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A Review of Simulation and Application of Agent-Based Model Approaches

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A Review of Simulation and Application of Agent-Based Model Approaches

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Abstract. In the past, various traditional methods used experiments and statistical data to examine and solve the occurred problem and social-environmental issue. However, the traditional method is not suitable for expressing or solving the complex dynamics of human environmental crisis (such as the spread of diseases, natural disaster management, social problems, etc.). Therefore, the implementation of computational modelling methods such as Agent-Based Models (ABM) has become an effective technology for solving complex problems arising from the interpretation of human behaviour such as human society, environment, and biological systems. Overall, this article will outline the ABM model properties and its applications in the criminology, flood management, and the COVID-19 pandemic fields. In addition, this article will review the limitations that occurred to be overcome in the further development of the ABM model.

1. Introduction

Generally, computational and mathematical simulation methods have been developed to emphasize the analysis of system comportment and the evaluation of strategies for predicting and describing model functions [1]. In addition, simulation has been defined as an identifiable representation of the model that can be assigned insights about the system or implementation under study. Therefore, the computational modelling methods has been used to express and solve the complex dynamics of human environmental crisis (such as the spread of diseases, natural disaster management, social problems, etc.).

According to Malleson (2012), three mains computational modelling methods can be used to simulate complex human environmental phenomenon, such as Cellular Automata (CA), Micro-Simulation (MSM) and Agent-Based Models (ABM). When applied to different research fields, each computational modelling method has its own advantages and limitations. However, compared with CA and MSM methods, ABM models are more important and relevant in simulating complex human phenomena in the real world [2]. For instance, several commonly used toolkits have been used to develop ABM applications in different aspect or case studies, such as ArcGIS Agent Analyst/Repast (marketing, social sciences and 2 or 3D simulation), Swarm (biological, logistic and transportation), MASON (artificial intelligence, robotics and machine learning), NetLogo (2 or 3D simulation, natural and social science), AnyLogic (transportation, urban dynamic and healthcare) and GAMA (land planning, ecological and economical) software.

2. ABM Definitions and Framework

Agent-Based Models (ABM) known as a modelling approach that can constitute a shift from social science to the use of models that can be used on a personal level. It is also called a computational model that contains several components such as the theories of games, complexity of systems, appearance, computational sociology, multi-agent systems and evolutionary programming [3,4]. Besides, it is also considered as a computing model that can invoke dynamic actions, responses and mutual communication protocols between agents in the same environment. In addition, the functions and capabilities of the model are also evaluated to determine the information about its behavior and the understanding of its attributes. From a simulation point of view, the function of a single component can range from very basic "if - then" reaction rules to more complex cognitively rich behaviour models.

The significant example is the BDI (Belief-Desire-Intention) structure according to the reuse model of artificial intelligence. BDI terminology believes: "the agent also determines that it has a set of beliefs about itself and the surrounding environment; a set of impulses is the computing state its purposes to declare, and a set of intentions is the computing state that the agent is trying to arrive at [5]. Generally, the concept of ABM model is to use a bottom-up approach to model complex systems from a single agent. However, a concrete approach of the ABM model is to use a set of autonomous agents to model and simulate real-life situations, where these agents can be simple entities in the calculation code segment, or they can be quite intelligent objects.

Normally, the ABM framework include two elements, such as the behaviour of the agent and the model's environment (Figure 1) [6]. Usually, agents will represent their individuals in the real world where their basic world and basic needs unchanged. Usually, agents located in space, time, and network or grid-like communities. The location of the agent and its response behaviour is expressed in the form of an algorithm in the computer program. In addition, agents can also be divided into different categories by specifying the required agent information according to the data structure, the mechanism of operating the information, and the rules of how to interact with each other and with the environment.

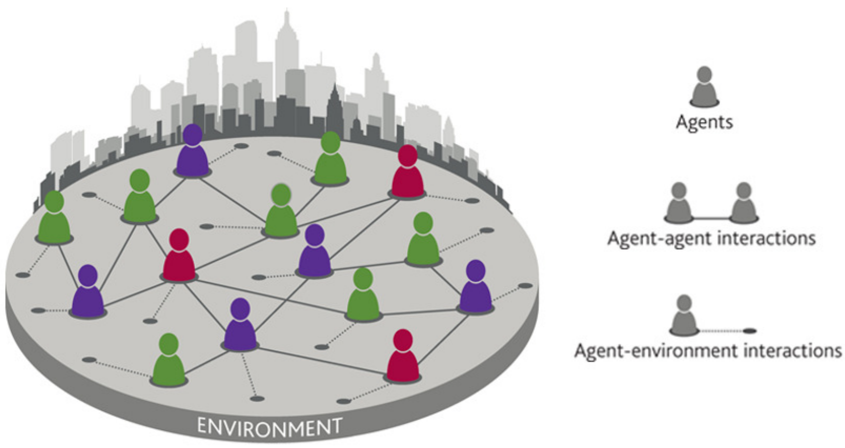

Figure 1. Schematic Representation of the ABM Model Framework [adapted from Turrell, 2016].

The environment is defined as the space in which the agent conducts behaviour and interaction. For example, the space in the environment can be discrete, continuous, or have network characteristics. However, by using designated software, users or modelers can write rules to control the movement of agents in a specific space and their interactions. For example, users can simulate and control the agent's movement in the discrete environment without losing their substance content in the physical space.

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3. ABM Applications

Currently, the application of ABM is gaining more and more recognition in scientific disciplines to simulate the dynamic of large-scale complex systems and observing their behaviours. There were several researches that have applying the ABM models in their studies such as the criminology, flood and COVID-19 pandemic fields.

3.1. Criminology

Recently, criminal behaviour is highly propagated in the media and frequently appear in TV shows and movies. In the past, criminal behaviour was analysed through qualitative and quantitative methods to examine non-digital data to discover the cause and impact of crime. However, traditional analysis methods cannot represent the complexity of human-environmental systems, especially human motives and behaviours. Various criminologists have begun to recognize understanding the changes in crime and the motives behind it spatially and temporally. Generally, the computational modelling methods such as the ABM model are more successful in expressing criminal behaviour than criminals [7,8].

Previously, the occurrence of residential burglary has imitated by using the ABM method [9]. Normally, the police will patrol the streets of towns to reduce the number of crimes. Often, the interaction between the offender's personal decision and the response to police patrols is very complex, and efforts to reduce crime anywhere does not necessarily lead to an overall reduction. This is because criminals initially active in the area can be transferred to another area until the police patrol continues to advance or implement any of the six displacement methods (time, space, objective, method, crime type, offender). Therefore, the ABM model was implemented to emulate criminals' responses to police actions and other crime prevention policies to strengthen the basis of law enforcement decision-making.

In addition, the advantages, applicability, and flexibility of the ABM model can also be used to simulate human behaviour and motivation in residential burglary. In general, the personal representation of criminal behaviour can be enhanced by combining it with a criminal environment model of similar scale. The simulation is important because it can geographically refine agent-based crime models (for example, allowing individual households with different wealth or living styles) and can identify the characteristics of individual victims [10]. In addition, the integration of the ABM model can develop a modern criminological thinking model, which includes a high-level criminal behaviour framework, and predicts information about potential criminal victims in the future.

3.2. Flood

In recent years, many parts of the world have suffered severe floods, causing serious damage and destruction to families, communities, governments and organizations. In the past, several studies have developed ABM models to study the effectiveness of physical/structural and social disaster preparedness and adaptation measures that used to reduce the impact of major floods and recover from them [11-13]. According to Coates (2019), the ABM model used to evaluate the flood prevention and recovery capabilities of small and medium manufacturing companies. In the United Kingdom, nearly 99.9% of small and medium enterprise (SMEs) were affected due to the huge economic losses caused by the flood. The ABM model is established to facilitate the investigation of how the flood prevention measures applied by SMEs affect the continuity of their business operations in the event of a flood.

Furthermore, in the studies of Yang (2018), the flood risk management approach has considered other human intervention measures, including early warning information, adaptive behaviour, personnel or property evacuation, and multilateral relief from local communities. The ABM model is used to simulate the flood response preferences and actions of each household in the Ng Tung Basin, Hong Kong to reduce flood losses [14]. Based on their previous flood experience, the model implements a human response framework for the early warning system and simulates their decisions on future flood accidents. Overall, the ABM model has proven to be useful for analysing flood losses and response measures and may help allocate flood contingency planning resources in flood events.

3.3. COVID-19

Nowadays, the COVID-19 pandemic has affected the entire world and the entire society. Generally, various economic activities related to human interaction have been changed to online activities instead of minimizing the spread of the COVID-19 virus. Therefore, the spread of COVID-19 has greatly influenced the construction industry, delayed, and stopped construction projects under development, disrupted the supply chain, and due to a shortage of quarantine personnel [15-17]. According to Araya (2021), the ABM model has been used to simulate the risk of spreading COVID-19 among construction workers in different activities. Overall, through the implementation of the ABM model, the results showed that due to the COVID-19 outbreak, the project labour force was reduced by 30% to 90%, which may affect future construction plans. Therefore, managers can minimize the outbreak of COVID-19 by redesigning high-risk activities and maximizing low-risk activities in construction projects.

Besides, Cuevas (2020) have applied the ABM models to estimate the risk of COVID-19 outbreak in different facilities. In general, COVID-19 is a highly contagious disease. It is spread through various methods of transmission, such as droplets when sneezing or coughing, and direct physical contact. Therefore, the ABM model was chosen to simulate the pandemic where it can accurately define the dynamics of the disease, especially when it can also distinguish the transmission process between people [18]. The decision-making of the simulated agent depends on the programming rules in the model, which correspond to the spatial pattern and the infection conditions, under which the agents interact to characterize the propagation process. In addition, the social characteristics and health status of each agent are defined through the interaction with each other by using the ABM model. Therefore, the ABM model has been applied to formulate strategies or policies to reduce the risk of COVID-19 transmission.

4. Discussion and Conclusion

The ABM model has been defined as a modelling method that can represent the shift from social sciences to models that work on the individual level. Besides that, it has also been identified as a powerful mechanism that can be used to solve and identify problems, especially in biology, ecology, sociology, criminology and environmental research. In general, the main advantage of ABM is that it can simulate the emergent phenomena from bottom to top when running the simulation. For example, the ABM model has been used in flood preparedness and flood risk management to reduce losses caused by the actions and interactions of victims (agents) and local authorities in flood disasters.

In addition, the ability, flexibility and applicability of the ABM model to observe in multiple dimensions also help to simulate the complexity of the agent. For example, it can be used to simulate the interaction between the decision and motivation of criminal behaviour and the surrounding socio-economic factors. In addition, ABM can flexibly simulate different descriptions and aggregation levels, which is also conducive to the police predicting potential victims or criminal targets in the future. Another dimension of flexibility is the ability to change levels of description and aggregation. Furthermore, the ABM model has also been used in the study of the COVID-19 pandemic to simulate the spread of the virus between human beings in the workplace. For example, the coexistence conditions that need to be prevented between communities are also simulated in order to reduce the risk of COVID-19 transmission.

Although there are many benefits of using the ABM approach as a research mechanism, it is subject to some limitations due to its application. Usually, the main difficulty that occurs is the functionality and capability of the ABM models in the complex system. Regularly, the results of this model are excoriated as inconsequential, inconsiderable, insignificant and trivial when it has been applied in a very complex system [19,20]. Besides that, another difficulty of ABM model is the use of implemented procedures based on theoretical assumptions and result models as a mirror image of the same processes and observations in the real world. Therefore, software engineers have implemented various solutions or strategies to improve the ability, flexibility and functionality of ABM in future research. In conclusion, ABM can be used to represent the real world in a software environment, thereby providing computer-based assistance in solving problems or enhancing cognitive ability.

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