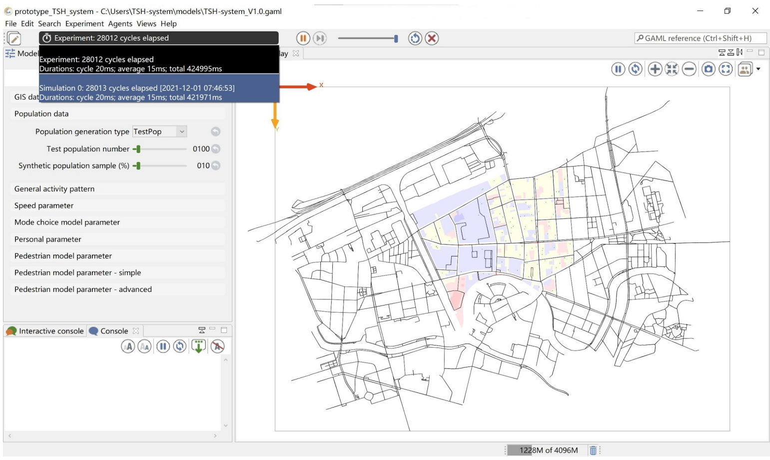

Fig. 1. Interface of the TSH-system model

3 Case study

The model was tested in a regular MSc course at the School of Architecture in Southeast University, China, which attempts to explore the future development model of the surrounding plots of transit stations [8]. This year, a case study was conducted in Shanghai, China (see Fig.2). Research site is located at plots X101-01 and X102-02 of Shanghai West Railway Station. It is not only the location of the Shanghai West Railway Station, but also a transfer station of Metro Lines 11, 15 and 20; thus, it is an important hub for the local and wider area.

Students conceived their designs based on a primary aim, for instance, to improve spatial orientation and wayfinding, to combine two grid road systems, and to create a high-quality microclimate. To test the effectiveness of their plans, they changed the GIS input files in terms of the land uses, activities, road network and pavement network, and ran the simulation model for their scenario. The model then presents hourly number of users in urban spaces, traffic volume over the road network, and walking demands across the pavement network which provided the designers with relevant metrics to help them revise their plans iteratively.

4 Data collection and initial results

The GIS data was based on a baseline of the built environment, with the modifications and designs prepared by the user as part of their proposed intervention. In addition to the spatial data, agent-behaviour data was required to enable a user to simulate the use of the urban system. To collect relevant behavioural data, an experiment was set up for which 30 participants (10 are students from the MSc course and 20 are volunteers) were recruited. It was conducted in Nanjing city in China. The experiment aims to explore the pedestrians' walking behaviour in affiliated areas of rail transit stations as well as the impact of the design of such areas (underground/semi-underground/open outdoor space) on their behaviour, cognition, and comfort. Each participant visited the different spaces of three subway stations and one railway station freely for 10 minutes while being monitored.

The ErgoLAB human-machine environment platform and a series of wearable physiological recording modules were used to collect and analyse multi-dimensional human factors data synchronously. The factors of time-space trajectories, electroencephalography, eye movement, electrodermal activity were investigated. Activity pattern data was collected by a survey. For the first step of building data-driven ABM, we will extract features of pedestrians' walking behaviour from the time-space trajectories including for example the movement direction angle.

By using the TSH-system agent-based model, Fig.3 shows the initial results of simulating the number of users of each urban space (darker blue plots means a higher amount of people) and walking behaviour (darker green lines means heavier traffic) for the baseline scenario, simulating how users would interact with the current TOD layout.

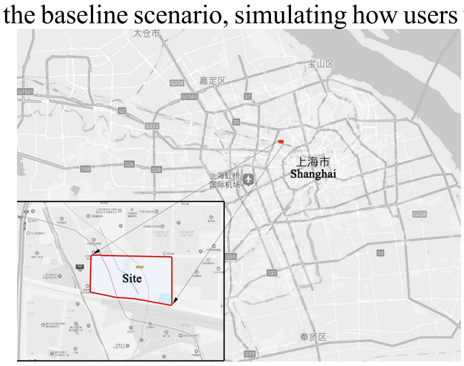

Fig. 2. Location of the case study site in Shanghai city, China.

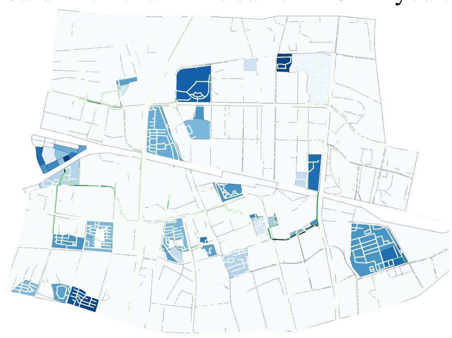

Fig. 3. Baseline scenario simulation of walking behaviour: the blue plots show the number of users per hour in a workday; the green lines show the traffic volume over the walking network.

5 Discussions and conclusion

These initial results illustrate the potential of enriching the prototype TSH-system model with the data from the experiment to generate more reliable output for evaluating a given design. This enables designers to compare alternatives for the physical design of TOD projects for a given population. Besides, the time-space trajectories, physiological, and psychological data we got matches the specification of the model, that is, simulating human behaviour in the public spaces around transit stations. Also, the way of collection was designed to avoid data bias by not only delivering surveys but also recording individual behavioural data using wearable physiological recording devices.

To incorporate the collected data into the model, we are analysing the data to extract significant drivers of individual behaviour in the TSH system and derive agent-rules. As always with such complex systems, there is uncertainty around key input parameters especially when these are based on an analysis of human behaviour. In the next stage of this project, using sensitivity analysis, we can test the impact of these parameters on the final result and use that to guide design updated data collection strategies and experimental setup. For TOD this specifically refers to mode choice and journey purpose, but also the agent's views on the quality and attractiveness of the space.

There are, however, some challenges in developing data-driven ABM. For example, it is time-consuming to prepare and cleaning the GIS files before integration with agent-based models. Standardisation of data formats, quality checks, and scaling up data to population level are also challenging issues. To this end, we aim to integrate this work with a geospatial data platform to take advantage of other relevant datasets (e.g. on the environment), linking this with the simulation model, and to presenting simulated data in the platform, providing a coherent picture to key decision-makers.

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