A calibration guideline for agent-based passenger mobility models

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1 INTRODUCTION

Agent-based simulation refers to the process of simulating the behavior and interactions of a finite number of self-interested "agents". The key construct is the agent, a micro-level entity behaving autonomously and capable of interacting with other agents through an environment. The ultimate goal of the simulation is to represent complex systems in different socio-demographic contexts and various interaction configurations between agents with respect to the environmental conditions and constraints. The main advantage of the multi-agent paradigm is the ability to represent non-linear phenomena with a high level of details that would be difficult to tackle with analytical approaches (Bonabeau, 2002). Moreover, the resulting system behavior can be observed and analyzed at an aggregated level and showcase macro-characteristics of the system. Among different applications of agent-based models, simulation of mobility in transportation systems is one of the most active areas of interest in transportation management, computer science, and complex systems studies.

Multiple physical, behavioral and dynamic models are deployed in agent-based mobility modeling in order to capture and finely reproduce mobility behaviors of individuals and reactions to changes in transport supply. These models consist of many parameters that must be determined according to the targeted real system. The optimal parameters lead the model to represent agents behavior observed in the system. In other words, the development of a model that reliably describes the mobility situation in a given territory requires the calibration of the model parameters to the conditions of this territory. "Calibration" is the process of defining the parameters values of the model to fit with an expected outcome. Increasing the resolution of the simulation increases its degrees of freedom that require more interactions to be modeled and, therefore, more parameters to be identified and calibrated (Flötteröd *et al.*, 2011). Thus, the complex nature of agent-based mobility modeling and a high level of detail involves methodological challenges in calibrating such models. This study focuses on investigating the existing methodologies for the calibration process of agent-based passenger mobility models.

A significant number of articles present agent-based modeling for specific cases studies in the context of passenger mobility (Zargayouna *et al.*, 2020), using various calibration approaches, or are directly focused on the calibration techniques of such models (Djavadian & Chow, 2017).

However, in the absence of the most up-to-date and complete overview of the progress in the key phase of building reliable transport models, this study aims to systematize the practiced and developed calibration approaches.

We examine the history of the agent-based calibration problem and compile an overview of the calibration approaches for agent-based mobility models described in the literature. The main contribution of this work is twofold: (1) presenting key questions for the calibration of transport models and pass through this interrogative lens the available literature on agent-based passenger mobility modeling; (2) highlighting the important challenges and issues that need to be addressed as future research and provide a guide for the research community on how to tackle these challenges with the suggestion of some perspective avenues. We reviewed over 50 articles in the target area and synthesized promising research directions for open calibration challenges from the vast literature on computer science and social sciences.

2 REVIEW METHODOLOGY

The calibration concept has been defined in transportation management since the seminal work of Greenshields *et al.* (1935) and the simulation calibration is defined by Wigan (1972) in the urban transportation system. While agent-based modeling dates backs to 1970's (Nagel & Axhausen, 2016), simulation tools are introduced to the transportation field at the beginning of the 21st century (cf. e.g. Mahmassani (2001); Ben-Akiva *et al.* (2001)).The review process starts with the collection of relevant publications during the last two decades from scientific databases including Scopus and Web of Science. These sources have been searched for articles in scientific journals and international conferences.

To systematically consider all relevant studies, we use the following search expression based on keywords: One keyword combination reflects the type of transport model within the scope of this review as "('agent-based' OR 'multi-agent' OR disaggregate) AND (passenger OR 'passenger demand' OR 'passenger flow' OR 'travel demand' OR transport OR traffic OR mobility) AND (model OR simulation)". The next keyword reflects the problem in transport modeling, which is the subject of this review and belongs to the set (calibration OR estimation OR 'parameter adjustment' OR tuning). Specific concerns have also been searched in the calibration literature, such as (uncertainty OR stochasticity) to identify publications that take into account these issues in their calibration process.

We collected 53 references from the mentioned sources that address the calibration problem for agent-based mobility simulations. Figure 1 depicts the taxonomy of the calibration problem. The problem is defined at the intersections of data collection and processing with agent-based simulation and/or decision-making models. Indeed, the parameters of the simulator and behavior model need to be calibrated against the collected data. The references are divided into three main groups based on the scope of the calibration problem. These three categories are compared following seven features that are defined for a calibration problem in Figure 1.

Furthermore, each study is screened across several categories of questions. This analysis allows us to further categorize studies and identify weaknesses that need to be addressed in upcoming research. Table 1 presents 26 questions that we pose to each study. Five groups of questions are designed to investigate each study. The first three groups include methodological questions to clarify the setting and characteristics of the calibration problem and its solution method. The two last groups aim to evaluate and compare the performance of the calibration models in practice. Thus an approximation can be provided to a reader regarding the application of each methodology in the literature. In addition, such a questionnaire allows us to revise the process of building an agent-based model of passenger mobility and identify the most significant challenges and peculiarities of its calibration. Considering these questions, this research was conducted using the systematic literature review method, following Kitchenham (2004).

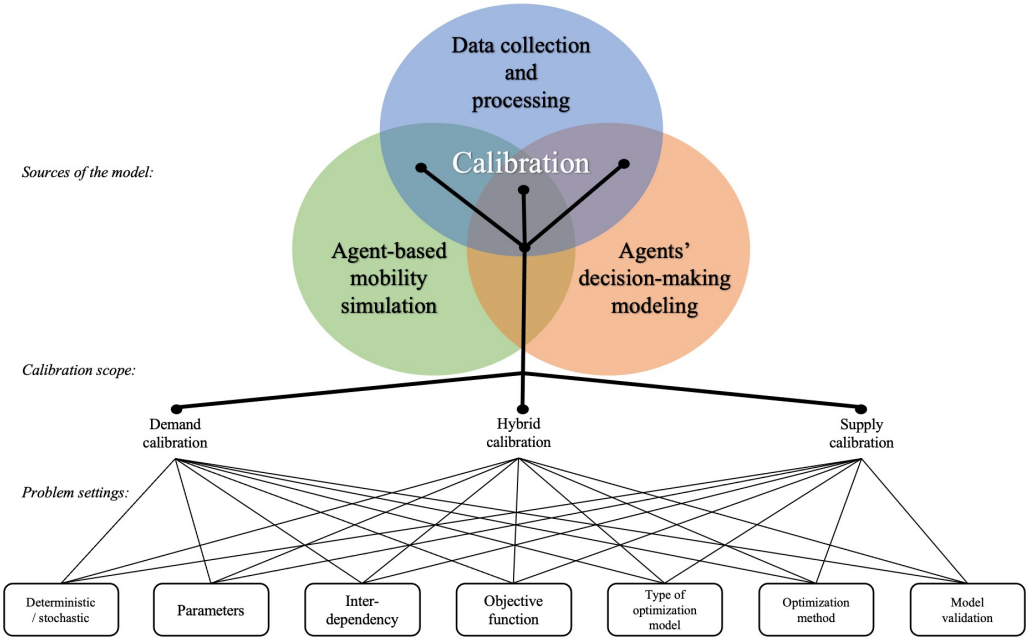

Figure 1 – *Taxonomy on the calibration of agent-based mobility simulation*

Table 1 – *The list of questions has been posed to each reference in the review process.*

Transport model description	
Q1	Which type of model is considered? / How does the study include agent-based simulation model?
Q2	What is the name and features of simulator? e.g, SUMO, SimMobility, MATSim, etc.
Charchteristics of the case study	
Q3	What are the general characteristics of the study area?
Q4	What is the population size? What are the general characteristics of the demand profile?
Q5	What is the size of the transport network in terms of the number of nodes and links?
Q6	Which transport modes are considered?
Calibration problem	
Q7	What is the scope of the calibration problem? (Figure 1)
Q8	What is the calibration strategy? direct calibration or surrogate-based?
Q9	Whether the problem is formulated as deterministic calibration or stochastic calibration?
Q10	What is the characteristics of model stochasticity in case of using stochastic settings?
Q11	How many parameters are calibrated?
Q12	What are the calibration parameters? Types?
Q13	Whether some sensitivity analysis is used to filter parameters prior to the calibration procedure?
Q14	Whether inter-dependencies are considered? If yes how?
Q15	What are the variables of interest, or performance measurements?
Q16	What (field) data is collected and used for calibration?
Q17	Which objective function is used?
Q18	Which optimization method, algorithm is used?
Q19	What additional performance control is used?
Q20	Whether calibration process is documented?
Transport model validation	
Q21	Whether validation process is performed for the calibrated model?
Q22	What validation method is applied in case of performing validation process?
Computation time	
Q23	How many evaluations of the objective function are made? with how many iterations each?
Q24	Which convergence criterion is applied?
Q25	Which computer resources are used?
Q26	What is the order of computation time for the calibration?

3 FINDINGS AND DISCUSSION

Analysis of the collected information from the questionnaire prepared categories for the classification and benchmark of the selected articles. The results of the literature review consist in two parts: (i) Classification of the studies based on the scope of the agent-based model calibration problem and identification of all the characteristics of each study (Figure 1); (ii) Identification of current scientific challenges in the literature. For instance, in the second part, we investigated how existing studies address the computational cost of the calibration process. However, the results highlight that it remains an extremely serious issue for calibrating large-scale multi-agent models with a high level of detail. Another angle of exploitation of the existing calibration experiences is the problem of a large number of parameters in agent-based transport models. We draw from the available studies different approaches addressing this challenge to select the relevant parameters for calibration and how the inter-dependency between calibration parameters is taken into account. We can also mention different challenges such as data issues for calibration, modeling of emerging transportation modes and services, stochasticity modeling, and observed variability that are dissected and will be presented by this study.

Moreover, we proposed future research directions, including several solutions from other fields of application of agent-based models to address the calibration challenges. We found that despite the existence of rich data from emerging technologies, their use in the calibration process of agent-based transport models is still in an evolving stage. Evaluating and improving access issues, pre-processing, and treatment issues of the data sets improve the model reliability. Thus these have to be considered for further investigation. In addition, by the wide application of machine learning (ML) models to different types of agent-based models, leveraging ML and artificial intelligence techniques to calibrate agent-based mobility simulation is an interesting research direction. From the optimization point of view, decomposition approaches can be applied to the models in order to benefit from parallel computing during the calibration process. The combination of decomposition approaches and search algorithms or meta-heuristics may overcome the curse of dimensionality of the calibration problem.

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