Study on a Decision Support System for Large-Scale Shopping Centre Location Planning Using a Multi-Agent System

Zhenjiang Shen, Mitsuhiko Kawakami, and Ping Chen
Kanazawa University, Japan

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Abstract: Multi-agent system as a bottom-up approach has been shown powerful in better understanding processes of urban development and growth. Most of them are approaching from economic theory and social behaviours but urban planning. This paper proposes an alternative approach to urban simulation that combines urban planning with agents' behaviour in multi-agent modelling thus to make scenarios analysis more reasonable particularly for decision based on urban land use plan. This paper discusses the approach as a computer simulative solution of a new large-scale shopping centre location for most regional cities in Japan where commercial heart of inner city is facing decline. We postulate that policy decision makers can get better understanding of the policies' impact on inner city commercial environment under different scenarios through computer experimentation.

1. INTRODUCTION

The commercial environment of most regional cities in Japan is experiencing decline in its centre area. More and more large-scale shopping malls shifting to out-of-city location is commonly recognised as the reason for the decline of city centres. Local governments have issued a series of policies in an attempt to promote the regeneration of central commercial environment by regulating the location of large-scale shopping centres.

There is a need to develop a simulation tool to exhibit the effects of different policy scenarios on the regeneration of central commercial

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environment. The context of social, economical and spatial processes in a city is a complex matter; this is exactly the situation at which multi-agent system model approach can be employed (Koch, 2005). Currently, there are a number of multi-agent models that simulate complex urban phenomena or dynamic development process in urban land use. However, as Batty and Torrens pointed out there are inherent limits for complex system models to predict urban future for purposes of problem solving (Batty and Torrens, 2005). We might be able to decrease this kind of limitation by implementing more complicated social behaviours as a procedure to approximate the real world environment in multi-agent simulation, and make it to be a better virtual laboratory. On the other hand, most of urban planners have a shared understanding that social behaviours are regulated by social norm and legislation, and those regulatory requirements could be utilised for definition of agents' behaviour rules in MAS simulation. Thus, not only the utility model based on economical and sociological theory but heuristic procedure based on urban plan regulations and relevant policies designated by urban law system can be integrated into agents' behaviour in the simulation model, this is likely to be considered as a worthwhile recommendation for installation of more wealthy agent behaviours in urban dynamic simulation using MAS.

So far at least, there are many projects that represent more and more acceptable and completive sets of agent behaviours in MAS simulation for various types of actors in urban space. Benenson (1998) simulated the population dynamics in a city, in which inhabitant agent can change their residential behaviour depending on the properties of their neighbourhood, neighbours and whole city. Ma, et al. (2004) accounted for uncertainty in large-scale shop location decision-making through representing developer agent's knowledge using Bayesian Decision Networks. CityDev, an interactive simulation model, provides a better reflection of reality in light of that it simulates the economic system of a city in its real and monetary aspects, in which students can play as Mayor or planner agents (Semboloni et al., 2004). There is also an multi-agent land-use and transport model for the policy evaluation of a compact city from the viewpoint of urban physical compactness, total trip length, energy consumption and the social welfare of residents (Kii and Doi, 2005). It has been demonstrated that multi-agent technology can be further used for generating sets of alternative land-use plans, in which agents are land-use experts that initiate the development of plan proposals and communicate with each other over time in order to draw up the proposals incrementally (Saarloos et al., 2005). However, few of them explicitly include the urban planning regulations and relevant policies as the preconditions or rules of agents' behaviour in simulation that should not only pursue agents' optimal behaviours conducted through solvable mathematical model, but also enable the agents to behave in response to actual constraints in land use.

The aim of the system presented in this paper is to provide a spatial decision support tool for local city planning on large-scale shop location. Different from other existing multi-agent studies aiming at decision supporting, this system utilises urban planning regulations and polices as agent's behaviour rules and an urban land use plan as simulating environment. Thus we can better measure the likely impact of land use policy at the local level. More specifically, planner agent provides the urban plan as the simulation environment and other agents who are active in the urban area behave consistently with rules of urban planning regulations and policies. Furthermore, planner agent should make proposes for revision of urban plan according to the simulation output of urban activities; consensus process under consultation of planner agent for amendment of bylaw is expected to be a simulative self-organization process between different agents.

In this paper, a case study is conducted to validate effect of restrictive items that are location candidate sites and floor area upper-limitation of new large-scale shop, which are described for regulating new large-scale shop development in bylaw system of a local city, Japan. For examination the impact of a large-scale shop on the commercial circumstance in inner city, the planner agent launches a scenario; the developer agent makes decision where to locate a new large-scale shop consistent with restrictive items, and household agents make decision where to go shopping through comparing respective utilities measured by price, distance, floor space and so on. This paper is structured as follows. First, the section 2 introduces the planning regulations for location of a large-scale shop in Japan, which is utilised as planning rules provided by planner agent in simulation. The followed section 3 outlines the framework of the system and gives an introduction to agent behaviour models of developer and household. Section 4 and 5 provide an illustration comparing different parameters and policy scenarios in terms of their effects on future inner city. Finally, Section 6 summarises the major conclusions and discusses points for future research.

2. PLANNING REGULATIONS FOR LOCATION OF LARGE-SCALE SHOP

2.1 Land use in urban planning area in Japan

In Japan, cities executing City Planning Law are grouped into two types. The first type is called Delineation City (DC), for that in these cities an

Urbanization Control Line (UCL) is set to divide urban planning area into Urbanization Promotion Area (UPA) and Urbanization Control Area (UCA). UPA is the area in which a local government is willing to promote urbanization and land use zoning ordinance must be carried out. UCA is the area where urbanization must be constrained. Land use zone is further classified into three major groups: residential, commercial and industrial uses including twelve categories of land use zones. Another type is called Non-Delineation City (NDC) in which urbanization promotion area and urbanization control area are not distinguished, but also consists of two kinds of area: the Certain Uses Area in which lands are classified according to how they are used and "White Land" in which land use type is not defined. Figure 1 shows the spatial relationship in urban planning area.

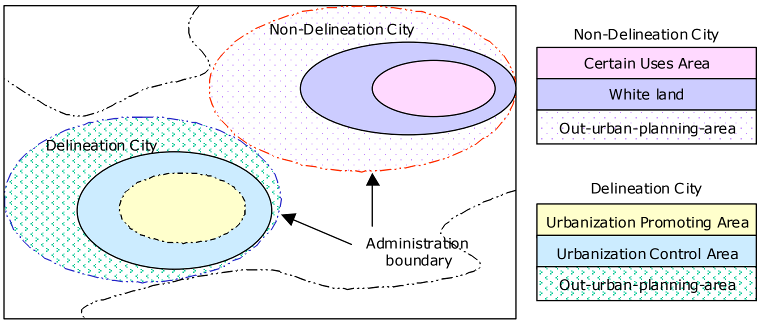


Figure 1. Urban Planning Area.

2.2 Large-scale shops and their possible location according to planning regulations

Under the Japan Large-scale Retail Location Law issued in 2000, there are two types of large-scale retail store. The first is defined as buildings with the shop floor area of 3,000 m^2 and over; the second is defined as buildings with the shop floor area of over 500, but less than 3,000 m^2. According to Japan Building Standards Law revised in 1995, the commercial facilities with more than 3000 m^2 floor space are referred as large-scale facilities. Here we adopt 3000 m^2 as the threshold of large-scale shopping.

Among twelve land use zone categories, there are the first class low-rise exclusive residential district, medium-high rise exclusive residential district, the first class residential district, the second class low-rise exclusive residential district, medium-high rise exclusive residential district and exclusive industrial district, in which large–scale shops are not permitted to locate. The regulations on large-scale shop location are shown in Figure 2.

There are also bylaws for regulating locations of large-scale shops in order to prevent inner city commerce from decline. Table 1 shows one in which the rules of location candidate sites, floor space upper-limitation of large-scale shops are stipulated. In this paper, the impact of the planning regulations and rules are visualized in order to observe the dynamic interaction of commercial environment between the inner city and its fringe.

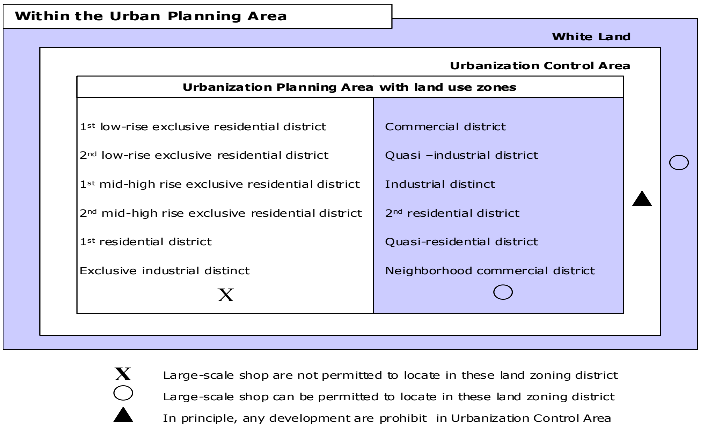


Figure 2. Regulations on location of Large-scale shop.

Table 1 Bylaw for planning regulation of large-scale shop location.

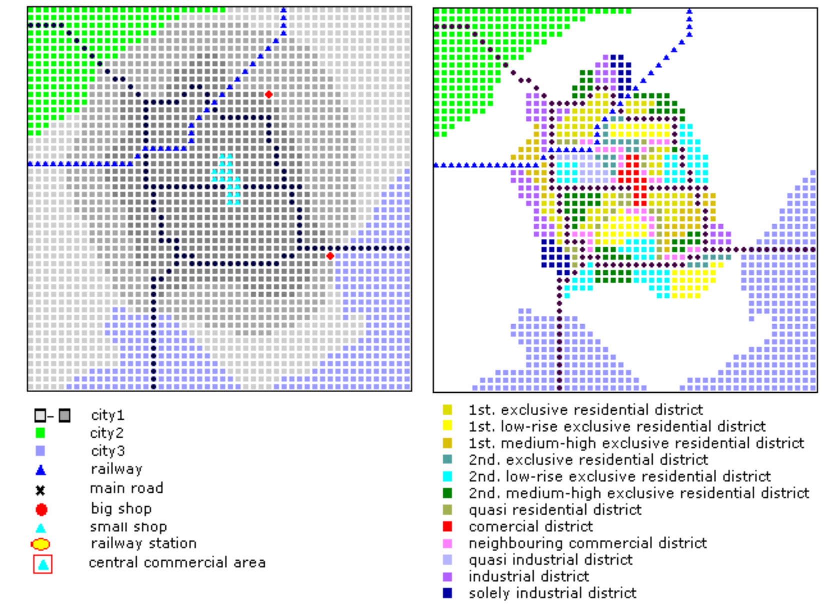
Location candidate sites	Sub conditions of location candidate sites	Floor space upper-limitation of large-scale shop (m^2)
Central area	CBD	No limitation
	Improvement areas along main road	20000
	Other improvement areas	3000
Railway Station area	Main road connecting station and other large-scale transport facilities	10000
Cultural preservation zone	Areas along main road	3000
	Other areas	1000
Sub central area	Areas along main road	5000
	Other areas	1000
Neighbourhood 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

3. FRAMEWORK OF SIMULATION

3.1 Agents in the simulation

Planner agent

Here, a planning conditions-based simulation approach is proposed to simulate the impact of large-scale shopping centres on inner city commercial environment. Although the model is again applied to a hypothetical city, the land use zoning and relevant policies are set the same as reality in a Japan local city. A planner agent is defined to provide planning information of each 0.25 square kilometre cell. The planning information includes not only land use plan but also planning regulations and policies associated with land use type, which could be changed by planner agent in the simulation through making consensus with other agents. In this paper we just make suggestion that planner can provide planning information and generate scenarios according to planning regulations and relevant policies. Actually, the role of planner agent for making consensus with other agents is remained as a future task.



(a) Urban Space (b) Land use zone in central city

Figure 3. The Environment of Simulation provided by planner agent.

The total urban planning area is represented as 50*50 cells including a central city and two neighbouring cities. The model assumes that the central virtual city has the typical characteristics of local city in Japan: 1) with a traditional commercial centre located in the heart of the city; 2) with urban planning area divided into UPA and UCA; 3) with defined land use zones within UPA. The upper-left neighbouring city like is a DC like central city and the right-down neighbouring city is a NDC. The urban structure is shown in Figures 3(a) and 3(b). Each cell on the urban space has its attributes defined and deployed by planner agent: The urban planning area types, land use zones and necessary urban facilities

Large-scale shop developer agent

Location can be very crucial for the development of shopping centre in the sense of affecting sales, market share and profits. Due to its importance and complexity, location problem itself has gained much interest. Modelling how to select a location with best competitive advantage for a shop, however, is not the focus of this paper. In this model, the large-scale shop developer agent probes the possible location for large-scale shopping centre under regulations and relative policies. If users click a button for launch a scenario, the planner agent will generate the initial setting for this scenario and the developer agent will search a location that matches the conditions described in the initial setting. To represent how the developer agent to find an appropriate location for a new large-scale shopping centres, we employed the Decision Table (T. Arentze, A. Borgers, et al, 2000) to describe this process (Table 2).

Table 2. Decision table of developer agent for large-scale shop location.

C1	Scenario	Center Activation (CA)				Railway Station Development (RSD)				Neighborhood Commerce			
C2	Location is permitted in UPA	Y			N	Y			N	Y			N
C3	Location is permitted in land use zone(s)	Y		N	/	Y		N	/	Y		N	/
C4	Floor space up-limit is acceptable	Y	N	/	/	Y	N	/	/	Y	N	/	/
A1	Create new B-shop	Y	/	/	/	Y	/	/	/	Y	/	/	/
		R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12

Household agent and Shop agent

Besides of planner agent and developer agent, there are other two kinds of agents living in this virtual urban space for examination and exhibiting of impact of large-scale shopping centres (hereafter: B_shop) on small shops (hereafter: S_shop) in inner city commercial environment: Shop, Household. Shop agents are further classed into two types according to the floor space: B_shop and S_shop. Developer agent locates a new B_shop when he gets the development permission from planner agent; S_shops concentrate in commercial area, no new S_shop is created in this simulation. The relationships between agents are show as Figure 4.

Small shops are assumed 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 are given exogenously. New B_Shop's floor space are set according to local planning regulations when it is opened by developer agent. All B_Shops' goods price is assumed follow an exponential decay with distance to city centre and is influenced by floor space and unobserved factors, given by

$$P_j = K * EXP(-b * d_{oj}) - Rnd() * S_j / a \quad (1)$$

Where

P_j is the price of the j th B_shop;

K is a constant, equal to the price of small shop in city centre;

b is the price decline index, which is given exogenously;

d_{oj} is the distance of the jth B_shop to city centre O;

$Rnd()$ is a random number generated by computer, representing uncertain part of price derived from the influence of shop's floor space,

S_j is the floor space of the jth B_shop;

a is a exogenous constant, here its value is set equal to 500.

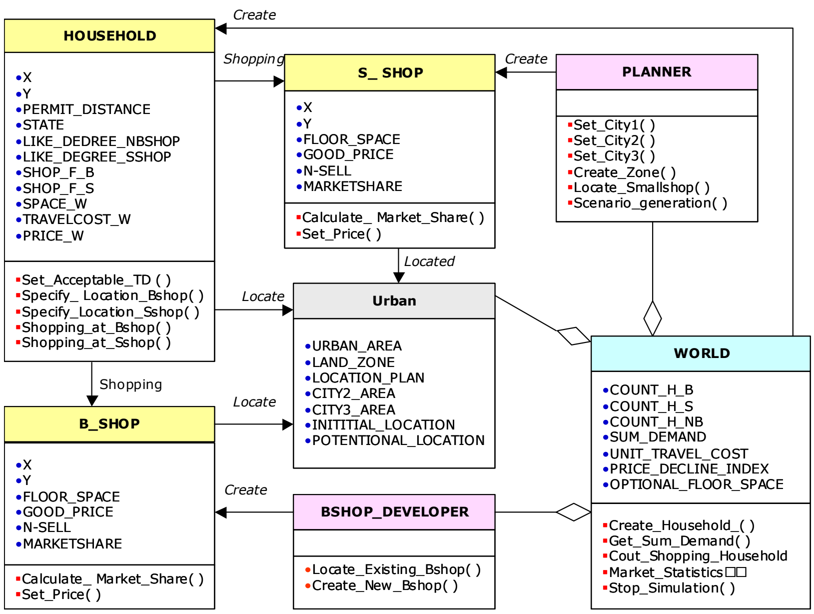


Figure 4. Objects and agents in the urban space.

To simplify, we assume that all households in one cell space have the same shopping preference and are represented by one household agent (hereafter 'household' means 'household agent'). The household agents are supposed to have different estimates as to distance, price, or shop's floor space when decide where to go shopping. Through simulation, the market shares for both of B_shop and S_shop will emerge as spatial pattern in the simulation world. The change of spatial ratio of S_shop to B_shop could be employed to assess scenarios generated by planner agent.

3.2 Household shop choice model

We adopt a standard random utility framework (Baltas et al, 2001) for household shop choice. In every step, what a household basically does is continuously comparing the shopping utility of optional shops and choosing where to go shopping unless his demands have been satisfied. When the total demands of all agents are satisfied, the simulation process will be ended. 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 (i.e. 50 units demand).
(3) Each step, a household wants to buy a unit of demand.
(4) A household only consider shops within a certain distance, his reachable distance γ.
(5) When available shops are under equal conditions in terms of utility, the household chooses one from them randomly.

The utility of household *i* associating with alternative shop *j* is given by

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

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

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

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

Where

V_{ij} is the deterministic part of the utility.

X_{kij} is the *k*th attribute describing store *j* presented to household *i.*, including price X_{1j} and floor space X_{2j}.

$f_j(X_{kij})$ is a function to evaluate the attractiveness of the *k*th attribute of shop *j* to household *i*.

TC_{ij} is a measure of the disutility of travel between site of household *i* and site of shop *j*.

β_{ik} is a specific taste weight of the household *i* with respect to the attribute *k* of a shop.

λ_i is a parameter reflecting the attitude of the household *i* toward the cost of travel, here it is set equal to –1.

α is an exogenous constant that represents the unit travel cost.

ε_{ij} is the unobserved random component of utility that is used to capture uncertainty of shopping behaviour.

The shop with the highest utility is supposed to be chosen, given by

$$P\ \{\text{choice is } j\} = P\ \{U_{ij} \geq U_{ik},\ \text{for all } k \neq j\} \qquad (6)$$

The simulation model described in this paper is currently implemented in KK-MAS (http://www2.kke.co.jp/mas_e/MASCommunity1.html), a tool for simulation of complex systems.

4. SENSITIVITY ANALYSIS FOR SIMULATION

Simulation process

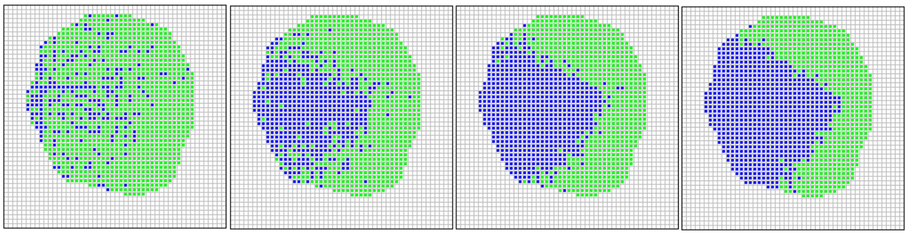
The shopping behaviours of household agents as described in section 3 are simulated for producing market shares of shop agents in urban space in order to visualize the impact of the new B_shop, which bring S_shop agents in a city centre into more intense competition.From the description given in section 3, the simulation process can be implemented as follows:

(1) Planner agent set urban planning areas, land use zones and commercial centre location.
(2) 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.
(3) Developer agent places the new B_shop in urban space according to defined scenarios and planning regulations.
(4) Give the initial values of parameter exogenously including unit travel cost, reachable distance and B_shop price decline index for the household shop choice model.
(5) Households then decide where to go shopping as described in section 3, until their demands are fulfilled.

Before policy scenarios simulation, we conduct a sensitivity analysis for our simulation model; see Figure 5 (a-d). At the moment, each parameter is examined respectively; we argue that if one parameter is proved valid in affecting shopping behaviour, it is self-evident that all parameters can work together to impose such affection.

Unit traffic cost (α)

Figure 5(a) shows the relationship between shop-sale and unit-travel-cost. Given that all shops are accessible to household (reachable distance=30), the less the unit travel cost is, the more likely the household to go shopping at out-centre large-scale shops and the less amount of goods the central centre sell. It is obviously that, if unit travel cost equal to 0, the market share of central small shops will shrink to 0.

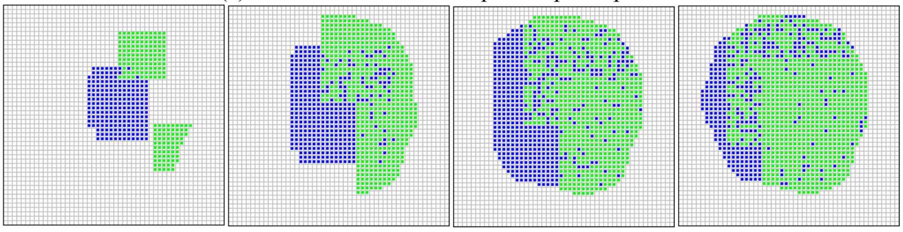


α=20 α=50 α=100 α=150

■ Household shopping at S_shop ■ Household shopping at B_shop

γ=30, b=0, S_1=10000, S_2=20000

(a) Unit travel cost and shop-sale spatial pattern

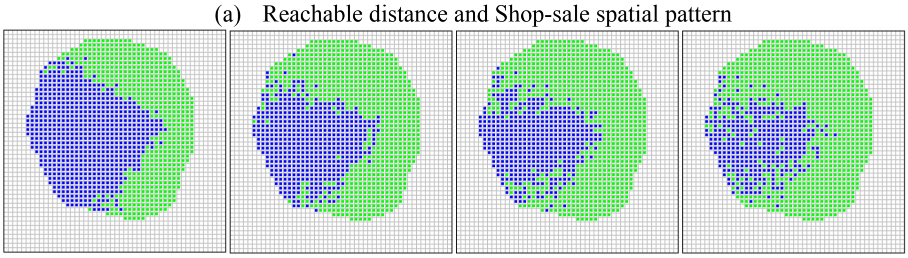


γ=5 γ=10 γ=15 γ=20

■ Household shopping at S_shop ■ Household shopping at B_shop

α=0, b=0, S_1=10000, S_2=20000,

(a) Reachable distance and Shop-sale spatial pattern

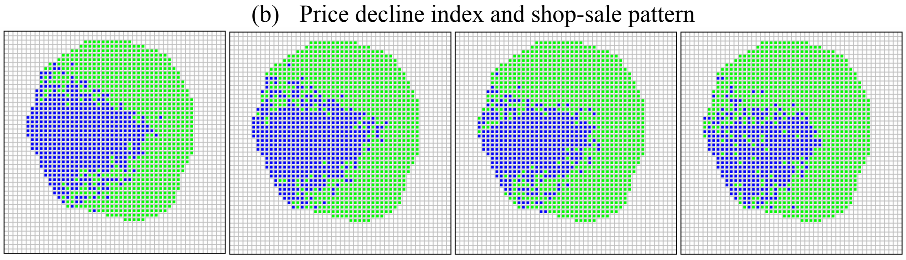


b = 0 b=0.04 b=0.08 b=0.1

■Household shopping at S_shop ■Household shopping at B_shop

α=150, γ=30, S_1=10000, S_2=20000

(b) Price decline index and shop-sale pattern



S_1 = 3000 S_1=8000 S_1=12000 S_1=20000

■ Household shopping at S_shop ■ Household shopping at B_shop

α=15, γ=30, b=0.05, S_2=20000,

(d) Floor space and shop-sale spatial pattern

Figure 5 Parameters validation

Reachable distance (γ)
Figure 5(b) shows the relationship between reachable distance and shop-sale. Reachable distance is a variable that indicate how far the household will be able to go shopping. In simulation, when reachable distance is less than 15, the sale amount of both B_shops and S_shops is increasing. After this point, the sale amount of S_shops decreases sharply. This is accounted for by the fact that once the large-scale shop is accessible, and do not need to pay travel cost, all reasonable people will choose to shop at the large shop.

Price decline index (b)
Figure 5(c) shows the relationship between price decline index and shop-sale. In simulation, when keeping other parameters as constant, the Price decline index and the sale amount of the shops present an approximate linear relation. The larger the index is, the lower the B_shop's goods price becomes and the lower the sale amount of S_shop is. This is consistent with our experience that the lower price of B_shop can usually attract more households.

Floor space (Sj)
Figure 5(d) shows that central shops sale performance is also affected by the B_shop's floor space. The larger floor space implies that the B_shop can serve goods with lower price according to the equation (1), which also indicated that floor space may affect price in an unobservable way. For example household may relate larger floor space to better shopping environment and more goods choice. So the increase of larger floor space will cause S_shops to lose their customers.

All above four cases are simulated in the same land use planning setting; the parameters validated in this section have good expression in the simulation. Households' shopping behaviours are significantly affected by factors, such as travel cost, shop location, price and floor space; thus result in different shop-sale spatial patterns that indicate city centre commerce performance.

5. POLICY SCENARIOS EVALUATION

As described in Table 1, there are two important indicators that are regulated location candidate sites and floor space upper-limitation in the bylaw for regulating new B_shop development. For examination of the two policy variables, planner agent generates the potential scenarios in simulation.

As regulated location candidate site is a discrete variable, planner agent employs a decision table for creating scenario (Table 3). Comparatively, the floor space upper-limitation value can be tested in simulation because it is simulative continuous variable. In respective location candidate site as different scenario, the policy analysis of floor space upper-limitation can be conducted.

Table 3. Decision table of planner for generating scenarios.

C1	Scenario	Center Activation (CA)					Railway Station Development (RSD)					Neighborhood Commerce Promoting (NCP)				
C2	Location is in center	Y				N	Y	N				Y	N			
C3	Location matches zone type	Y			N	/	/	Y			N	/	Y			N
C4	Location is consistent with bylaw	Y		N	/	/	/	Y		N	/	/	Y		N	/
C5	Distance to existing shops is appropriate	Y	N	/	/	/	/	Y	N	/	/	/	Y	N	/	/
A1	Set potential location	Y	/	/	/	/	/	Y	/	/	/	/	Y	/	/	/
A2	Set floor space up-limit	N	/	/	/	/	/	10000	/	/	/	/	3000	/	/	/
		R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15

Because some location candidate sites are similar in terms of impact on city centre S_shops and our purpose is to verify the effectiveness of MAS in policies analysis, some location candidate sites are excluded in this experiment. The following three scenarios are compared:

1. Centre Activation (CA): To reverse the decline, encourage large-scale shop to locate in the centre commercial area without upper-limitation for floor space, but strictly restrict out-centre location.
2. Railway Station Development (RSD): In order to develop railway station area into a comprehensive business area, B_shop can be opened near the station, with an upper-limitation of 10000 m^2.
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^2.

The base scenario with two existing B_shops as described in section 3 is compared to CA scenario, RSD scenario and NCP scenario. All these alternative scenarios are simulated with same initial parameter setting as base scenario (Table 4), which is a scenario in which no new B_shop development would be permitted. This allows us to compare the policy implications for the centre shops.

Table 4 Basic setting in simulation, which are the same in different scenarios

Initial setting for simulation	
Unit travel cost=150;	Small shop price=300
Permit distance=30;	Each household demand=50
Price decay index=0.05;	Household number=1270
Floor space of small shop=300	B_shop agent number=2(basic scenario)
Floor Space of 1st. Big Shop=10000;	B_shop agent number=3(other scenarios)
Floor Space of 2nd. Big Shop=20000	S_shop agent number=17

5.1 CA scenario

The spatial effects of CA scenario in which a new B_shop without floor space upper-limitation is set at the central commerce area as shown in figures 6,7. The spatial pattern in Figure 6 is represented by the distribution of market share of centre S_shop. From a comparison with Base scenario, it can be seen that with the establishment new B_shop the original centre shop is faced with fierce competition and they lost most of their market share. But from the Figure 7, it can also be told out that the whole centre market share is greatly improved. This indicated that CA scenario do have effect in the sense to improve the market performance of city centre, but may do severe harm to the centre S_shops if there is no limitation on B_shop's scale.

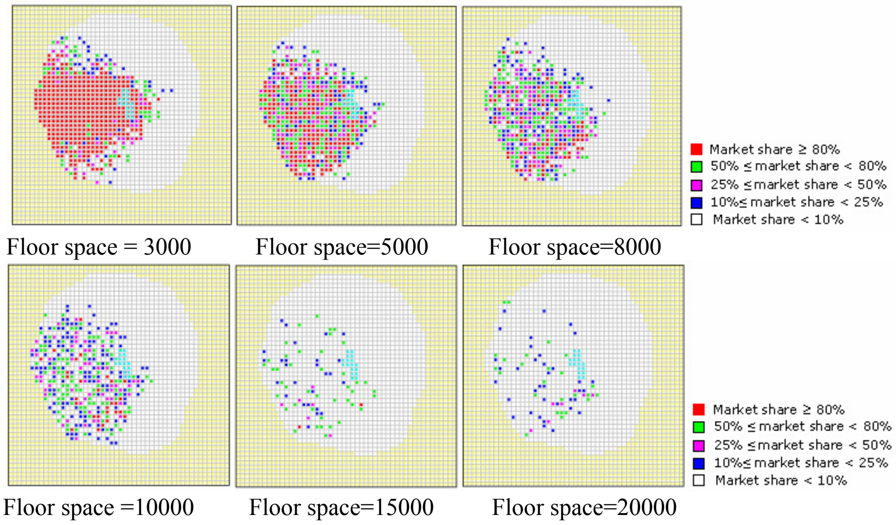


Figure 6. S_shop-sale patterns in CA scenario.

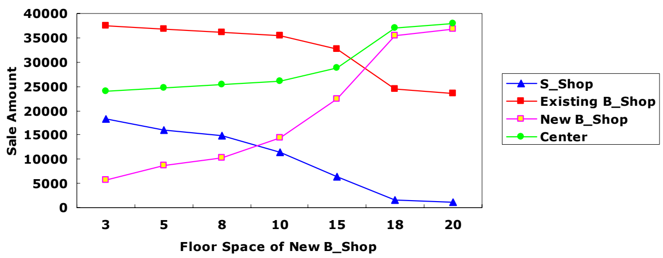


Figure 7 The sale statistics in CA scenario (floor space unit: 1000 m2).

5.2 RSD and NCP scenario

The effects of scenario RSD and NCP on centre small shop are not as remarkable as those in scenario CA, but reflect that both of RSD and NCP have no any help to promoting the centre commence development, see Figure 8. To compare, we make developer in three scenarios to give a standard floor space to new B_shop, 3000 m^2. Then an interesting result generate out, as show in Figure 9. In later two scenarios the loss of market share of S_shop caused by the new B_shop is more than in CA scenario. This further indicates that the CA scenario might be an effective measure to improve the activity of centre commerce if there is a reasonable limitation on B_shop's floor space.

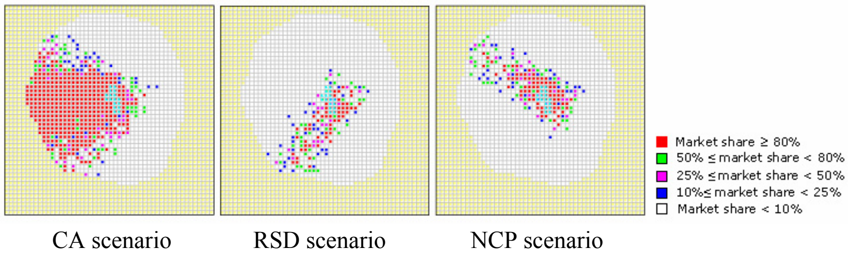
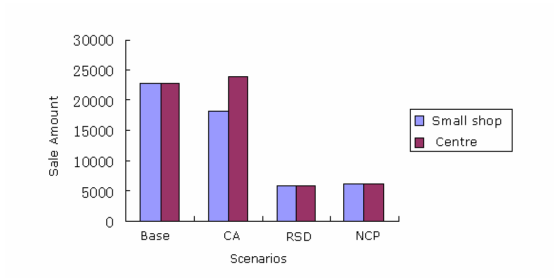


Figure 8. S_shop-sale pattern in RSD and NCP.



(when floor space of new B_shop=3000 m^2)

Figure 9. Centre area and S_shop-sale in scenarios.

6. DISCUSSION AND FURTHER RESEARCH

In this study a multi-agent system is presented in the context of Japan to simulate the process of city centre decline through local interaction. By introducing real urban planning regulations and relevant policies to forming agent's behaviour environment and rules, this study explores a way to improve the persuasion of future simulated in MAS and thus better support urban planning decision-making.

Land use zone regulation of national law system and local bylaw for new B_shop are adopted in this study, consequently the potential location candidates of new B_shop can be limited to narrower extent through decision tables. Multi-agent approach exhibits how market spatial pattern emergent from household shop choice process affected by urban policies.

This suggested that it is feasible for urban planners to regulate local bylaw to direct the development of B_shop. Specially, in this paper, the impact of B_shop on the commercial environment of city centre is visualized in several scenarios different in the value of the upper-limitation of floor space and possible location for B-shop.

However, there are still many challenges remained for further research. The most important challenge is how to evaluate spatial patterns that do not have adverse impact on inner city through agents' interaction. The second is how to considerate agents' self-organization process for making consensus. Moreover, given the complexity of urban systems, more social-economic information should be taken into account in simulation. Though the system now is able to visualize the processes and relations between shop location and inner city decay based on Multi-agent platform, there is still a big limitation in dealing with data and visualization. In future we will integrate the model with GIS, and then more satisfying outcomes can be expected.

7. REFERENCES

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