International Journal of Service and Knowledge Management
International Institute of Applied Informatics
2024, Vol. 8, No. 1, IJSKM834

Social Impact Simulation Including Social Capital, Based on Current Status of Multi-Agent Simulation

Tomoichi Ebata *, Ryo Ariyoshi †, Shinji Tanaka ‡

Abstract

In recent years, there has been growing interest in social impact bonds (SIB), one of Environmental, Social, and Governance (ESG) investments. However, the motivation for SIB investments has not been so high because the purposes of SIBs are difficult to evaluate. In particular, social capital (SC), one of the factors for SIB evaluation, is trust and a network of human relationships. Still, it is an invisible resource and is not easy to calculate. This paper proposes a "social impact simulation (SIS)" that makes SC visible and enables quantitative evaluation of SIBs. We survey the trends and status of multi-agent simulations over the past 30 years, examine the implementation of new agent modeling and behavior required for SIS, and discuss methods that enable the analysis and prediction of complex social impacts. In addition, we introduce the social impact simulator for a case and report on how to make the simulator effective for social impact visualization.

Keywords: Multi-Agent Simulation (MAS), Social Capital (SC), Social Impact Bond (SIB), Social Impact Simulation (SIS), Subjective Well-Being (SWB)

1 Introduction

In recent years, there has been a growing interest in ESG bonds that focus on environmental, social, and governance elements. Social impact bonds (hereafter referred to as SIBs) [1], one type of ESG bond, are expected to solve the problems of current capitalism. However, the market's motivation to invest in SIBs is low. This is because it is difficult to quantify the social problems and the outcome of their solutions, and it is also difficult for investors to predict risk and return. In particular, social capital (hereafter referred to as SC), one of the evaluation indicators of SIBs,

* Societal Infrastructure Architecture Research Department, Service Systems Innovation Center, Hitachi, Ltd.
† Global Research Institute for Mobility in Society Institutes of Innovation for Future Society, Nagoya University
‡ Department of Civil Engineering Transportation and Urban Engineering Research Group, Yokohama National University, Yokohama, Japan

is an invisible resource of social ties and resources, such as trust, networks, and cooperative relationships among people and organizations. SC is hard to visualize and quantify, making it difficult to use for observation and prediction.

This study focused on an "individual," the smallest fundamental unit that constitutes SC, neither objects nor environments. Since an individual's SC changes daily over a long period, depending on the surrounding environment and community, we thought that visualization and qualification of SC as a whole society could be observed simultaneously. Therefore, we investigated multi-agent simulation (hereafter referred to as MAS) [2], as a method of evaluating the entire system by focusing on the individual.

In our research, we reviewed MAS papers from the last 30 years and categorized them into five fields. We also examined how advances in personal computer (hereafter referred to as PC) hardware and software influenced the growth of MAS. In the urban/transportation field, increased PC resources enabled geographic information systems (hereafter referred to as GIS) and mobility agents. However, despite versatile MAS simulators, we found it difficult to incorporate agent interactions, characteristics, and personalities. To incorporate these factors, we introduced "social impact simulation (hereafter referred to as SIS)" to visualize social impacts.

Social impact [3] is the social and environmental outcomes of projects or activities. We decided to focus on the relationship among SC, Built Environment (hereafter referred to as BE), and Subjective Well-Being (hereafter referred to as SWB) in this study. The SIS proposed in this paper calculates outputs of policies and their outcomes as social impact, which differs from MAS in three points: "Modeling of Agents," "Behavior of Agents," and "Scalability and Flexibility of Agents."

We created a three-layered model for individual agents and outlined how individuals influence communication using imitation strategies. We also developed a method to mass-produce them through genetic algorithms (hereafter referred to as GA).

Incorporating these methods, we developed a SIS simulator for park managers, which moves 40,000 agents a period of five years. The results indicated that regular events to facilitate communication among the agents might increase the residence SC and the number of park visitors.

This paper is structured as follows: Chapter II introduces the background of SIBs and SC visualization. Chapter III covers an overview of MAS, its field and trends over the past 30 years, and a specific MAS simulator in the urban/transportation field. Chapter IV discusses the application of MAS for SC visualization, including difficulties in using MAS. Chapter V presents our study on SIS and outlines the goals and requirements for achieving "Modeling of Agents," "Behavior of Agents," and "Extensibility and Flexibility of Agents." Chapter VI provides real-world examples of our SIS implementation. Chapter VII and after concludes with our considerations, findings, and future research directions.

2 Background

2.1 Social Impact Bond

In recent years, ESG bonds, which focus on environmental, social, and governance elements, have been attracting increasing attention. ESG bonds include green bonds (hereafter referred to as GBs), sustainable bonds, and SIBs. Among these, SIBs, in particular, are expected to be a solution to the problems of current capitalism, such as the pursuit of profit without regard to social responsivity or environmental impact and the widening gap between the two.

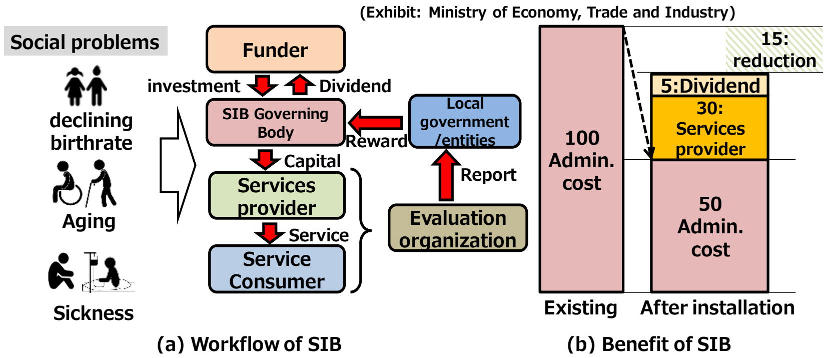


Figure 1: Configuration of SIB

SIBs are issued by local governments and entities, with private investors and financial institutions purchasing them. SIB governing body manages the funds. Service providers receive funding from the SIB governing body to deliver services to consumers. Independent evaluation organizations assess service outcomes, determining if they meet initial objectives. The government and entities pay the SIB governing body based on evaluation results (Figure 1).

2.2 Problems with SIBs as ESG Bonds

GB market is approximately \$269 billion and \$800 million in 2020 [4], and the number of news headers shows that the public interest in GB is bigger than that in SIB, according to Google Trends™ (Figure 2).

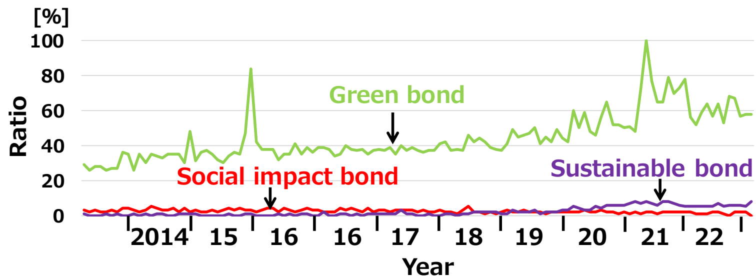


Figure 2: Number of news headers on ESG bonds

Thus, SIBs are less willing to be invested in the market compared to GBs. GBs have explicit purposes (e.g., prevention of global warming), which are relatively easy to measure (e.g., energy consumption), and their outcome (e.g., contribution to the SDGs) is easy to report. In comparison, the social issues handled by SIBs are more difficult to visualize and quantify in terms of content and achieved results. It is also difficult for investors to judge risk and reward. Compared to GBs, SIBs have the following problems.

(1) Difficulty in evaluation and measurement: Whereas the success of SIBs is related to achieving social outcomes or impact, it is not easy to evaluate and measure them.
(2) Uncertainty of impact: SIBs, as with regular bonds, provide a return on risk, but social impact is more difficult to predict than other impacts brought about by ESG bonds.
(3) Complexity and cost of implementation: The design, performance, and operation of SIBs require complex contracts, specialized knowledge, experience, and high prices.
One of the SIB evaluation indicators is SC. SC is invisible social connections and resources, such as trust, networks, and cooperative relationships among people and organizations, which are difficult to visualize and quantify. The problems described above about SIBs are thought to arise from the difficulty in visualizing and quantifying SC.

2.3 Previous Studies of SC Visualization

Research on SC visualization dates back to 1994. Some methods for calculating SC specifically for social affairs were proposed [5][6]. Some research was also conducted on statistical methods of SC visualization by taking its components from a particular social case [7][8]. Some studies defined SC as a resource individuals can access through networks and constructed concepts based on network theory [9]. Other studies used sensor technology to visualize SC within organizations [10].
These studies used one of the following methods: (1) surveying people and quantifying their responses; (2) analyzing connections between people and organizations to evaluate patterns of information dissemination and cooperation within networks; or (3) evaluating and quantifying the economic impact of social capital.

2.4 Consideration of SC Visualization by MAS

The following practical problems exist with SC visualization: (1) subjective factors and cultural differences must be taken into account, (2) quantified indicators do not capture the whole picture of SC, (3) the concept of SC is complex and multifaceted with calculative and non-calculative aspects coexisting. From the above, we thought it was not easy to observe the actual values of SC.
On the other hand, however, as mentioned in section 2.2, SC is defined as invisible social connections and resources, such as trust, networks, and cooperative relationships among people and organizations. If so, creating, modifying, or eliminating SC is theoretically possible by provisioning two or more objects that behave as defined SC. We thought that the whole SC in the real world might be visualized by preparing the same number of such objects as in the real world.
Therefore, instead of using a specific case and its environment in previous studies, we focused on the individual, the smallest fundamental unit that makes up the SC, and began considering using MAS to achieve this.

3 Overview of MAS

3.1 Purpose of MAS

MAS is a method of modeling and simulating the behavior of multiple agents in a particular environment through their interactions. The agents, such as human beings, trains, buses, and buildings can be installed as visible objects, and control systems, natural phenomena as invisible objects. MAS is used in various fields, including society, economy, environment, engineering, and computer science, as an essential tool for understanding complex problems in the real world. As for examples of MAS applications, it can address many problems, including urban traffic congestion, evacuation behavior during disasters, formation of social norms and ethical behavior, competitive and cooperative strategies, market interactions, and price formation.

3.2 Problems with MAS

MAS has the following problems.
(1) High computational load: The calculation load becomes high by interacting with multiple agents. The bigger the agent number, the longer the simulation time.
(2) Validity of modeling: MAS can model complex phenomena, but verifying whether the model is valid is difficult. Field experiments will be required to examine the model.
(3) Difficulty in predicting agent behavior: MAS agents are subject to random elements and influence from other agents, making it difficult to predict their behavior accurately.
(4) Difficulty interpreting results: Specialized knowledge is required to interpret simulation results. In addition, when the results differ from expectations, it isn't easy to find the causes.

3.3 MAS Application Field and Trend

3.3.1 Changes in MAS application over 30 years

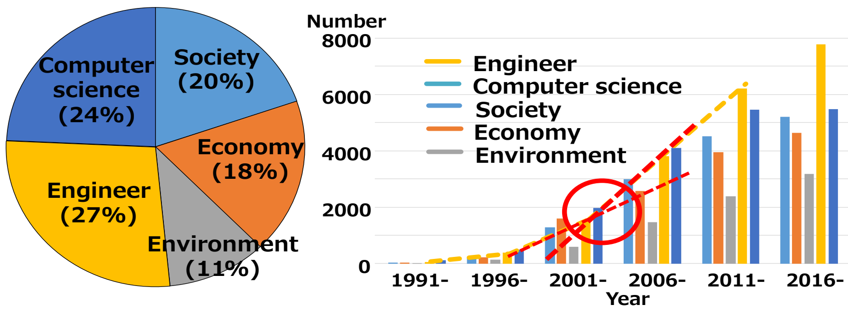
MAS is applied to various fields, including society, economy, environment, engineering, and computer science. We counted the number of papers from the 1990s to the present by entering the following keyword in Google Scholar™ databases in Table 1.

Table 1: Fields of application of MAS over 30 years

Field	Keyword	Concrete Examples	Num. of paper
Society	Policies	Tax policies on society	1208
	Urban Development	Disaster and other buildings	5183
	War	Military strategies	1324
	Crime	Predicted crime rates	535
	Plague	Prediction of epidemics	997
	Human	Ethical behavior decisions	4697
	Crowd behavior	Evacuation behavior during a large-scale disaster	199
Economy	Market	Prices, supply and demand	4321
	Investment	Stock forecasting and trading	1936
	Business	Market entry or exit	6647
Environment	Ecosystems	Population dynamics	1780
	Climate	Climate change action	2455
	Disaster	Tsunami Prediction	2025
	Pollution	Air and water pollution	1472

Field	Keyword	Concrete Examples	Num. of paper
Engineer	Plant	Schedule Management	5541
	Transportation	Goods transportation planning	5416
	Mobility	Congestion relief measures	3210
	Energy	Electricity Demand Forecasting	5408
Computer science	Artificial life	Evolution of artificial life forms	1624
	AI	Learning, Competition by AI	6739
	Robotics	Collective action and harmony	2736
	Game	Strategy or equilibrium point	1972
	Security	Threat analysis of measures	4365

The pie chart on the left in Figure 3 shows the ratio of the total number of papers and the figure on the right shows the change in the number of papers on a five-year basis.



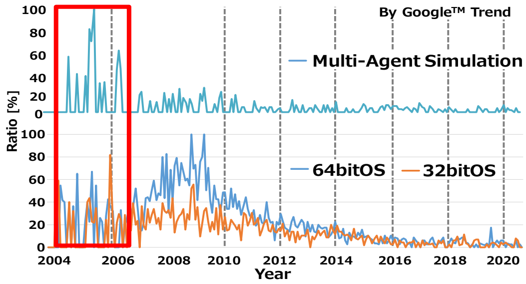
(a) Ratio of number of papers (b) Change in number of papers

Figure 3: Total number of papers and change

There was a trend of increasing research using MAS in all fields, and the increase in engineering-related papers was observed around 2001 and has surpassed that of computer science since 2006.

3.3.2 Technical Singularity of MAS

As mentioned in 3.2, one problem with MAS is the high computational load, which can be mitigated by increased computer resources. The scalability of the number of agents and the simulation speed in MAS improved as the PC clock speed and amount of memory increased. In a 64-bit Operating System (hereafter referred to as OS), the upper memory capacity could exceed four terabytes, more than 500 times larger than 32-bit OS. Comparing the ratio of the number of news headlines among "Multi-Agent Simulation," "64-bit OS," and "32-bit OS" by Google Trend, we supposed that the transition from 32-bit OS to 64-bit OS started in earnest around 2004-2006, and as a result, MAS came to be favored by the advent of high-performance PCs.



(a) Ratio of number of New header

	Memory capacity	HDD Capacity
32bit OS	Max. 4GB	Limit 2TB
64bit OS	Approx. 2TB	2TB or more

OS: Operation system

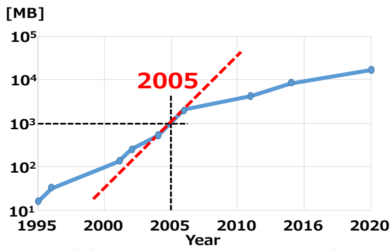
(b) Difference in OS specs

Figure 4: Relationship between MAS development and OS changes

Furthermore, examining the amount of memory installed in a notebook PC series, we found that the rate of memory growth increased significantly around 2005.

Year	Memory (MB)	CPU (MHz)	HDD (GB)	OS
1996	16	120	0.81	Win95
1997	32	166	2	Win95
2002	128	700	20	WinXP
2003	**256**	900	40	WinXP
2005	**512**	1200	40	WinXP
2007	**2048**	1060	80	WinVT
2012	4096	2700	750	Win7
2015	8192	2500	SSD256	Win10
2021	16384	2800	SSD512	Win10

(a) Specs of notebook PC by year



(b) Amount of memory growth

Figure 5: Changes in the amount of memory installed in notebook PCs

As a result, MAS, which used to be performed using a small number of agents, can now be performed on a real-world scale, and research on MAS in engineering has increased.

3.4 Considerations on Human Agents in MAS

We have surveyed papers since the 1990s focusing on human agents with built-in autonomous behavior algorithms. Below is a summary.

(1) Before 2000, a small number of human agents were used; however, the number of agents increased in the study, which focused on some areas such as "group psychology."

(2) Some behavioral psychology studies using human agents were on strategic planning against natural or artificial disasters or terrorism. However, the spaces were small, such as in a room of a building or part of a town.

(3) Human agents were often used as experiments and validations for research into psychological patterns. More than 15 psychological models were in the papers, including the "Tragedy of the Commons" and "Cognitive Map."

(4) However, the so-called "standard psychological model for human agents" does not exist yet.

3.5 MAS in the Urban/Transportation Field

3.5.1 Characteristics of MAS in the Urban/Transportation Field

The left side of Figure 6 shows the number of papers for MAS objects (freight or passenger) in urban/transportation, and the right side shows t the number of papers for passenger transportation (business or private) every five years.

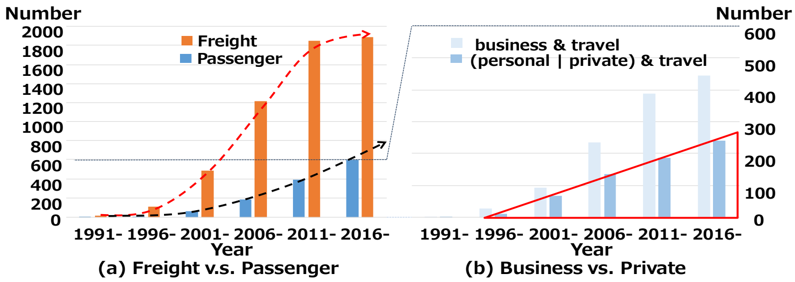


Figure 6: Number of papers in the urban/transportation field

The number of papers including "passenger" is smaller than that of "freight," however both have been increasing steadily and not only the number including "business travel" but also "private travel" have been growing. This trend may reflect the recent increase in shared or on-demand mobility services.

3.5.2 Relationship between MAS and GIS in the Urban/Transportation Field

Focusing on GIS, we examined studies using MAS since the 1990s and identified the following trends.

(1) Until 2000, GIS-based MAS was used for small-scale virtual towns and did not take the real world.

(2) From 2001 to 2005, MAS began to be applied in various fields. The development of MAS in a wide variety of fields, such as power plants, population, agriculture, etc., became more prominent.

(3) From 2006 to 2015, MAS applications came to focus on "urban transportation," "environment," and "energy." With the advent of Google Maps™, OpenStreetMap™, etc., real-world urban/transportation could be handled on maps.

(4) Since 2016, models of agent behavior have become more complex. Vehicle movements now consider not only the "shortest distance/time" but also psychological behaviors such as driver and pedestrian "personality."

3.5.3 MAS Simulators used in Urban/Transportation Field

Figure 7 compares the number of MAS simulators used in the field of urban/transportation papers since the 1990s.

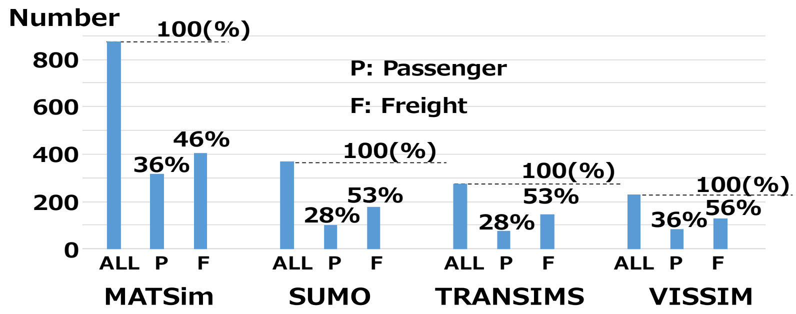


Figure 7: Comparison of simulators in urban/transportation research papers

MATSim [11], SUMO, TRANSIMS, and VISSIM™ are the most popular MAS simulators. NetLog and Anylogic were also popular, but the percentage of applications in the urban/transportation field was less than 50% in each case.

4 Consideration of MAS for SC Visualization

This chapter describes the visualization of SC by MAS, based on the discussion in Chapter III.

4.1 Advantages of using MAS for SC Visualization

We believe the following benefits are possible when using MAS to visualize SC.

(1) Individual agent characteristics: Attributes such as the agent's socioeconomic status, education level, values, etc. can be incorporated.
(2) Interactions between agents: Relationships between agents (friendships, family relationships, workplace connections, etc.) can be modeled to simulate how these relationships contribute to forming SC.
(3) Network structure: The topology of social networks, e.g., the patterns of connections between agents, can be modeled to explore the factors that influence SC.
(4) Change over time: It is possible to track how agent behavior and network structure change over time.
(5) Policy impact: Simulating how a particular policy or intervention affects SC is possible.. Thus, by using MAS to visualize SC, researchers and policymakers can better understand the interplay of various factors in the formation and maintenance of SC.

4.2 Problems of using MAS Simulator for SC Visualization

4.2.1 How to use Versatile MAS simulator

Figure 8 shows illustrates how to use versatile MAS simulators, widely used in urban planning and transportation studies.

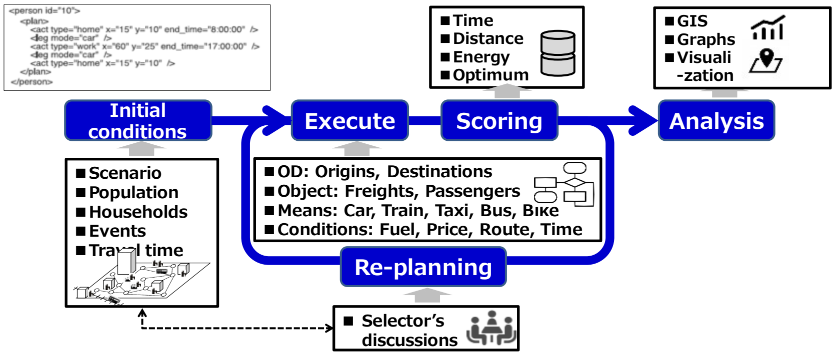


Figure 8: How to use versatile MAS simulator

Versatile MAS simulators work as a framework for day-to-day activity-based simulations. The simulation process involves setting conditions, performing calculations, and outputting results. Various aspects like the environment, human behavior, vehicles, and algorithms can be configured and evaluated. The road network is made up of links and nodes, and agents move through this network following predefined action plans.

4.2.2 Problems of Versatile MAS Simulator

Most versatile MAS simulators are designed for simulations spanning hours or days, with agents typically representing vehicles on roads. However, when dealing with scenarios involving organizational structures, human relationships, or aspects like SC and SWB influenced by human communication, it becomes necessary to create human agents and modify the core framework or add custom code using APIs. Consequently, it is difficult for a versatile MAS simulator to handle SC and SWB without extensive modifications.

4.3 Exploring SC Visualization in MAS for Urban/Transportation

The following trends were identified in studies using MAS since the 1990s, focusing on SC and SWB of drivers, passengers, and other mobility agents.

(1) Until 2005, no study combining "mobility" and "psychological modeling" appeared, presumably because the use of GIS software was difficult due to computer resource constraints.

(2) Since 2005, realistic MAS has been conducted with the same number of mobility and passenger agents as in the real world. However, the number of SC applications that use psychological models has been negligible.

(3) In recent years, most agents have used physical models. However, few applications use psychological models.

Versatile MAS simulators in urban and transportation face complexity problems with agent descriptions. Agent configurations are often static, typically defined in a specific format, e.g., XML. Whereas this defines specific agent behaviors, it struggles to capture complex agent interactions. The agents find it difficult to autonomously change based on their own SC or be influenced by others to update their SC. Given these difficulties, it is clear that new simulation concepts and simulators with innovative functions are necessary for effective SC visualization and SIB evaluation.

5 Social Impact Simulation (SIS)

This chapter describes SIS based on a new concept different from MAS in the urban/transportation fields.

5.1 Overview of Social Impact

Social impact is the short- and long-term social and environmental output and outcomes that result from a project or activity. Social impacts have included the spread of the Internet and the realization of social networking services. Social impacts are also expected to expand into various fields such as environment, economy, politics, technology, education, health, and wellbeing. Figure 9 illustrates social impact from an evaluation perspective. Evaluation of existing social activities is measured in terms of money, quality, and speed, to increase assets and expanding business. On the other hand, social impact is measured in terms of the overall picture of the problem, future projections, promotion of social equity, and decision-making support for measures.

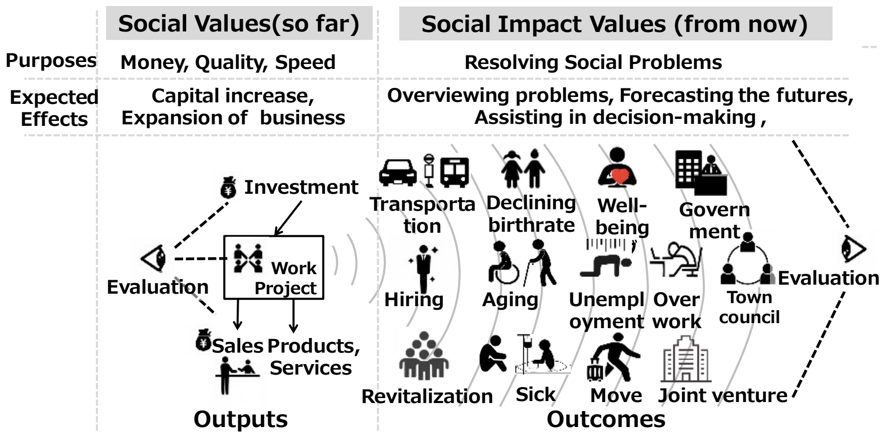


Figure 9: Values of social impact

5.2 Problems of Evaluation of Social Impact with MAS

Versatile MAS simulators can generate a virtual social space, experiment with agents, and obtain the outputs. However, outcomes are not easy to get. The reasons for this are listed below.

(1) *Modeling of agents:* Treating agents as simple moving targets without emotions is insufficient. The diversities and irregularities of real-world humans must be understood and reflected when modeling agents' decision-making processes and behavior patterns.

(2) *Behavior of agents:* Treating agents as passive objects responding to physical constraints is insufficient. It is necessary to understand how agents interact with each other over time and are affected by other agents.

(3) *Scalability and flexibility of agents:* It is insufficient to place and move many agents over an extensive map. Simulation time and computer performance must be addressed when generalizing simulations to larger scales, such as social problems. In addition, the interaction of agents and the social environment will require the design of highly flexible agents, such as creating and disappearing agents and other objects during the simulation.

5.3 Purpose of Social Impact Simulator (SIS)

We decided to design a "Social Impact Simulator (SIS)" to address the issues discussed in the previous section. This simulator aims to get both outputs and outcomes, as shown in Figure 10(b).

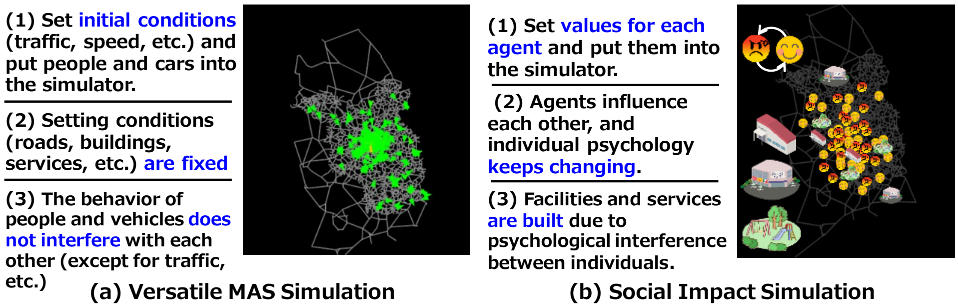


Figure 10: Coverage of SIS

In SIS, the values of various individuals are put into the agents. The agents influence each other, and their impact visualizes psychological and social changes. This is to visualize and quantify not only the efficiency of transportation and mobility but also individuals' emotional and social changes.

5.4 Requirements for SIS

Table 2: Requirements for social impact simulator

Item	Problems	Design Requirements
1	Modeling of agents	(1) Mechanism agent framework and its layers that link Social Capital of mobility to Subjective Well-Being of mobility.
		(2) Methods to perform specific calculations at each framework layer described above (1).
2	Behavior of agents:	(1) Situations of influence among agents and the concept of interaction of these influences.
		(2) Layers to be interacted with and specific methods of interaction
3	Scalability and flexibility of agents:	(1) Logically valid agent data generation methods
		(2) Design policy for a simulator engine running a large number of agents

As for the modeling of agents in Table 2, it is necessary to clarify the environment surrounding the agent, the agent's qualities, and the structure of the agent's SWB and to put them into a computable method that a simulator can handle. As for the behavior of agents in Table 2, it is necessary to specify how agents affect or are affected by encounters between agents and then drop them into a computable method. As for the scalability and flexibility of agents in Table 2, generating a large amount of agent data is necessary. However, these agents require methods of generating agents that do not simply use random numbers or fixed initial values but use existing data without changing the data trend. It also involves computing methods for running such a large number of agents.

5.5 Objectives of SIS

The social impact is to simulate whether the modes of transportation and the results of that transportation in a given region give people a sense of well-being and satisfaction. Many studies have shown that people's daily travels contribute to their health and, in turn, reduce health care and social security costs [12][13]. Some studies have shown what kind of city transportation service satisfies the community. Still, as noted in 2.3 above, few have attempted to design and estimate it quantitatively. The purpose of the simulation in this study is to answer questions such as, "How much value does the 'transportation service' give to the city's people now?" "What will happen if the transportation service in this city is left as it is?" and "What measures can be taken now?"

5.6 Modeling of Agents

5.6.1 Two Elements of SIS

SIS consists of the following two elements.

The first element is environments, which consists of two components, BE and SC. BE is the overall environment that humans have constructed and developed, including buildings and infrastructure. SC is a concept that refers to resources and elements associated with people and social connections, such as social ties and relationships, trust, cooperation, communication, and empathy [14][15][16].

The second element is agents. The agents may appear more likely to achieve SWB through improved mobility. However, that is not necessarily correct because it depends on individual behavior and activities.

Therefore, we decided to introduce a component, "Subjective Mobility (hereafter referred to as SM)" [17] [18], including three subcomponents, "mobility for individual," "behavior of trips and travel," and "activity for satisfaction." These three subcomponents are fundamentally based on individual values, behavioral principles, and policies, and they also interact with and influence each other with BE and SC. Figure 11 illustrates these relationships in a layer diagram.

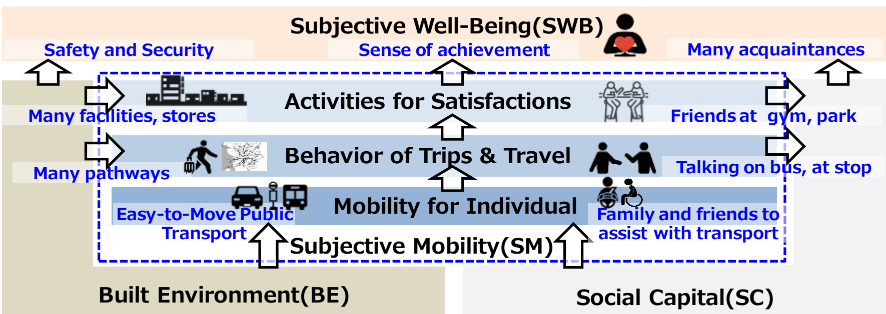


Figure 11: Layer diagram

SM is affected by both BE and SC. For example, "good public transportation, and easy to get around" or "family and friends who drive me around" improves mobility for individuals. The behavior of trips and travel is affected by mobility as well as by BE. For example, many pathways increase freedom of choice. The behavior of trips and travel may also create a sense of community and communication through encounters during travel, which may affect SC. The activities for satisfaction are affected not only by BE but also by the behavior of trips and travels. For example, more facilities like stores, will naturally increase activity and satisfaction. The activities of satisfaction also encourage interaction among individuals by increasing the frequency of access to specific places. This will contribute to the improvement of SC.

5.6.2 *Methods in the Layer Diagram*

We considered the methods needed in each layer in Figure 11 to the agents in SIS. An overview is shown in Figure 12. Here, methods are the ability to interact with other agents and access their data.

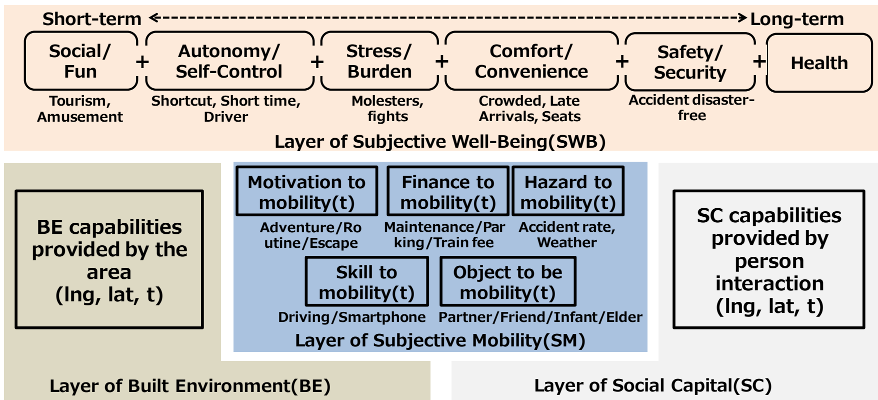


Figure 12: Methods of each layer

The layer of SWB implements methods of destination entertainment, mobility, self-determination, stress reduction, convenience, comfort, safety, and health. The layer of SM implements methods for mobility motives, mobility funds, mobility risks, mobility skills, and mobility targets based on information obtained from the layer of BE or SC methods and the agent's personality. The layer of BE implements methods related to the environment provided by the area's location. In contrast, the layer of SC implements methods to create or extinguish by SC through human communication. This method is discussed in detail in 5.7.
All methods' outputs change with the time parameter (t). The time parameters reflect agents' physical strength, energy, family structure, interests, financial resources, etc., and change with age. The outputs of the layer of BE also may continue to change with the environment. The outputs of the layer of SC also need to be reflected by changing the area's characteristics.

5.7 Behavior of Agents

This section describes the interactions that can occur when an agent performs communicative actions with another agent on the simulator.

5.7.1 Interactions of Agents

As explained in 5.6.2, the layer of SM is a function of interpreting BE and SC into SWB. The methods of the layer of SM have various attributes, which not only determine SWB thought mobility but also have the potential to influence the other agents. For example, a daily observed phenomenon in our society is that people with high BE or SC potential influence people with low one. SC gives a person's SWB. In addition, the person is also affected through SC or SWB of itself and others [19][20]. It means that each agent is the "inducers" that affect others, and other agents are the "receivers" affected by others simultaneously.

5.7.2 Imitation Strategy

Imitation strategy involves individuals observing and adopting the successful behaviors of others, avoiding the need for personal experience or trial and error. This strategy is found in applications of evolutionary game theory, social sciences, and ecology. In MAS, the strategy is used as an interaction method, often implemented using the Pairwise-Fermi method [21], which is defined based on agent distance or similarity.

$$V(i, j) = -A\,S(i, j)\,d(i, j) \quad \cdots\cdots (1)$$

V(i, j) represents the interaction potential between agents i and j, A is a constant that controls the intensity of the interaction, S(i, j) represents the similarity between agents i and j, and d(i, j) represents the distance between agents i and j. The following equation is used to calculate the probability that agent i imitates agent j's strategy (strategy imitation) (Equation (2)).

$$p_{i \leftarrow j} = \frac{1}{1+\exp\left(\frac{\pi i - \pi i}{\kappa}\right)} \quad \cdots\cdots (2)$$

π represents the gain from strategy implementation, with κ indicating sensitivity to gain differences between agents, typically set at 0.1. Considering π as an individual's mobility potential, the values from Figure 12 can express the impact when an agent with a high potential SM interacts with one having a low potential SM. SM is subject to constant fluctuations due to various factors, including negative ones like long-distance travel and loneliness, and positive factors like robust transportation infrastructure and local communication relationships. The concept of imitation strategy in SM is shown in Figure 13.

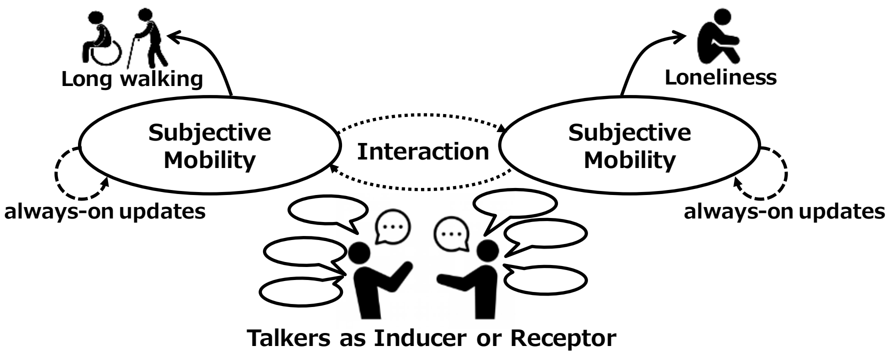


Figure 13: Imitation strategies with talking

Suppose the values of each function specified in Figure 12 are considered, for example, as three discrete strategies. In that case, these strategies can be represented in a state transition diagram like Figure 14.

In previous studies, SC has been calculated quantitatively using questionnaires, social network analysis based on such questionnaires, and economic indicators. In contrast, the method used in this study, in which agents are created on a computer, encounter opportunities are generated, and SC is calculated using the Pairwise-Fermi method, etc., is considered new and highly novel.

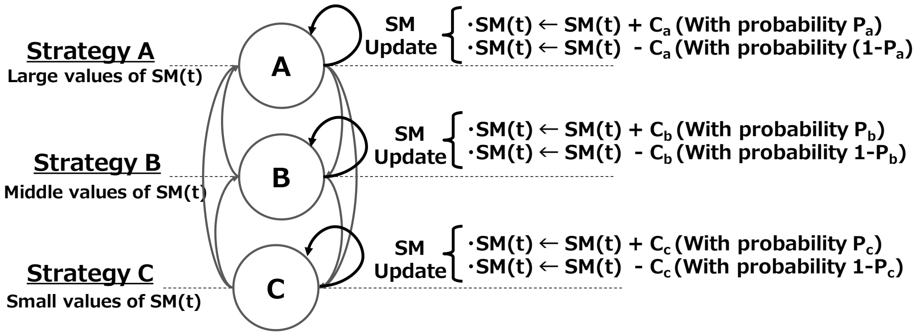


Figure 14: State Transition Diagram of Imitation Strategies by SM

Figure 14 shows how the imitation strategy changes due to influences concerning others' SMs and the values obtained from the SM.

5.8 Scalability and Flexibility of Agents

SIS differs from MAS in that it measures both individual and community by agents. Therefore, it requires the preparation of many agents that correctly reflect humans with different standards of behavior in the real world. Two generation methods are described below.

5.8.1 Methods to Create from Statistical Data

This method generates agents using information from the actual area to be simulated.

For example, the number of people in the target area is surveyed, and agents are generated for that number of people. For example, in Figure 15, the number of agents and generations can be derived as the number of people from the area. In this case, however, the problem remains that it is impossible to set the details of each agent, and some conditions must define each agent's personality.

Target	Gender	Number	Condition
Single and Parent 20-49	female	12,644	Office workers
	Male	14,137	
Middle 50-64	female	2,905	
	Male	4,847	
Elder 65-	female	2,425	Married couple in same residence
	Male	2,335	

Figure 15: Number of agents and conditions

5.8.2 Methods to Mass-Product from Existing Analysis Data

Interviewing many subjects is impractical and raises privacy problems. To address this, we proposed a method using pre-existing analyzed values. Worldwide published papers contain questionnaire results and their analyses, revealing community characteristics. We explored the possibility of reverse-engineering agents from these results. If solved, this approach enables (1) creating numerous agents mirroring questionnaire and analysis outcomes, (2) avoiding privacy problems, and (3) forming a group of agents that combine multiple questionnaire results. We attempted to achieve this using GA. Figure 16 shows an overview of this algorithm.

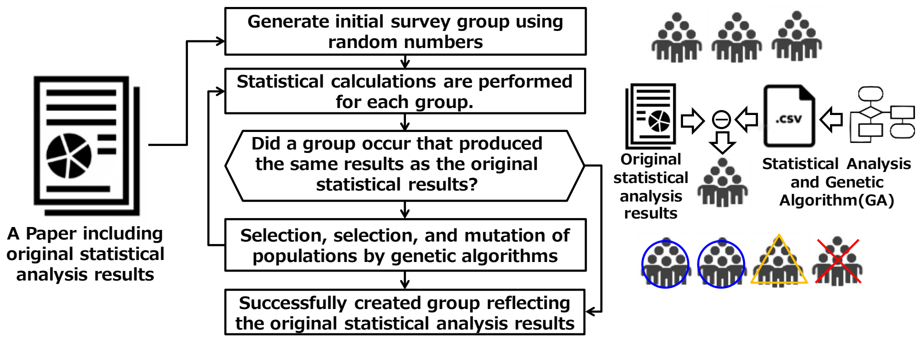


Figure 16: Mass produce agents using GA

We first surveyed twenty new employees to test the above algorithm's effectiveness. Respondents were asked to answer their work problems on a 5-point scale (1: not applicable to 5: applicable), and a factor analysis was conducted on the results (Figure 17).

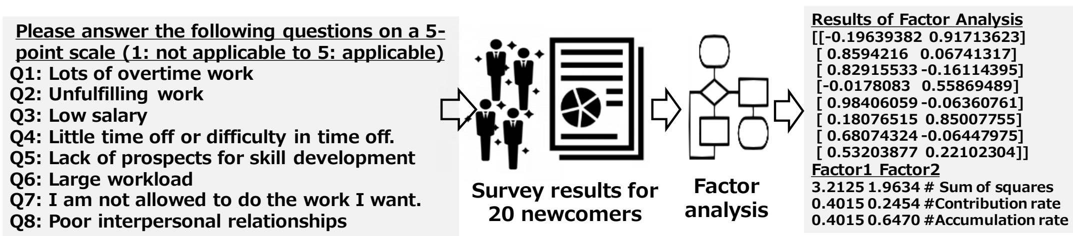


Figure 17: Questionnaire and factor analysis for new employees

The variables that were found to be strongly correlated with the first factor were x2, x3, x4, and x7, which represent "low motivation," and the variables that were strongly associated with the second factor were x1, x4, and x6, which mean "working hours." Using the values of this factor analysis, we attempted to generate 200 people and 2,000 agents using the algorithm in Figure 16, which leads to the same questionnaire results as the factor analysis results. The GA used in this study was based on the tournament method [22] with 1600 integers from 0 to 4 (for the generation of 200 individuals) or 16000 genes (for the generation of 2000 individuals), 100 chromosomes, a cross-incidence rate of 0.8, and a mutation rate of 0.3 (Figure 18). The machine was Windows 11 (64bit), AMD Ryzen 9 4900H 3.30 GHz processor, and 32.0 GB implemented RAM. The language used was Python 3.8.10.

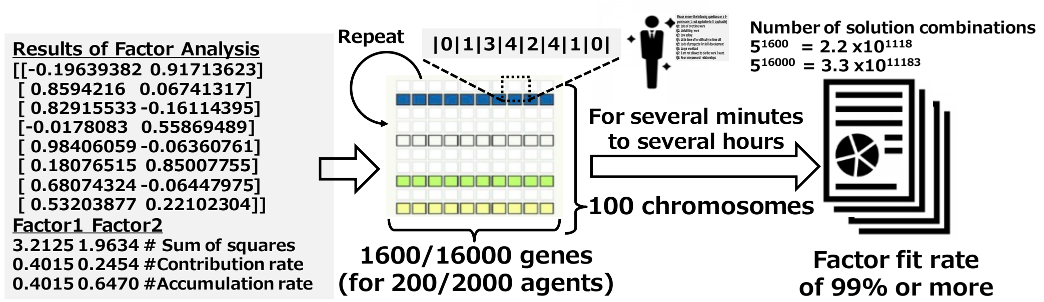


Figure 18: Generation of agents matching factor analysis results

In creating data for 200 people, we measured the Euclidean distance from the original statistical analysis results and created survey results with 99% agreement in the 569th generation and 99.4% agreement in the 918th generation. In addition, for 2000 respondents, it was found that 99% of the data could be generated in the 5500th generation and 99.9% of the data in the 9141st generation. The time required for one generation was about 2.0 to 3.0 seconds. Thus, we have a prospect of mass-producing many agents that reflect the original statistical analysis result.

5.8.3 Self-Lifetime Management of Agent

As mentioned in 3.2, MAS avoids the overhead of subsequent processing by reserving an amount of memory for agents in advance. In SIS, (1) neither the number nor the type of agents should be fixed in the initial state, and (2) the timing at which agents appear or disappear constantly changes due to interference from other agents and the environment. It also assumes (3) the entry from external systems, like joining from a real user's smartphone, etc.
Hence, it is desirable that the simulator does not manage all agents but is configured so that each agent manages its occurrence and state update.
To achieve these, we designed a "one thread for one agent" method that uses lightweight threads "goroutine" provided by the runtime library of Go language [5]. Compared to general threads (such as threads in the Java™ language), a goroutine requires less than 1/1000th (a few KB) of the stack memory. Although Java™ has an upper limit of about 1000 threads in effect, Go language can have tens of millions of threads, which is enough to launch all the agents of a social simulation, and has a small start and stop overhead, allowing for concurrency parallel processing.

6 Applications of SIS Simulator

This chapter outlines application examples of the Social Impact Simulator based on the previous chapter’s contents.

6.1 Simulation for Park-PFI Operators

Park Private Finance Initiative (hereafter referred to as Park-PFI) [23] is a procedure for selecting private operators to establish or manage park facilities such as restaurants and stores through public solicitation. Suppose the revenue generated from the facilities installed by the operator is returned to the park. In that case, the operator is given incentives such as relaxing the maximum building coverage ratio for newly installed cafes, stores, and other facilities.

In this simulation, in the area shown in Figure 15, to stabilize the PFI business by increasing the income of the Park-PFI operator, we tried to see if the number of park visitors could be improved by holding weekend events in the park, enhancing SC to promote interaction among residents, and increasing SWB (entertainment and health). We attempted to see if the number of visitors to the park could be improved by holding weekend events and enhancing SC that encourages interaction among residents.

The left figure in Figure 19 shows the methods used in each layer of the agents in this simulator. The upper right figure in Figure 19 also offers an overview of the Park-PFI project and the targeted simulation area. The lower right figure shows the simulation's results. Thanks to this simulation, we could quantitatively estimate new findings, such as that regular park events effectively attract visitors or that improved visitor attraction on weekends contributes to increased visitor attraction on weekdays.

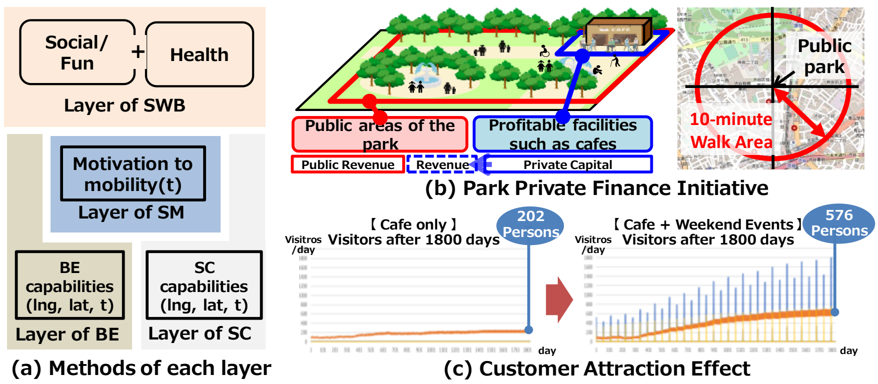


Figure 19: Overview of simulation for Park-PFI operators

7 Discussion

7.1 Insight from the Evaluation

In this paper, we attempted to analyze a new approach to calculating social capital using our method, which performs the calculation using multi-agent simulation. From the validation of Park-PFI in Chapter VI using this approach, we believe that this method has achieved specific results for calculating social capital.

7.2 Methodological Contributions

This paper adopts a new approach, whereas previous studies have relied primarily on analyzing questionnaire results from a small number of subjects based on the empirical findings of experts. Earlier methods were time-consuming, expensive, and difficult to reuse the results. However, this study uses the same number of agents as the real-world population to simulate the daily behavior of agents over five years. Although this approach is time-consuming to simulate, the case in Chapter VI was completed in a few dozen hours on a personal computer, demonstrating that it is cost-effective.

7.3 Impact to Industries

Calculating and predicting social capital based on subjective well-being (SWB) has become essential in modern society. In particular, as SWBs are strongly related to people's physical and mental health, this study will be helpful in the healthcare, medical, pharmaceutical, nursing, food, and life insurance industries. It will also reduce long-term care insurance costs among social security budgets. While the simulation approach presented in this paper does not guarantee the formation of current or future social capital, it does provide the industry with a means to consider policies before fully implementing them. This approach helps policymakers make more informed choices by building predictable future scenarios.

8 Conclusion

This paper examines social impact simulation (SIS) that calculates the outputs and outcomes of social impact as one method of expanding the market for social impact bonds (SIBs) to solve the problems facing capitalism today. Social capital (SC), one of the factors for SIB evaluation, is an invisible social connection and resource such as trust, networks, and cooperative relationships among people and organizations, which are difficult to observe and predict. For such "visualization of SC," we focused on the "individual," the smallest fundamental unit that constitutes SC, and decided to base our research on MAS, which handles a large number of individuals as agents and enables "visualization" of social phenomena as a whole.

First, we surveyed papers from the past 30 years on the use of MAS. The results show that the number of papers and interest in MAS increased from 2001 to 2005. This was brought about by the advent of 64-bit operating systems on PCs and the associated increase in resources that enabled PCs to provide the computational power to deploy MAS simulations from the experimental and verification level to the real world. It was also found that versatile MAS simulators, which pre-describe agent attributes and behaviors and realize agent movement and interference through time-based iterations, have difficulty incorporating agent characteristics and personalities and calculating SC and SWB.

Therefore, we decided to modify the existing MAS from three perspectives to realize SIS. By "modeling of agents," we showed that layers of BE, SC, SWB, and SM were inserted between them and placed methods that could serve as a basis for computing the mobility literacy of an agent. In addition, as "behavior of agents," we incorporated imitation strategies and proposed a specific computation method using the Pairwise-Fermi method. Furthermore, regarding "scalability and flexibility of agents," we devised a technique for mass-producing agents using GA and a method to autonomously generate agents to annihilate themselves using lightweight agents in a programming language. An example was used to demonstrate that this simulation can contribute to the visualization of SC of individuals and society.

9 Future Work

In this study, we presented a method using GA for the mass production of agents. We plan to consider what constraint functions should be used and what chromosomes should be modeled for mobility information.

We also plan to study how to implement SIS developed in this study to versatile MAS simulators in 3.5.3. The versatile MAS simulators are multifunctional and have been used and trusted for a long time. Such implementations will enable many people, especially decision-makers in governments, to use it to visualize SC and social impact easily.

Reference

[1] N. A. Garrett, J. C. Gertler, and B. A. Olken, "A Theory of Social Impact Bonds," NBER Working Paper No. 27527, Jul. 2020. [Online]. Available: DOI 10.3386/w27527

[2] A. M. Uhrmacher and D. Weyns, Multi-Agent Systems: Simulation and Applications, 1st ed. Boca Raton, FL, USA: CRC Press, 2009

[3] J. M. Jackson, "Social Impact Theory: A Social Forces Model of Influence," in Theories of Group Behavior, B. Mullen and G. R. Goethals, Eds. New York, NY, USA: Springer, 1987, pp. [page range]. [Online]. Available: https://doi.org/10.1007/978-1-4612-4634-3_6. [Accessed on Oct. 30, 2023].

[4] Amundi Research Center, "Green vs. Social Bond Premium," Amundi Research Center, 2022. [Online]. Available: https://research-center.amundi.com/article/green-vs-social-bond-premium. [Accessed on Nov. 18, 2023]

[5] Robert D. Putnam: "Social Capital and Public Affairs," Bulletin of the American Academy of Arts and Sciences, Vol. 47, pp. 5- 19, 1994.

[6] D. DiPasquale and E. L. Glaeser, "Incentives and Social Capital: Are Homeowners Better Citizens?" Journal of Urban Economics, vol. 45, no. 2, pp. 354-384, 1999.

[7] Burt, R. S., "Structural Holes: The Social Structure of Competition," Harvard University Press, 1992.

[8] Burt, R. S., "The Social Capital of Structural Holes," in "New Directions in Economic Sociology," M. F. Guillen, R. Collins, P. England, and M. Meyer, Eds. Russell Sage Foundation, pp. 148-190, 2001.

[9] N. Lin, "Building a Network Theory of Social Capital" Connections, vol. 22, no. 1, pp. 28-51, 1999.

[10] E. M. Daly and D. Gruhl, "Sociometric Badges: Using Sensor Technology to Capture New Forms of Collaboration," in Journal of Organizational Behavior vol. 31, no. 2-3, pp. 134-153, 2010, doi: 10.1002/job.673.

[11] A. Horni, K. Nagel, and K. W. Axhausen, Eds., "The Multi-Agent Transport Simulation MATSim," London: Ubiquity Press, 2016. [Online]. Available: http://dx.doi.org/10.5334/baw. License: CC-BY 4.0. [Accessed on Oct. 30, 2023].

[12] S. L. Szanton, B. Leff, J. L. Wolff, L. Roberts, and L. N. Gitlin, "Home-based care program reduces disability and promotes aging in place," Health Affairs, vol. 35, no. 9, pp. 1558-1563, 2016.

[13] L. M. Besser and A. L. Dannenberg, "Walking to public transit: Steps to help meet physical activity recommendations," American Journal of Preventive Medicine, vol. 29, no. 4, pp. 273-280, 2005.

[14] A. Portes, "Social Capital: Its Origins and Applications in Modern Sociology," Annual Review of Sociology, vol. 24, pp. 1-24, 1998.

[15] J. F. Helliwell and R. D. Putnam, "The Social Context of Well-Being," Philosophical Transactions of the Royal Society B: Biological Sciences, vol. 359, no. 1449, pp. 1435-1446, 2004.

[16] I. Kawachi and L. F. Berkman, "Social Cohesion, Social Capital, and Health," in Social Epidemiology, L. F. Berkman and I. Kawachi, Eds. Oxford: Oxford University Press, 2000.

[17] D. Merllie, "How to compare 'subjective' and 'objective' mobility," Sociologie du Travail, vol. 50, no. Supplement 1, pp. e50-e65, Dec. 2008. DOI: 10.1016/j.soctra.2008.07.004.

[18] G. O. Collantes and P. L. Mokhtarian, "Subjective assessments of personal mobility: What makes the difference between a little and a lot?" Transport Policy, vol. 14, no. 3, pp. 181-192, May 2007.

[19] H. Li, C. Cheng, and J. Yu, "Social Capital, Socioeconomic Status and Self-efficacy," Applied Economics and Finance, vol. 2, no. 1, pp. 1-10, Feb. 2015. DOI: 10.11114/aef.v2i1.725.

[20] R. D. Putnam, Bowling Alone: The Collapse and Revival of American Community. New York, NY, USA: Simon & Schuster, 2000.

[21] K. M. A. Kabir, M. S. Islam, and S. Nijhum, "Exploring the performance of volatile mutations on evolutionary game dynamics in complex networks," Heliyon, vol. 9, no. 6, Art. no. e16790, Jun. 2023. [Online]. Available: https://doi.org/10.1016/j.heliyon.2023.e16790. [Accessed on Oct. 30, 2023].

[22] D. E. Goldberg, Genetic Algorithms in Search, Optimization, and Machine Learning. Boston, MA, USA: Addison-Wesley Longman Publishing Co., Inc., 1989.

[23] N. Wang, "Private finance initiative as a new way to manage public facilities: A review of literature," Facilities, vol. 32, no. 11/12, pp. 584-605, 2014. DOI: 10.1108/F-09-2012-0069.

OpenStreetMap is a trademark of the OpenStreetMap Foundation and is used with their permission.
VISSIM is a trademark of PTV AG.