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Agent-Based Models in Transport Planning: Current State, Issues, and Expectations

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Abstract

Agent-Based models have come to be known as powerful techniques for solving complex questions that arise from understanding human behavior. In this paper, we present an overview of agent-based models and its application to the field of transport planning, and discuss the challenges needed to be overcome for the further growth of agent-based modeling in the field of transport.

Keywords: Agent-Based Models; Travel Behavior; Transport Planning;

1. Introduction

Today's transportation system in our society is made up of complex large-scale interactions that are driven by partly unpredictable behavior of travelers as they interact among themselves and with their dynamic environment, in a bid to get from one place to the other. Agent-based systems provide an appropriate method to model such complexity. Originating in the field of computing systems, they are systems where agents, representing software entities within their environment, independently perform their duties while interacting with other agents [29]. In order to understand the behavior of a 'single cognitive entity' better [27], they are seen as great means of developing distributed complex systems where these systems are broken down to the level of agents driven by their activity constraints, in order to solve a particular problem [8]. Other research communities seeing similarities in the problems that agent-based systems were solving in the field of computing, adopted similar approaches to modeling that could solve problems in their respective fields. This has led to the expansion of agent-based models across various fields from Psychology to Transport Planning. The advent of agent-based transport models brought with it the ability for transport planners to model the nature of travel behavior and be able to test decisions that could directly impact travelers.

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Chen and Cheng [8], gave an overview of the pioneering work of agent-based models in traffic and transportation system. Nagel and Marchal [22] gave an overview of agent-based models also referred to as multi-agent simulation for transportation networks. Helbing and Balietti [15] gave a general review of agent-based modelling in social and economic systems underscoring its importance in understanding human behavior and interactions. Here, the general advantages of agent-based models and the steps for multi agent simulations have also been outlined with an example of transport planning. This paper thus extends these works by reporting the recent progress of agent-based models in the transport field and pointing to possible future directions. The many years that have passed have brought with them changes in how agent-based models are being applied in the transport field. The introduction of new techniques due to the growth of computational abilities and the nascent problems arising from general technological development leave many challenges to be solved. This paper further seeks to review the challenges needed to be overcome by agent-based models to still be relevant for future transport planning.

The remainder of this paper is divided into the following sections. Section 2 gives an overview of agent-based models in transport planning, section 3 briefly highlights the popular tools that are used for the simulation of these agent-based models, from small scale agent-based simulations to large scale multi-agent simulation. Section 4 discusses the challenges facing agent-based models and section 5 concludes with a perspective on future expectations.

2. Agent Based Models in Transport Planning

In this paper, we focus on agent-based models in transport planning. These are defined here as models providing a microscopic representation of travel decisions of individuals as they move from place to place. These models reveal the behavior of individuals (agents) as they interact with other agents and the environment, and the implications of their interaction in the transportation system. Before delving deeper into agent-based models, it is best to give a brief overview of why it is important for today's transport planning.

Transport planning saw a change in the 1950's with the development of the 4-step transport model [9], which is still relevant today. The classic 4-step model provides transport planners with an aggregate traffic flow representation, which is then used to recommend policies such as road expansions, introduction of tolls, etc. However, the complexities faced in the transport networks and the objectives of transport planning have changed over time and with it, the need to better understand travel behavior at a microscopic scale. These changes include the shift in focus from expanding transport infrastructure to the current focus on travel demand management [12], especially with the introduction of new transport modes and technology such as autonomous vehicles, urban air mobility, route guidance technology, mobility as a service (MaaS) applications, etc.

There is an increasing need to develop models that can answer questions such as: how to promote cooperation in road networks to achieve system optimum on already existing transport networks [18] [20]; how to reduce vehicle emissions [11]; how to meet growing demands while efficiently and effectively using existing infrastructure [31]; how to evaluate possible equity effects that could come with policies such as road pricing [13]; how to optimize transport policies to cater for new modes of transit such as autonomous vehicles, urban air mobility, ridesharing, e-bikes, etc. [24] [4] [11] [25]; how best to resolve first-mile last-mile access problem [30]; and many more questions that are springing up in the research community. These questions point to the need of understanding the behaviors of travelers; their detailed trip attributes and sensitivity to the transport system. The classic 4-step model does not capture how most travelers behave due to its nature of modelling aggregate data (space, time and travelers). Moreover, aggregate data cannot clearly define the behavior of travelers [7]. The use of aggregate data causes loss of vital information that makes the 4-step model for example not sensitive to changes in trip attributes nor travel time dependencies among other disaggregate information that is needed to answer the above questions.

Agent-based models however, provide a suitable platform for meeting this need. At the core of agent-based models is the conceptual definition of what an agent is. Agents are singular entities that are independent, make autonomous decisions, and are capable of interacting with other agents and their environment. They are governed by a set of behaviors we can refer to as rules that define how they interact among themselves and with the environment. These rules can be created from real world behaviors. This allows two physically identical agents when faced with a situation, make different decisions due to their autonomy [22] and could result in an emergent phenomenon [7]. These characteristics of agents are part of what distinguishes an agent-based model from aggregate approaches. A second aspect of an agent-based model that makes it capable to model real world complexity is its modularity and flexibility [27] [22]

[15]. The best way to solve a complex problem is to break it into different modules. The agent-based model provides a framework where different models required to solve a problem can be integrated into one system and each agent in that system can then use the most appropriate model for solving its specific problem. Its microscopic framework is able to integrate different transportation related models including, models of land use changes, activity schedules, commercial location choice, housing location choice, mode choice, car ownership, road pricing, etc. as needed into one single framework.

Hence, we can highlight three basic components that make up agent-based models from the perspective of transport planning: *The physical environment:* This constitutes the scenario data for the agent-based model. It includes variables such as the transport network, land use data, transport supply (public transit vehicles), etc. These items do not change and are usually set as initial and boundary conditions. *The agents:* These can be travelers or vehicles (occupied by individuals). *Strategies of agents:* These are rules guiding various interactions in the environment. Based on these different rules agents can be given activity schedules, activity type, activity location, mode of travel between activities (for travelers), etc. These strategies form different modules in the agent-based model and can be added depending on what patterns are studied.

All of these components are simulated by what is called the Mobility Simulator. The Simulator simulates the physical transport system. It receives the strategies of agents, uses them to compute what happens to the agents as they move along the physical environment. Delving into the Mobility Simulator is beyond the scope of this paper and is usually not the main focus for transport planners modelling travel behavior [22].

A popular approach of applying agent-based model in transport is through complete activity based demand modeling. Agent-based model in transport can be used to combine activity based models with traffic assignment so as to build a complete disaggregate model of travel behavior [12]. This enables the understanding of the effect of the decisions of different travelers and their interaction, with other travelers and the transport network as travelers compete in the network to carry out their daily activities. Activity-based models capture the travel demand from a disaggregate point of view as the various out of home activities of individual travelers are taken into account as a source for inducing travel demand.

Activity based models should not be confused with agent-based models, though similar in acronym (ABM). An activity based model also called activity based travel demand model is a travel demand modelling approach based on predicting travelers' activities where the daily activities carried out by households and/or individuals can be predicted along with the location, time and or mode used for these activities. Here a population synthesis is carried out to model the whole population and the individuals that make up the whole population are assigned travel dairies containing a schedule of their activities. This activity scheduling can then serve as a module in the agent-based model framework.

After the above overview of some of the various aspects of agent-based models, we follow with a summary of different popular tools currently applying these models. The objective of this is to anchor the discussion about what is possible today and from there look at the challenges facing agent-based models and future possibilities as these tools evolve over time.

3. Existing Models

To build a multi-agent simulation for an agent-based model is simply to create a transport network, introduce agents to this network and give them rules on how to behave on the network based on real life scenario [22]. While this might seem simple, many modules that make up this system are complex in their interaction. Although these simulations can be programmed from scratch or through user-friendly platforms such as Netlogo [20], there is limitation in applying these platforms to large-scale networks. As the agent-based modelling field developed over time, there were developments in simulation software covering large networks for traffic assignment, traffic flow modelling, etc. Examples of these include AIMSUN [5] focused entirely on reproducing traffic conditions in an urban network, and Sumo [19] for a multi modal simulation of road traffic. In addition, there was the development of activity based demand simulators such as ALBATROSS, FEATHERS, etc. These tools could not integrate the different aspects of transport modelling together, nor give a comprehensive agent-based modelling structure. The general approach was then to combine these models in a 'loosely' fashion [2]. The very first major fully integrated large-scale agent-based model simulation is TRANSIMS [28]. Followed by other simulation frameworks improving on it. These include MATSim [16], SimMobility [2], and Polaris [3] among others.

TRANSIMS (TRansportation ANalysis and SIMulation System), a project of the Los Alamos National Institute, is used for disaggregate modeling of travel behavior on large-scale transport networks. TRANSIMS has been used to create different mobility scenarios for cities such as Portland [26], and Switzerland [23]. MATSim (Multi-Agent Transport Simulation), similar to TRANSIMS was built to solve some of the challenges of using TRANSIMS, one of which was its lack of open access. MATSim is a mesoscopic traffic flow simulator used for dynamic traffic assignment. MATSim provides a fully integrated agent-based model of traffic flow and resulting congestion by tracing synthetic travelers' daily schedules and decisions. SimMobility is "the first agent-based integration of a fully econometric activity based demand model system with a simulation based dynamic traffic assignment system" [2]. SimMobility provides a multi-scale simulation platform that covers interactions of land-use, transportation and communication, modelling millions of agents. POLARIS (Planning and Operations Language for Agent-based Regional Integrated Simulation) aiming to solve interoperability issues that TRANSIMS and MATSim face in integrating different models together, provides a plug-n-play system for legacy software in its framework. There are also newer frameworks developed to extend existing frameworks such as EQASIM [10], and BEAM [6] that have extended the MATSim framework. Many of these models are under continuous development and improvement but the issues outlined in the following sections slow down these developments.

4. Challenges of Agent based Models

All limitations of agent-based models have not been clearly understood because of the complex phenomena that come with modeling human behavior. Some of the known challenges of agent-based modelling previously cited by researchers [15] [14] [21], have been addressed over time. The main issues that still remain have been sumarised below.

Input Data. The input data used in an agent-based simulation framework is fundamental to the results produced. It is necessary to take note of the different errors that could arise from input data, and understand how these errors could affect the model. The data collection process is one way error can be introduced into the model. While one may want to model all aspects of human behavior and the transport system, the data required to accomplish this is not readily available, and could be costly to obtain. This leaves the choice to be selective and to choose the necessary data based on availability. At the end of the day, data is a statistical representation of reality. How good is the data used in representing the population? What is the margin of error? Identifying the important data to be used, that would best suit the model is essential to reducing errors in the output of the model.

Available data may be in different forms and require cleaning or transformation in order to be used in the agent-based model. The cleaning process can introduce errors from missing values, wrong inputs, incomplete data, and/or coding mistakes. Errors may result from converting data from its original format to the format suitable for the simulation tool. Proper documentation of the cleaning process could help to check the quality of the data used for the model. Sometimes it may be necessary to transform aggregate data into disaggregate form required for the agent-based models, for example, using aggregated OD matrix to assign trips to agents in different zones. Possible errors that could arise from this process need to be identified and checked. A common way to check these kind of errors is to validate model results against the observed macroscopic data.

There are also subtle aspects of data effects that are rarely discussed in connection to agent-based models nor properly reported. Bias, Uncertainty and Time variability. Some of the data used are obtained from stated preference surveys (SPs) and revealed preference surveys (RPs). Bias from SP and RP surveys could introduce bias to the results of the model. In cases when such surveys are used, bias issues should be accounted for in the agent-based reports. Uncertainty from generation of the input data could also affect model output and need to be documented in agent-based reports. For example, agent-based modelers may not consider how an OD matrix they used in their model has been estimated for different zones, and as a result how these estimates affect the output are usually not reported. Finally, there is an issue of time variability. It may not be possible to obtain data required for agent-based modeling within a single year. This time variability among different data inputs can affect the model and needs to be reported and discussed.

Cost of Computation. The system dynamics of an agent-based model is dependent on a representation of a complex environment, with a large number of agents whose behaviors are simulated. Multi-agent simulations of travelers' behavior provide a framework for integrating various models together. Coupling these multiple models, which could include land use, mode choice, route choice, destination choice, scheduling, etc. would definitely raise the complexity of a simulation. Furthermore, many simulation runs could be needed for proper calibration of the model. The larger the scale of the model and the more complex the questions, the more computing resources it requires which then affects the performance of the model. A MATSim simulation run for a Paris Scenario capturing 10% of the population can take 5 hours to complete on a modern cluster [17]. This weakness in agent-based models makes the 4-step model still appealing up to today.

Transparency. A major critic of agent-based models is the transparency of the agent-based simulation. Agent-based models are complex. There is no easy way of understanding the numerical details and the mechanical process of how agents interact with each other and the environment. The simulated results depend on the parameters' values and the initial and boundary conditions set. Furthermore, the results can vary based on the inner workings of the model even with the same parameters, an effect caused by the random elements contained in the model. Understanding the internal aspect of the model facilitates a clear understanding of the model's behavioral output. There are ways of ensuring transparency of the model dynamics. This could be through sensitivity analysis, mathematical descriptions of the different states of the model, quantification and description of model variability, and clear descriptions of parameter set-up and calibration. If this is practiced, it will facilitate reproducibility of these models and garner trust in their simulation results.

Validation. Validation of a model is essential as it shows how well the model can reproduce reality. In agent-based modeling, different validation techniques are employed such as face validation based on experience, and verification - checking against real life traffic counts, mode distributions, etc. Additionally, carrying out sensitivity analysis with the model simulation enables one to explore how the model's results change based on variation of inputs. Furthermore, an important aspect of agent-based models is in predicting future travel scenarios. Yet, there are no existing reports that have validated the forecasting ability of agent-based models. A possible way to do so will be to conduct Before and After studies. These studies can, for example, show if an agent-based model can predict traffic demand based on infrastructural changes that have occurred within a certain timeframe. While these sort of Before and After studies exist for 4-step models, there are none to the knowledge of the authors available for agent-based models. It will be worthwhile to look at the predictions made by these various agent-based simulations in the last decades and validate their various predictions with the current time.

Reproducibility. Reproducibility is an important concept in scientific research. Other researchers should be able to reproduce the results of an agent-based simulation provided open source data is used. Presently there are no known cases of reproducibility of these multi agent simulations. This is due to the non-streamlined process of calibrating and imputing parameters for the models. Also aspects of the scenario building process, which include initial and boundary conditions set, updates carried out while refining the model, and importantly the software versions used, may not necessarily be published. There is a need to define reporting standards for agent-based model research to enable reproducibility by any researcher.

Standardization. There is a need to have a properly defined body of knowledge for agent-based models where there is a common language and definition of terms, clear standard procedures, analysis and model expectations. Presently there are ways for standardized presentation of agent-based models. The use of methodical teachings in schools is important to educate new researchers in the field. Proper documentation is important for understanding the inner workings of a model presented. Documentation should include the data cleaning process, version controlling of changes made, the software version used, etc. Developing these practices would further increase the diffusion of these standardized practices.

5. Future Expectation and Conclusion

The use of agent-based models to model transport behavior is growing. In this paper we began with a brief history of agent-based models, and why and how it is applied in transport planning. We described some of the tools being used for agent-based simulations in the transport field, and particularly described the current challenges of agent-based modeling.

While there is still a long way to go for agent-based models in transportation, there is a lot of progress being made. As better computing techniques are being developed, computational costs of agent-based simulations is reduced, which allows to further expand the application of agent-based models. In addition, as the knowledge body grows, standardization can also be achieved.

The growth in the application of agent-based models for transport planning should also materialize, as different government agencies adapt it for transport policy planning. Some of the entities in the industrial sector of the transportation field are also using agent-based models for predictions of demand for their services. This is bringing further growth in the usage of agent-based models. Agent-based models are also already being applied in real time to traffic management systems [8]. This could mean that there is a possibility of expanding the simulation for real time modeling of agent interactions with their environment. This could be through the development of various applications that can serve as personal transportation assistants, MaaS or even real time interactions of connected autonomous vehicles.

One of the upcoming research fields is in the area of achieving system/social optimum with agent-based models. Currently multi agent simulations achieve user equilibrium, a state where all cost of travelers' routes in the system are the same and are lower than the cost of unused routes. A system optimum is a state where the total system travel cost is better off even at the increased cost of a traveler's route. While this topic is outside the scope of this study, a brief description underscores the growth of agent-based models and reveals its future potentials. Such studies look at combining persuasive technologies that can nudge travelers toward altruistic characteristics to drive cooperation among them, a key to achieving system optimum. Also Game based models are being developed which is a fusion of agent-based models with Serious Games [18]. Currently small scale simulations are being conducted to test this concept [20], other agent-based cooperation techniques are being applied to freight transport [1]. These works show that agent-based models provide a viable approach to finding stable optimal solutions.

The future looks bright for agent-based modeling in transport planning in the midterm. There are many challenges that need to be overcome, understanding these challenges and taking necessary steps to develop the right practices would create a better pathway for agent-based models in solving transport related issues in the society.

References

[1] Abdulsattar, H., Mostafizi, A., Siam, M.R., Wang, H., 2019. Measuring the impacts of connected vehicles on travel time reliability in a work zone environment: an agent-based approach. Journal of Intelligent Transportation Systems , 1–16.

[2] Adnan, M., Pereira, F.C., Azevedo, C.M.L., Basak, K., Lovric, M., Raveau, S., Zhu, Y., Ferreira, J., Zegras, C., Ben-Akiva, M., . Simmobility: A multi-scale integrated agent-based simulation platform, in: 95th Annual Meeting of the Transportation Research Board Forthcoming in Transportation Research Record.

[3] Auld, J., Hope, M., Ley, H., Sokolov, V., Xu, B., Zhang, K., 2016. Polaris: Agent-based modeling framework development and implementation for integrated travel demand and network and operations simulations. Transportation Research Part C: Emerging Technologies 64, 101–116.

[4] Balac, M., Rothfeld, R.L., Hörl, S., . The prospects of on-demand urban air mobility in zurich, switzerland, in: 2019 IEEE Intelligent Transportation Systems Conference (ITSC), IEEE. pp. 906–913.

[5] Barceló, J., Casas, J., Ferrer, J., García, D., 1999. Modelling advanced transport telematic applications with microscopic simulators: The case of AIMSUN2. Springer. pp. 205–221.

[6] BEAM, . URL: https://beam.readthedocs.io/en/latest/about.html. accessed: December 2019.

[7] Bonabeau, E., 2002. Agent-based modeling: Methods and techniques for simulating human systems. Proceedings of the national academy of sciences 99, 7280–7287.

[8] Chen, B., Cheng, H.H., 2010. A review of the applications of agent technology in traffic and transportation systems. IEEE Transactions on intelligent transportation systems 11, 485–497.

[9] de Dios Ortuzar, J., Willumsen, L.G., 2011. Modelling transport. John Wiley and Sons, New Jersey.

[10] eqasim, . URL: http://www.eqasim.org/. accessed: November 2019.

[11] Fagnant, D.J., Kockelman, K.M., 2014. The travel and environmental implications of shared autonomous vehicles, using agent-based model scenarios. Transportation Research Part C: Emerging Technologies 40, 1–13.

[12] Feil, M., 2010. Choosing the daily schedule: Expanding activity based travel demand modelling. Thesis, eth zurich. ETH Zurich.

[13] Meyer de Freitas, L., Schuemperlin, O., Balac, M., Ciari, F., 2017. Equity effects of congestion charges: An exploratory analysis with matsim. Transportation Research Record 2670, 75–82.

[14] Heath, B., Hill, R., Ciarallo, F., 2009. A survey of agent-based modeling practices (january 1998 to july 2008). Journal of Artificial Societies and Simulation, Social 12, 9.

[15] Helbing, D., Balietti, S., 2011. How to do agent-based simulations in the future: From modeling social mechanisms to emergent phenomena and interactive systems design why develop and use agent-based models? Santa Fe Institute Working Papers , 1–55.

[16] Horni, A., Nagel, K., Axhausen, K.W., 2016. The multi-agent transport simulation MATSim. Ubiquity Press London.

[17] Hörl, S., Balac, M., Axhausen, K.W., . Dynamic demand estimation for an amod system in paris, in: 2019 IEEE Intelligent Vehicles Symposium (IV), IEEE. pp. 260–266.

[18] Klein, I., Ben-Elia, E., 2016. Emergence of cooperation in congested road networks using ict and future and emerging technologies: A game-based review. Transportation Research Part C: Emerging Technologies 72, 10–28.
[19] Krajzewicz, D., Hertkorn, G., Rössel, C., Wagner, P., . Sumo (simulation of urban mobility)-an open-source traffic simulation, in: Proceedings of the 4th middle East Symposium on Simulation and Modelling (MESM20002), pp. 183–187.
[20] Levy, N., Ben-Elia, E., 2016. Emergence of system optimum: A fair and altruistic agent-based route-choice model. Procedia Computer Science 83, 928–933.
[21] Manzo, G., Matthews, T., 2014. Potentialities and limitations of agent-based simulations. Revue française de sociologie 55, 653–688.
[22] Nagel, K., Marchal, F., 2007. Computational methods for multi-agent simulations of travel behavior. first ed.. Elsevier Ltd, Oxford, UK. book section 6.
[23] Raney, B., Cetin, N., Völlmy, A., Vrtic, M., Axhausen, K., Nagel, K., 2003. An agent-based microsimulation model of swiss travel: First results. Networks and Economics, Spatial 3, 23–41.
[24] Ruch, C., Hörl, S., Frazzoli, E., . Amodeus, a simulation-based testbed for autonomous mobility-on-demand systems, in: 2018 21st International Conference on Intelligent Transportation Systems (ITSC), IEEE. pp. 3639–3644.
[25] Schröder, J.O., Weiß, C., Kagerbauer, M., Reiß, N., Reuter, C., Schürmann, R., Pfisterer, S., 2014. Developing and evaluating intermodal e-sharing services–a multi-method approach. Transportation Research Procedia 4, 199–212.
[26] Simon, P.M., Esser, J., Nagel, K., 1999. Simple queueing model applied to the city of portland. International Journal of Modern Physics C 10, 941–960.
[27] Sycara, K.P., 1998. Multiagent systems. Ai Magazine 19, 79–92. URL: <GotoISI>://WOS:000074385300006.
[28] TRANSIMS, . Transportation analysis simulation system. URL: http://ndssl.vbi.vt.edu/transims-33docs.html. accessed: December 2019.
[29] Zambonelli, F., Van Dyke, P.H., 2003. Signs of a revolution in computer science and software engineering. Springer-Verlag Berlin, Berlin. volume 2577 of *Lecture Notes in Artificial Intelligence*. pp. 13–28.
[30] Zellner, M., Massey, D., Shiftan, Y., Levine, J., Arquero, M., 2016. Overcoming the last-mile problem with transportation and land-use improvements: An agent-based approach. International Journal of Transportation 4, 1–26.
[31] Zheng, N., Waraich, R.A., Axhausen, K.W., Geroliminis, N., 2012. A dynamic cordon pricing scheme combining the macroscopic fundamental diagram and an agent-based traffic model. Transportation Research Part A: Policy and Practice 46, 1291–1303.