Agent-Based Modelling for Sustainable Tourism

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Abstract. Agent-based modelling (ABM) is a computer-based system to simulate the interactions, relationships and behavior of individual agents in a defined spatial context. Due to its stochastic and heterogenic nature, the method has the potential to represent the complexity of the tourism system with a broad range of possible applications. In the context of visitor flow management for instance, ABM can function as a possible decision support tool for policy makers to better understand and evaluate the dynamics of future scenarios and proposed policy changes towards a more economically, socially and environmentally resilient tourism development altogether. The following paper discusses the potential and implications of agent-based models in tourism research with a complex system approach in regard to ABM's inherent elements of agents, interactions and environment. It introduces the planned application of ABM in an ongoing project dealing with visitor flows in an urban as well as rural destination context and draws up possible implications for sustainable tourism development.

Keywords: ABM · AI · Visitor flow management · Sustainable tourism

1 Introduction

When planning a trip, adventure, or vacation, humans often wear rose-tinted glasses with certain expectations – from stress-free to perfect weather conditions, unforgettable experiences, or queues with little waiting times [1]. However, perfect expectations and wishes do not always reflect reality. A vacation in a certain destination might be influenced by long waiting hours at a ski resort, unpredictable weather scenarios, dangerous situations [1], or changes due to unforeseen pandemics such as COVID-19 [2]. Although there is a general understanding of how tourism and the environment are related, there is still a lack of knowledge on the details of these relationships [3]. Thus, Amelung et al. [3] propose the need for a more integrative and systemic research approach altogether. One method to explore these relationships is agent-based modelling (ABM), a

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method that uses computer-based simulations of interactions between different agents (e.g. individuals, hotels, entertainment facilities, etc.) in a certain system or environment to better understand complex systems and their dynamic behavior [1, 4, 5]. This paper will present the conceptual structure of an ongoing research project on data-driven sustainable tourism and its underlying vision for ABM within it.

2 ABM in Tourism Research

By definition, ABM "is," the set of techniques [in which] relations and descriptions of global variables are replaced by an explicit representation of the microscopic features of the system" [6]. In short, ABM can be used to explore dynamic and systemwide changes triggered by individual actions, choices or changes over a certain period of time [1], making it part of complex system research [5]. Similarly, tourism destinations entail various agents who have dynamic, unpredictable, or nonlinear relationships with each other, which Baggio [7] describes as complex systems. Possibilities for using ABM in tourism research range from understanding tourists' decision-making processes on destination choice [8], reflecting on the industry's impacts on the environment [1, 3], to gaining insights on visitor flows and tourism planning [9].

2.1 Key Features of ABM

Student [1] describes the key features of ABM as agents, ongoing interactions in a spatial setting over time (i.e. the environment), and variable types – labelled rules [10] or regulations [5] elsewhere. Agents are generally "a collection of autonomous decision making entities" [10], with a predefined set of behavioral rules guiding their interaction with other agents and the surrounding environment [1]. Depending on the model, they are able to possess memory and different degrees of rationality, learn from other agents, adjust themselves to influencing events or change their behavior to better suit their environment [1, 10, 11]. The environment of an agent-based model can either be an abstract construct or the representation of real space. According to the complexity of the research question, the modeler decides on the level of details to integrate and sets boundaries of movement (e.g. ways of exiting or entering the system). Interactions shape the mechanism of a model and function as a linkage between agents, the environment, and the system they represent [1]. They are defined by underlying protocols on the dynamics of communication, relationships, movement patterns, and capabilities in how to respond to the environment [11]. Additionally, they might include a factor of randomness to better represent the uncertainties and stochasticity in the real world [1].

2.2 Visitor Flow and ABM

While visitor flow management in urban destinations usually aims for a better distribution of tourists on popular routes and spaces (i.e. points of interest), visitor flow control in a rural setting might seek to generate and utilize spillover effects instead. In both cases ABM presents an intelligent decision support tool that helps destination managers or

city planners to better understand and utilize tourist flows and to ultimately make better decisions on tourism distribution and the planning of new tourist infrastructure.

As ABM studies use extensive computer simulations to detail how different human and natural agents interact with each other at various points in time and space [3], an advantage of ABM is its combination of environmental aspects with different stakeholders or agents [1, 3] and the possibility to identify behavioral patterns that would be difficult to obtain by using traditional research methods [5]. Compared to different data collection and modeling methods (ranging from survey-based methods to differential equations and statistical techniques), another strength of ABM is the possibility to couple this form of modeling with theories such as complex networks or game theory [5]. Within the course of the project presented in this paper, more sophisticated approaches of ABM parametrization from individual tourist data using machine learning (ML) and artificial intelligence (AI) will be developed, thereby addressing a method that has been neglected in the most recent literature review of ABM in tourism studies [5].

3 Data-Driven Tourism for Sustainability (dTS)

Based on historical data, many contemporary ABM approaches are neglecting the power of AI to analyze and detect the behavior of agents (i.e. tourists) in different contexts. The dTS project proposes a new framework to develop a spatial agent-based model and simulation demonstrator that helps to simulate emergent movement patterns of tourists under varying conditions and system status.

3.1 The dTS Project in Short

The dTS project, funded by the Austrian Research Promotion Agency (FFG), seeks to answer the question of how the combination of fair AI and agent-based modelling/simulation can contribute to resilient and sustainable regional tourism in Austria, on the example of visitor flow control. The project combines the interdisciplinary know-how of three university partners, two technology partners, and two pilot destinations in the region of Land Salzburg, Austria. The two use cases have been selected with the aim of strengthening the entire region, exhausting mobility resources, and working towards carbon neutrality. The involved pilot cases do not only vary on the degree of technological level as far as data availability is concerned, but also differ in the environmental setting of the destination, one being a rural region that offers a national park, ski areas and mountains, and the other being an urban and cultural hotspot.

dTS proposes a scalable and portable model for resilient and sustainable tourism. The result will be the design of a scalable data exchange and simulation platform that is also capable to serve as a data circle for visitor flows. Using fair artificial intelligence and agent-based simulations, the authentic movement and behavioral patterns of the target groups are to be learned and understood and afterward incorporated into a sustainable and gentle mobility concept. This also enables the modelling of “what-if” scenarios in the sense of decision support for the respective administrations. All these developments are done under the paradigm of data privacy, leading to a privacy-by-design philosophy, omnipresent in the chosen approach of the dTS project.

3.2 Agents – Environment – Interactions

Implementation of a spatial ABM to simulate tourist flow is not a trivial task as there are numerous practical questions that arise in the process of establishing a spatial ABM system capable of modelling and simulating the behavior of individual tourists. As a platform for spatial ABM modelling, the project proposes the GAMA platform, already supporting the use of vector and raster spatial datasets as the model environment. This makes it possible to use 2D spatial information about road networks as a medium for the movement of agents and to build footprints as their origins and destinations.

As a source of vector information about streets and buildings, OpenStreetMap (OSM), the most prominent Volunteered Geographic Information dataset with global coverage, is proposed as a free-of-charge solution. However, the non-restrictive mapping and annotation policy of OSM can cause issues regarding data cleanliness and heterogeneity, making it necessary to be clean and homogenize the data before being used in an ABM environment. Here, Ontology Design Patterns will be created and utilized as a semantic basis for the homogenization of different datasets.

Next, the behavior capabilities of agents in the model need to be defined. For tourist flow simulations it is important that agents are capable of multiple modalities of transport, such as walking, cycling, driving in a car, or riding on public transportation, so that their effects on the city's and attractions' congestion levels can be captured. Another important capability is that tourists are able to act as individuals or as groups, because tourists can travel alone, in small groups (i.e. with friends and family) or in large groups such as on organized tours. This will be achieved by applying ML and AI methods that can learn patterns and sequences from tourist movement and visiting data. Furthermore, the project proposes to implement an AI controller and recommendation system that can be trained by reinforcement learning on repeated simulation runs, which will then provide intelligent alternative tourist routes in the city in case of congestion at certain attractions. Here, agents should have bounded rationality, as they may not have access to all relevant information and make decisions based on their fettered access to information (i.e. making non-rational decisions).

4 Conclusion

In order to base decisions on the results of computer-based models, they need to be an adequate representation of the complex reality they are drawn from. Especially the validation of complex systems (i.e. destinations), poses challenges that in many cases cannot be met [6] due to the unpredictability of the system and the lack of independent datasets for comparison [3]. As proposed in the described project, the integration of empirical data, the spatial mapping on OpenStreetMap and the use of artificial intelligence to train agents towards authentic movement and behavioral patterns effectively contributes to solving the problem of validation. Furthermore, improved validation is sought through the active involvement of stakeholders in two pilot regions and the formation of interdisciplinary teams as for instance suggested by Student and Johnson et al. [1, 12].

The application of ABM offers great potential for sustainable tourism development as it enables the respective administrations to better grasp the complexity of the tourism

system in an illustrative and realistic manner. The holistic modelling of "what if" scenarios can help to utilize spillover effects, prevent spatial conflicts, and contribute to an overall better experience of visitors, tourism stakeholders and locals alike.

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