Multi-level Agent-Based Simulation for Supporting Transit-Oriented Development in Beijing

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Abstract. Planning new transport infrastructure that is integrated in the wider urban environment is key to promote use of public transport and other greener modes, while also ensuring high quality of public space around transport nodes and links. This work presents a multi-level approach to provide decision-support using a simulation model of a city neighbourhood combined with a more detailed model of a small scale area around a new development site. By linking these two models scenarios can be explored which take into account urban planning and the effect of long-term changes in a city on a detailed design for one particular location. A model in Repast Simphony covers the land-use and transport infrastructure in a district, while a NetLogo model simulates pedestrian movement. This is applied to a case study in Beijing, China, with preliminary results showing the potential of this approach to introduce this style of modelling to architects and urban planners.

Keywords: transport system, pedestrian modelling, agent-based model, TOD

1 Introduction

Although car-oriented development has stimulated urban expansion, it has generated a large number of negative spaces affiliated with transport infrastructures and resulted in fragmentation of the urban fabric. Similarly, rail infrastructure can lead to poor quality urban space if it does not take into account the wider area. Integrated Land Use and Transportation planning, infrastructural urbanism, and Transit-Oriented Development (TOD) have gained worldwide attention. Initially promoted by urban planners as a basic principle of New Urbanism, the TOD strategy aims at encouraging individuals to use public transit in preference to private vehicles and complementing public transport with non-motorised travel for shorter distances [7]. Recently, urban researchers and practitioners have realised the need to consider a wide range of spatial scales, multiple transport modes and people-oriented public spaces design in developing successful TOD [4]. Moreover, urban and transportation planning, urban design, and architecture design are co-dependent processes, meaning that the decision of high-level planning could have direct impact on lower-level urban and building designs (and vice versa). Therefore, employing a holistic approach that arises from a negotiated, multi-scale, and proactive style of design is of great importance.

Simulation tools can support this decision-making process by assessing various planning and policy alternatives against a range of performance indicators. Urban models, in particular agent-based models, are powerful in testing different configurations of an urban system to support decision-making [5]. Agent-based modelling can reflect the behaviour of the people in the environment linked to land use and availability of transport infrastructure [6]. Simulating navigation of humans among other users in different environments is key to assure safety and comfort in a cost-effective and efficient manner before real-world implementation. For instance, studies on simulating emergency passenger train designs and conditions play a crucial role in identifying challenges in evacuation scenarios, offering possible solutions, and ultimately saving lives of passengers [13]. With the introduction of innovative urban design such as shared spaces, beside replicating collision-free navigation among other users, the importance of understanding socio-psychological interactions between road users for predicting road users trajectories, estimating flow and density relationships has been highlighted, achieving solutions for the optimal design of a new area before implementation [14]. In [10] such pedestrian models are compared with data from controlled experiments. Instead of building massive and highly detailed agent-based models of urban systems, Perez et al. [15] suggested "developing modular architectures that can host complementary modelling paradigms in different and fit-for-purpose modules".

Despite a growing body of literature on modelling the interactions between transport, urban spaces, and humans, there is limited research on multi-level simulation for TOD. This paper aims to integrate the high-level land-use and transportation modelling with micro-level pedestrian modelling in areas around public transport hubs. There are two ways of model integration (also known as model coupling), i.e., schema integration and process integration [1]. In this work, the latter approach will be used: the output of one model is an input for another. In earlier work we analysed the impact of transportation and public space designs on local air quality and micro-climate condition [2, 3], and others have demonstrated similar approaches (e.g., [9]). This paper introduces a pedestrian simulation model which receives input from an agent-based model of the wider city, applied to a case study in Beijing.

2 Methodology

The multi-level approach uses two models, as follows:

1. **Macro-level**: Simulate private car and public transport travellers' behaviour in transportation network – land use systems at an urban district scale, by adapting a Smart-City Model implemented in Repast Simphony.
2. **Micro-level**: Simulate the movement of pedestrians around a public transport node. Agent-based modelling is performed in NetLogo by adapting the pedestrian_floor-2exits-usepath model [11, 12].

The output of subway station areas' occupancy over time from the macro-level will be used to generate pedestrian agents within and around transit hubs in a micro-scale simulation, as it reflects the number of people entering and leaving this location as an effect of its position and function within the wider urban environment. The output of the micro-level model then provides insights in the throughput and dwelling time of the transport system.

2.1 Macro-level modelling

In the macro-level model, firstly, the status quo of the road network, subway system, and land use is represented at a self-defined sampling segment in QGIS. Linking to the GIS data, the Smart-City model then generates a heterogeneous synthetic population based on the socio-demographic data from the 6th population census of Beijing and the public transport statistics in 2018 Beijing transport annual report. Afterwards, the agents travel for a workday, following their activity patterns, selecting destinations, and determining the time spent on different types of land uses. These lead to the output of individuals' arrival and departure times in public transit stations.

2.2 Micro-level modelling

The micro-level model selected here is a simple model of pedestrian movement compared to the more detailed models reviewed above. One reason for choosing such a model is for education purposes, as it allows users with little modelling experience to understand the code and even adapt it to their needs. In the 2019 and 2020 ABM summer school held at HZAU in Wuhan, China, the authors explored different ways of teaching agent-based modelling to beginners, finding that using and extending an existing model is a powerful tool for instilling simulation techniques to students. Moreover, this model is a good demonstration of linking CAD representation, as often used by urban planners and architects, with an agent-based simulation.

3 Case study and results

Beijing Subway FANGSHAN Line is located in the south-west Beijing. At present, this Line is being extended to the north and Sihuanlu station is a new subway hub. Being surrounded by residential buildings, a hospital, a school, and commercial centres, station areas planning should consider the distribution of land uses and non-motorised transport network, in line with the design of public spaces. Along these lines, we chose an area within a radius of 2.5km from the subway hub for macro-level modelling (see Figure 1, left). Afterwards, we zoom in to an area within a radius of 500m from the subway station, as depicted in Figure 1 (right). Figure 2 shows a snapshot of the micro-scale pedestrian modelling in the station area in NetLogo.

Having simulated the baseline scenario, different urban design alternatives are tested and assessed to compare different accessibility and walkability of the road networks, kinds of designs of the public spaces, and multiple land use redistributions.

4 Concluding remarks

The case study results show how model integration can give valuable insights in the impact of design choices on TOD, in a way that is accessible to not only computer scientists, but especially to architects and urban planners who typically do not have experience with such agent-based models. Preliminary model results demonstrate that relevant output can be generated for a range of scenarios, including changes in the design and the function of the TOD within the district. These scenarios will be presented and discussed in more detail at the ABMUS2021 workshop and in the full paper, with a particular emphasis on the link between the multiple simulation levels. Next steps in our research are to combine this with the air quality and thermal comfort results of other micro-simulation models [2] to study the impact and exposure of pedestrians, which might again influence their behaviour at the macro-scale and could support further revision of sustainable master plans and the design of transit networks.

Fig. 1. Case study: the micro-level site (left) and the macro-level site (right). The yellow dot indicates the station, the red dash is the subway line, & red tracts are commercial land uses.

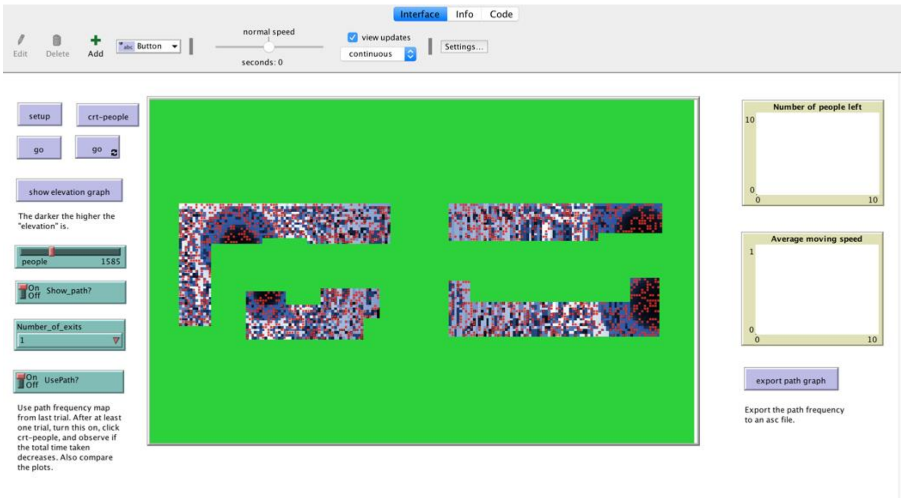

Fig. 2. A snapshot of the building-human system modelling in NetLogo, adapted from [11].

References

[1] Dolk, DR, Kottemann, JE. Model integration and a theory of models. *Decision Support Systems*, 1993, 9: 51-63.

[2] van Dam, K.H. Yang, L., Xiao, D., (2019) Combining an activity-based urban transport model with air turbulence flow simulation to analyse the impact of traffic on air quality, presented in the *4th International Workshop on Agent-Based Modelling of Urban Systems 2019*.

[3] Yang, L., Zhang, L., Stettler, M.E.J., Sukitpaneenit, M., Xiao, D., and van Dam, K.H. (2020) Supporting an integrated transportation infrastructure and public space design: A coupled simulation method for evaluating traffic pollution and microclimate. *Sustainable Cities and Society*, 52. https://doi.org/10.1016/j.scs.2019.101796

[4] Yang, L., van Dam, K. H., Majumdar, A., Anvari, B., Ochieng, W. Y. and Zhang, L. (2019). Designing integrated transport infrastructure and public space plans while considering human behaviour changes: A review of state-of-the-art concepts, methods, and tools. *Frontiers of Architectural Research*, 8(4). https://doi.org/10.1016/j.foar.2019.08.003

[5] Law, A. M., & Kelton, W. D. (1991). *Simulation modeling and analysis* (2nd ed. Vol. 2). New York: McGraw-Hill.

[6] Batty, M. (2009). Urban modeling. *International Encyclopedia of Human Geography*. Oxford, UK: Elsevier.

[7] van Dam, K. H., Nikolic, I., & Lukszo, Z. (2013). *Agent-Based Modelling of Socio-Technical Systems*, Springer.

[8] Congress for the New Urbanism. 2000. Charter of the New Urbanism. *Bulletin of Science, Technology & Society* 20 (4):339-341.

[9] Hatzopoulou, M. and Miller, E.J., 2010. Linking an activity-based travel demand model with traffic emission and dispersion models: Transport's contribution to air pollution in Toronto. *Transportation Research Part D: Transport and Environment*, *15*(6), pp.315-325.

[10] Hoogendoorn, S.P. and Daamen, W., 2007. Microscopic calibration and validation of pedestrian models: Cross-comparison of models using experimental data. In *Traffic and Granular Flow'05* (pp. 329-340). Springer, Berlin, Heidelberg.

[11] Crooks, 2018, Pedestrians Exiting Building model in NetLogo, available online from https://github.com/abmgis/abmgis/blob/master/Chapter06-IntegratingABMandGIS/Models/Pedestrians_Exiting_Building/pedestrian_floor-2exits-usepath.nlogo

[12] Crooks, A., Malleson, N., Manley, E. and Heppenstall, A., 2018. Agent-based modelling and geographical information systems: a practical primer. SAGE Publications Limited.

[13] Anvari, B., Nip, C.K. and Majumdar, A., 2017. Toward an accurate microscopic passenger train evacuation model using MassMotion.

[14] Anvari, B., Bell, M.G., Angeloudis, P. and Ochieng, W.Y., 2016. Calibration and validation of a shared space model: case study. Transportation Research Record, 2588(1), pp.43-52.

[15] Perez, P, et al. 2017. Agent-Based Modelling for Urban Planning Current Limitations and Future Trends. In: Agent Based Modelling of Urban Systems.