

## 46. Study on Development and Application of MAS for Impact Analysis of Large-scale Shopping Center Development

マルチエージェントシステム(MAS)を用いた大規模商業施設の影響評価に関する研究

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日本においては、大規模商業施設の郊外立地などにより中心市街地の商業機能などが衰退しているため、多くの都市において様々な都心再生政策が実施されてきている。しかし、都市システムに内在する不確実性と複雑性のため、大規模商業開発や都心再生政策の影響を評価することが難しい。本研究は、マルチエージェントシステム(MAS)を用いて、商業施設の立地に対する規制誘導政策を評価することを試みた。具体的には、商業施設の立地と世帯の購買行動を反映することができるシミュレーション・モデルとして、Shopsim-MASモデルを開発した。このモデルを用いて、商業施設の立地に対する規制誘導施策に対応して、都市圏における世帯の買い物行動をシミュレーションすることにより、商店と世帯の相互作用から発生した買物行動について予測することができ、政策の影響を示し、評価することができる。

*Keywords:* City center decline, Development regulations, Impact analysis, Multi-agent system.

都心衰退、開発規制、影響分析、マルチエージェントシステム

### 1. Introduction

The commercial environment of many local cities in Japan is experiencing decline so local governments have developed all kinds of city center generation policies to constrain this trend and revitalize the central city commercial environment. However, it is difficult to evaluate the potential impact of current policies on the future of a city due to the uncertainty and complexity inherent in an urban system, which arose from complex components of the urban system and complicated interactions between the different elements. Therefore, tools, which can provide insight into future impact of planning policies while embrace the complexity and uncertainty of the urban systems, are in an imperative need. It has been demonstrated that Multi-agent System (MAS) is powerful in exploring the uncertainty and complexity inherent in an urban system<sup>1,2)</sup>. Recently in Japan, Some researches began using MAS to analyze the phenomena of local city center decline in Japan. For example, Yosuke Ando et al.<sup>3)</sup> carried out a research on city center vacancy in which they simulated the emergence of vacant buildings and the effect of empty space on commercial space using agent based model.

The purpose of this study is to explore MAS to simulate the potential impact of city center generation policies. Different from most 'game-playing' MAS models which are based on pure agents' behavior disregarding urban planning institution, this study introduces the real land use zoning and planning regulations as constraints for agent's behavior, this is a big step forward for using the MAS simulation for planning practice. In this paper, the policies specially refer to the development regulations concerning the location sites and upper limitation of large scale shopping centers, which attract much attention of local governments since their closing in city centers and shifting to out-of-center location are commonly recognised as one of the major reasons for the decline of city Centers. The MAS model in this study is called Shopsim-MAS which is designed to simulate interactions between individuals that affected by the development regulations and to investigate their global effects on city centers' commercial environment. Within this model, a planner, a developer, households and shops are regarded as agents. The shopping-market spatial patterns emerging from interactions between shops and households are used for examination and exhibiting the impact of different development regulations.

### 2. Method

Given our purpose outlined in the previous section, it is our first step to extract development regulations used for regulating the location sites and floor space of large-scale shop centers (hereafter called B-shops) from the Urban Planning Law of Japan and a local city's center revitalization bylaw. Based on these regulations, different policy scenarios can be easily defined by users using Shopsim-MAS. Three possible policy scenarios are used to illustrate the application of Shopsim-MAS for impact analysis of development regulations. In these scenarios different B-shops' location sites and floor space upper limitations are prescribed.

These policy scenarios are carried out in a virtual city which are represented by a digital urban space. This space is constituted by cells which are heterogenous in terms of land use zoning status that are represented by a set of codes in the model and associated with variables indicating whether there is an existing large-scale shop or not. The 'citizens' of this virtual city are agents that are thought

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related to the policy scenarios, comprising of a planner agent, a developer agent and shop agents and household agents. The planner represents the local government who provides planning information and initiates policy scenarios; the developer constructs large-scale shops under policy constraints; new buildings of large-scale shops intensify the market competence and households make decisions regarding where to go shopping according to their own preference measured by maximum expected utilities. The shopping-market spatial patterns generated from local interaction between shops and households in each policy scenario are compared and analysed, thus the impact analysis of the development regulations are realized.

### 3. Development regulations for B-shops

Development regulations for B-shops are different between municipalities in terms of possible location sites and floor space upper limitation and are written in various formats. In this study regulations about B-shops's location sites described in Urban Planning Law are applied, and local regulations about B-shop development in Kanazawa City are also applied from 2002(see Table-1 and 2). In the urban planning area of this city, restrictions on B-shops's location and floor space upper limitation are different according to the planned zoning types defined in Commercial Environment Planning. Table-1 shows rules of location candidate sites, floor space upper limitation of B-shops that are stipulated in this city's bylaw. In this paper, these regulations are interperated into possible policy scenarios that will be launched in the virtual city.

Table-1 Bylaw for planning B-shop's location in Kanazawa City.

Location candidate sites	Requirements on candidate sites	Floor space upper limitation (m <sup>2</sup> )
Central area	CBD	No limit
	Improvement areas along main road	20000
	Other improvement areas	3000
		10000
Railway Station area	Areas along the main road connecting to station and other major transport facilities	10000
Cultural preservation zone	Areas along main road	3000
	Other areas	1000
Sub central area	Areas along main road	5000
	Other areas	1000
Neighborhood commercial areas	Areas along main road	3000
	Other areas	1000
Residential areas	Areas along main road	3000
	Other areas	1000
Industrial areas	Areas along main road	3000
	Other areas	1000

Table-2 Planning regulations on location of the B-shop.

Urban planning area	Land use zone	Permitting State
Urbanization Promoting Area	1 <sup>st</sup> low-rise exclusive residential district	X
	2 <sup>nd</sup> low-rise exclusive residential district	
	1 <sup>st</sup> mid-high exclusive residential district	
	2 <sup>nd</sup> mid-high exclusive residential district	
	1 <sup>st</sup> residential district	O
	Exclusive industrial district	
	Commercial district	
	Quasi-industrial district	
	Industrial district	
	2 <sup>nd</sup> residential district	
Urbanization Control Area	Quasi-residential district	O
	Neighborhood commercial district	
White Land	—	▲
X B-shops are not permitted to locate in these land zoning district O B-shops can be permitted to located in these land zoning district ▲ In principle any development are prohibit in Urbanization Control Area.		

### 4. Framwork of Shopsim-MAS

For examining the impact of B-shop development regulations, four types of agents are designed in this model. Two types of agents directly affect physical infrastructure of the virtual city, including a planner agent who makes planning decisions such as land zoning, development strategies, and a developer agent who builds the new B-shop whose scale and location must be consistent with planning policies. Our model employed the Decision Table<sup>4)</sup> to describe the decision-making process of the planner agent and developer agent. Besides the planner agent and the developer agent, there are two kinds of agents living in this virtual urban space, which are shop agents and household agents. New B-shops development will affect the supply of goods, market competition and household shop choice. Household agents decide autonomously where to go shopping according to their individual preference. Brief descriptions of the shop agent and the household agent are done as follows because the impact of different development regulations on the city commercial environment can emerge from the local interaction between shop agents and household agents as different spatial patterns.

#### 4.1 Shop agent

Shop agents are further classified into two types according to their floor spaces: B-shop agent and S-shop agent. S-shop here means the small and medium-size shop. The developer locates a new B-shop when he gets the development permission from the planner agent; S-shops concentrate in the commercial area and no new S-shop is created in this simulation.

S-shops are assumed to have homogeneous attributes, i.e. they have same goods prices and floor spaces. Households and B-shops however are heterogeneous. Existing B-shops' floor spaces and prices are given exogenously. The new B-shop's floor space are set according to local planning regulations when it is opened by the developer agent. Actually, the competition strategies of a new S-shop in a real society will not open to public, thus we assume that the new B-shop will launch a price strategy to compete with the existing

shops in simulation as equation (1), in which competitive impacts of the S-shops in terms of price and location and attractiveness of other existing B-shops in terms of floor space are considered.

$$P_n = K * \text{EXP}(-b * d_{on}) + \text{Rnd} * (S_n - S_c) / a. \quad (1)$$

Where:

The price of the new B-shop is  $P_n$ ; parameter  $K$  is a constant, equal to the price of small shops in city center; parameter  $b$  is the price decline index, which is given exogenously; variable  $d_{on}$  is the distance of the new B-shop from the city Center  $O$ ;  $\text{Rnd}$  is a number between 0 and 1 generated by computer following the uniform distribution, representing uncertain part of price derived from the influence of difference between new B-shop's floor space  $S_n$  and all existing B-shops' average floor space  $S_c$ ;  $a$  is an exogenous constant and here its value is set equal to 500.

#### 4.2 Household agent

The households have different estimates about distance, price, and shop's floor space when they decide where to go shopping. Through simulation, the market shares between B-shop and S-shop will emerge as spatial pattern in the simulation world. The change of spatial ratio of S-shops' market share to B-shops' could be used to assess scenarios initiated by the planner agent.

We adopt a standard random utility framework<sup>5)</sup> for household shop choice. In every step, households compare the expected shopping utility of optional shops, and choose where to go shopping unless their demands have been satisfied. This model is used to estimate the market shares of S-shops, B-shops and the new B-shop in simulation.

We assumed that:

- (1) The goods sold in all shops are homogeneous, i.e. the household goes to buy the same goods at all the shops.
- (2) Each household has a constant demand for goods. When the total demands of all agents are satisfied, the simulation process will be ended.
- (3) Each step, a household wants to buy a unit of demand.
- (4) A household only considers shops within a certain distance, his reachable distance  $\gamma$ .
- (5) The shop with the highest utility is supposed to be chosen. When available shops are under equal conditions in terms of utility, the household chooses one from them randomly.

The expected utility of household  $i$  associating with the alternative shop  $j$  is given by

$$U_{ij} = V_{ij} + \varepsilon_{ij}, \quad (2)$$

$$V_{ij} = \sum_k f_j(X_{kij}) - TC_{ij}, \quad (3)$$

$$f_j(X_{kij}) = \beta_{ik} \cdot X_{kij}, \quad (4)$$

$$TC_{ij} = \lambda_i \cdot \alpha \cdot \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}. \quad (5)$$

Where:

Variable  $V_{ij}$  is the deterministic part of the utility;  $X_{kij}$  is the  $k$ -th attribute including price and floor space describing store  $j$  presented to household  $i$ ;  $f_j$  is a function to evaluate the attractiveness of the  $k$ -th attribute of shop  $j$  to household  $i$ ;  $\beta_{ij}$  is a measure of the disutility of travel between site of household  $i$  and site of shop  $j$ ;  $\beta_{ij}$  is a specific taste weight of the household  $i$  with respect to the attribute  $k$  of a shop;  $\lambda_j$  is a parameter reflecting the attitude of the household  $i$  toward the cost of travel, here it is set equal to  $-1$ ;  $\alpha$  is an exogenous constant that represents the unit travel cost. Variable  $\varepsilon_{ij}$  is the unobserved random component of utility that is used to capture uncertainty of shopping behavior.

#### 4.3 Spatial patterns and market shares

Based on the random utility model, spatial patterns, generated from household agents' shopping behaviors, are represented by different combinations of shop's market shares. A shop's market share is measured by a fraction of cells where shopping rate of a household agent in the shop is more than 80%. If without the random component in the utility, even though household agents have different estimates of  $X_{kij}$ , the spatial pattern can be figured out in the first step of the simulation with a clear boundary between S-shop and B-shop's market shares. The random component can destroy the clear boundary and create different spatial patterns as shown in the Figure-1. However, when S-shops and B-shops are located at the same place, the boundary will not exist and a random spatial pattern will emerge. According to the simulation results of the case that B-shop and S-shop have different location, the smaller random component is, the clearer the boundary line appears. Thus, differences between household agents expressed by the random component will cause different spatial patterns. For checking the boundary between S-shop and B-shop's market shares, the smaller random component can deliver expected results because the impact from the differences of household agents in this paper is not important. Hence, the random value 500 for the utility model of both S-shop and B-shop are employed for further simulation.

### 5. Policy scenarios evaluation

In order to illustrate how MAS might be used to analyze impact of B-shop develop regulations on inner city regeneration, three policy scenarios are formulated, which different in terms of location sites and floor space upper limitation of B-shops. These scenarios are supposed to be performed in a virtual city which are the main components of the urban space of Shopsim-MAS.

### 5.1 The hypothetical urban space

This study concerns a hypothetical urban space of 2500 cells (50 X 50) where each cell measures 500 m X 500 m. The urban space comprises a central city and two neighboring cities. The model assumes that the central virtual city has the typical characteristics of Kanazawa city in Japan, namely with a traditional commercial center located in the heart of the city; with urban planning area (1230 cells) divided into Urbanization Promoting Area (UPA) and Urbanization Control Area (UCA) and with defined land use zones within UPA. All these planning information is assigned to each cell of central virtual city by the planner agent. The urban space spatial structure is shown in Figure-2 (a) and (b). The 1<sup>st</sup>-6<sup>th</sup> types of land use districts in Figure-2 (b) are zones where B-shops can be permitted to locate.

### 5.2 Process of simulation and policy scenarios

The shopping behaviors of household agents as described in subsection 4.2 are simulated for producing market shares of shop agents in urban space in order to visualize the impact of the new B-shop. The simulation process can be implemented as follows:

- 1) The user of Shopsim-MAS defines a policy scenario to be implemented.
- 2) The planner agent sets the spatial structure and initiates this scenario.
- 3) S-shop agents and existing B-shop agents are created in the urban space. Household agents are created and distributed to the whole central city urban planning area.
- 4) The developer agent places the new B-shop in urban space according to defined scenarios.
- 5) The user sets the initial values of parameter including unit travel cost, reachable distance of the new B-shop.
- 6) Households then decide where to go shopping as described in subsection 4.2 until their demands are fulfilled.

Based on the development regulations described in section 3, three scenarios are formulated for locating a new B-shop in the virtual city. 1) Center Activation(CA): To reverse the decline, encourage large-scale shop to locate in the center commercial area without upper limitation for floor space, but strictly restrict out-center location. 2) Railway Station Development (RSD): In order to develop the railway station area into a comprehensive business area, B-shop can be opened near the station, with an upper limitation of 10000 m<sup>2</sup>. 3) Neighbouring Commerce Promotion (NCP): To improvement community convenience, encourage B-shop to locate in neighbouring commercial area, with an upper limitation of 3000 m<sup>2</sup>.

### 5.3 Model test

As described in the household shop-choice model, the main exogenous parameters affecting deterministic utilities of household agents are unit travel cost ( $c$ ), reachable distance( $\gamma$ ) and floor space ( $S$ ). In order to examine the operational characteristic of the shopsim-MAS, a sensitivity analysis for parameter validation is conducted. Here each parameter is examined respectively and it is argued that if one parameter is proved valid in affecting shopping behavior, it is self-evident that all parameters can work together to impose such affection. The simulation is carried out under the setting as follows. Households in one cell are supposed to be homogeneous and are regarded as one agent; hence there are 1230 household agents in the simulation. Each household agent has 50 demands that indicates the number of shopping times in one month. There are two existing B-shops and seventeen existing S-shop in the city center. The floor space of the first B-Shop is set as 10000 m<sup>2</sup> and the second B-shop's is set as 20000 m<sup>2</sup> referring to the floorspace stipulated in planning regulations. In National Survey of Price (www.stat.go.jp), the floor space of a small scale shop is under

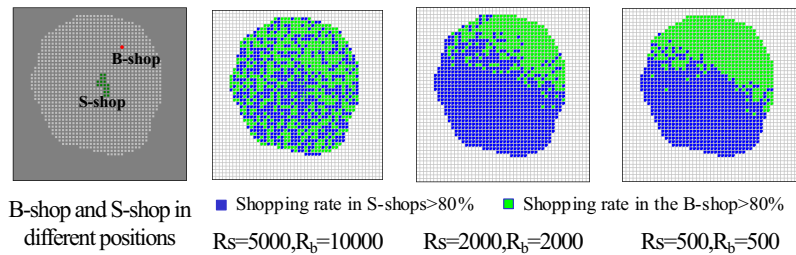


Figure-1. The spatial patterns of shopping behaviours.

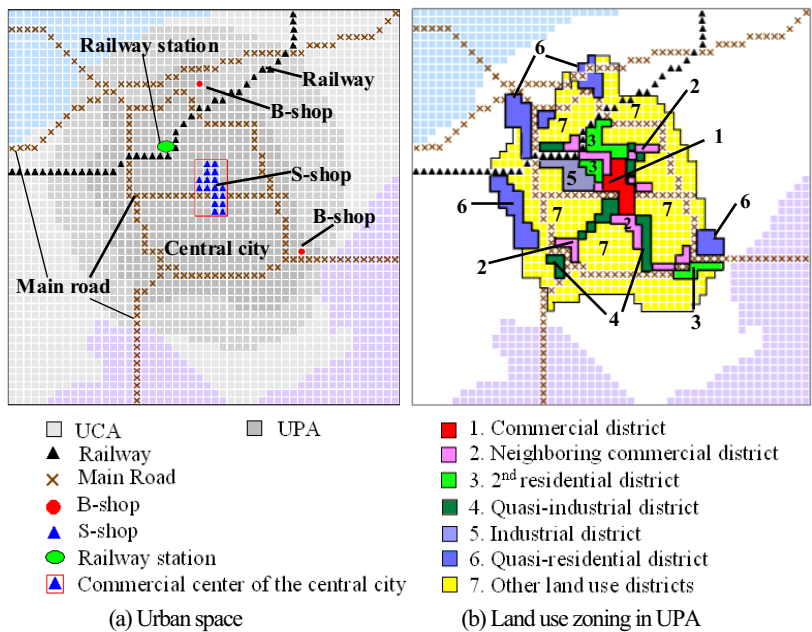


Figure-2 The hypothetical urban space spatial structure.



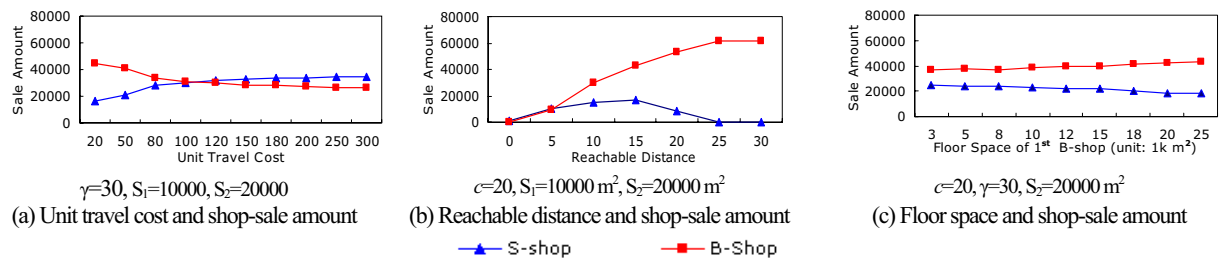


Figure-3 Parameters sensitivity examination.

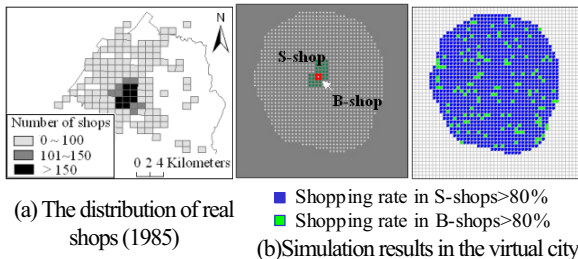


Figure-4 Real shops' distribution and virtual simulation.

Table-3 Comparison of sale amount in real and virtual center.

Mesh size	Shop (number)	Floor space (m <sup>2</sup> )	Sale amount	Market share
Reality (1km <sup>2</sup> )	S-shop (2006)	192445	186(billion en)	89%
	B-shop (4)	26483	22.4(billion en)	11%
Virtual (0.25km <sup>2</sup> )	S-shop (36)	10800	55475(demand)	90%
	B-shop (1)	1500	6025(demand)	10%

and that of B-shops is 26483 m<sup>2</sup>. For model test, the center area is mapped into 36 cells with 36 S-shops (the floor space of each S-shop is 300 m<sup>2</sup>) and 1 B-shop (1500m<sup>2</sup>), where the ratio of total S-shops' floor space(10800 m<sup>2</sup>) to B-shops' is 7.2, almost same with the real floor space ratio of S-shops to B-shops. The setting of Household agents is same with that in parameter examination. Figure-4 (b) shows the virtual shops' positions based on the real city and the simulation result. It can be seen that the performance of S-shops surpassed much that of B-shops because of their obvious advantages in number and floor space. Table-3 shows the comparison between the real data and the simulation result, which are in consistent with each other. Consequently, we can conclude that Shopsim-MAS can be employed as a promising tool to simulate spatial patterns of market shares.

#### 5.4 Comparison of different scenarios

Actually, there are some B-shops and S-shops in the center closed because of operating deficit and many B-shops locating outside the city center of Kanazawa after 1985. However, it is difficult to take into account all real shops in the simulation because of limited system capacity. Hence scenarios analysis is conducted under simplified hypothetical conditions.

Three scenarios are simulated with the same parameter settings as in the parameter sensitivity examination. The existing shops' positions are only set as Figure-2 similar to the location of B-shops in the eastern and southern Kanazawa City. The spatial effects of CA scenario is shown in Figure-5 and 6. Spatial patterns in Figure-5 are represented by market shares in terms of shopping rate. It can be seen that market shares of center shops (including S-shops and the new B-shop) and existing B-shops are separated by a boundary, but market shares concerning S-shops and the new B-shop appear a random pattern since both of them have the same location. S-shops are faced with fierce competition after establishment of a new B-shop in the city center and they lost most of their market share. From Figure-6, it can be learned that the larger the new B-shop is the more market share of the center shops, but S-shops' market share decreases. This indicates that CA scenario do have effect in improving the market performance of center shops as a whole, but may cause severe harm to the center S-shops at the same time if there is no limitation on B-shop's scale.

To compare three scenarios, the developer agent is made to develop a new B-shop of same floor space, 3000m<sup>2</sup>, in all these scenarios. The competition faced

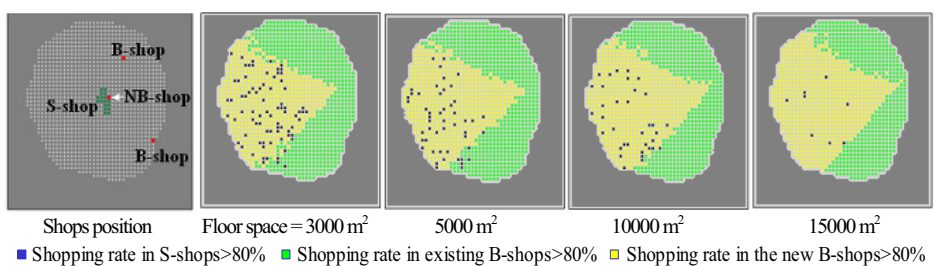


Figure-5 The spatial pattern of shopping rate of CA scenario.

by S-shops in the scenario RSD and NCP is not as strong as those in scenario CA, but market statistics reflect that both of RSD and NCP provide no any help in promoting the center commerce development(Figure-7). In later two scenarios the loss of market share of S-shops caused by the new B-shop is more than in CA scenario, as show in Figure-8. This further indicates that the CA scenario might be an effective measure to improve the activity of center commerce if there is a reasonable limitation on

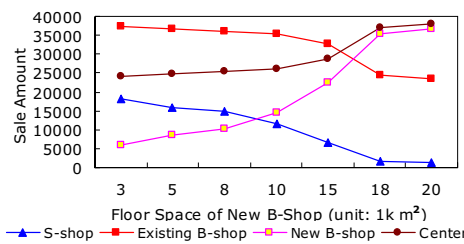


Figure-6 The sale statistics in CA scenario.

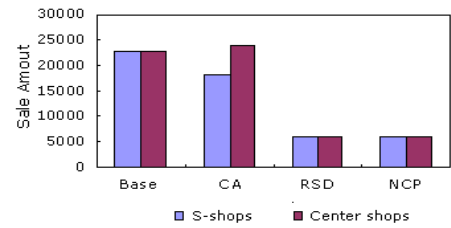


Figure-7 The sale statistics of shops in the city center.

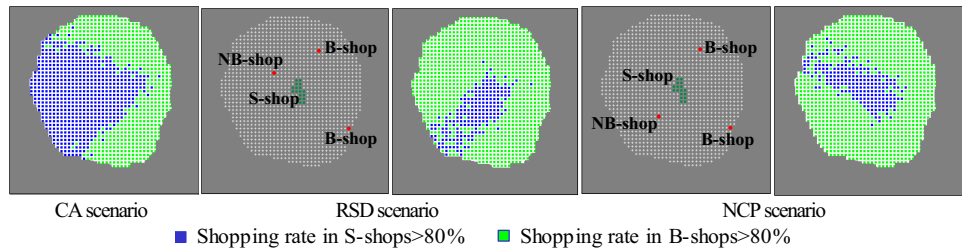


Figure-8 Spatial patterns of shopping rate in different scenarios (new B-shop floor space=3000m²).

B-shop's floor space. Comparing with commercial zones in master plan of Kanazawa city, CA and NCP scenario are accepted at the same time in the planning concepts, which might find a solution to the conflict between the affluence of the commercial center and the expansion of the city. If the model capacity can be extended to fit for the complex of reality, Shopsim-MAS can be employed as a promising tool to analyze the dynamic process regarding B-shop planning.

## 6. Discussion and further research

In this paper, the use of MAS for impact analysis of large scale shopping center development regulations is proposed and illustrated. First, by introducing real urban land use zoning to form agent's behaviour constraints, the Shopsim-MAS simulate the virtual urban space in a more practical way in the context of urban planning. Second, the operational characteristic of the Shopsim-MAS is examined through parameter sensitivity analysis and test with commercial survey data(1985) of Kanazawa. During this process, Shopsim-MAS exhibits how market spatial patterns emerge from the saling and shopping process indirectly affected by development policies, and how these spatial patterns can be used to analyse the impact of development regulations. The impact of the new B-shop on the commercial environment of the city center are visualized according to the three scenarios, which indicate that to develop new B-shop in the city center might be an effective measure to improve commercial activity of city Center as long as there is a reasonable limitation on B-shop's floor space.

As show in this paper, Shopsim-MAS proved to have a good performance in analyzing the impact of large scale development regulations from aspects of location sites and floor space. However, it does not necessarily mean Shopsim-MAS can be readily used in practice though we believe it would be the case. There are still many challenges remaining for further research. For example, the impacts of the dynamic competition between S-shops and B-shops on spatial market patterns are left as an unsolved problem. The most important challenge is how to deal with large amount data that required by micro-simulation and calibration in MAS. It is clear that a reasonably complete urban simulation model will need enormous amounts of detailed data, not only including land use, households and their characteristics, but also environmental and social-economic features. Data for planning are generally available in GIS form, and may be readily integrated into the database for model development. In future we will integrate the MAS model with GIS, and then more satisfying outcomes can be expected.

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