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Application of Multi-agent Models to Urban Expansion in Medium and Small Cities: A Case Study in Fuyang City, Zhejiang Province, China

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Abstract: In this study, three-phase satellite images were used to define rules for the allocation of time and space in construction land resources based on a complex adaptive system and game theory. The decision behavior and rules of government agent, enterprise agent and resident agent in construction land growth were explored. A distinctive and dynamic simulation model of construction land growth was built, which integrated multi-agent, GIS technology and RS data and described the interaction among influencing agents. Taking Fuyang City in the Changjiang River Delta as an example, an assessment process for the remote sensing data in construction land and scenario planning was constructed. Repast and ArcGIS were used as simulation platforms. A simulation of the spatial pattern in land-use planning and the setting of scenario planning were conducted by using the incomplete active game, which was based on different natural, social and economic levels. Through this model, a simulation of urban planning space and decision-making for Fuyang City was created. Relevant non-structured problems arising from urban planning management could be identified, and the process and logic of urban planning spatial decision-making could thus be improved. Cel1-by-cel1 comparison showed that the simulation accuracy was over 72%. This model has great potential for use by government and town planners in decision support and technique support in the policy-making process.

Keywords: multi-agent system; medium and small cities; urban expansion; game theory; Fuyang City

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1 Introduction

Theories and methods in the spatial and temporal variation of land use have become an increasingly popular focus of study in recent years (Valbuena *et al.*, 2010). The earliest proposed model utilized equations but as a static model, it could not efficiently reflect the complexity of land-use change (Monticino *et al.*, 2007). Based on vast amounts of land-use change data and socio-economic statistics, the experience statistical model has provided the most general template. On the other hand, the system dynamics model was built on the basis of control theory, system theory and information theory. The model aims to reflect the interactional relationship between the structures, functions and dynamic behaviors of the complex system. However, the system is based on experience and equations. It is therefore unlikely to efficiently evaluate spatial information. During the 1980s and the 1990s, many deep and detailed studies were conducted on spatial growth and the formation of cities with applied fractal theory and Cellular Automata (Ding, 2006; Liu *et al.*, 2006; Matthews *et al.*, 2007; Armesto

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et al., 2010).

In the 21st century, issues of urban growth and land-use change have become more prominent in academic circles. Theories and models including Cellular Automata, Genetic Algorithm, Artificial Neural Network and Artificial Life have been widely applied by geography researchers and are prevailing in contemporary interdisciplinary studies (Tao *et al.*, 2007; He *et al.*, 2008; Zhang *et al.*, 2008). Among these, the CA model is considered to be the classic method and is most commonly used. With flexible transition rules, it is a dynamic model that combines the metrology mathematical model and the system dynamics model. This model has proven effective in making dynamic forecasts of land growth. However, it can not provide an explanation for the process and origin of city growth and hardly considers the dynamic social environment that plays such a decisive role in land-use change (Li and Liu, 2008; Liu *et al.*, 2010).

In order to overcome the limitations of the above-mentioned model, this article established an urban land expansion model that considered the influence of temporal agent on land use, while also retaining dynamic simulation characteristics. This modeling method, based on the multi-agent system, was introduced to the urban simulations. The multi-agent model incorporated complex adaptive system theory, artificial life and distributed artificial intelligence technology (Ligmann and Sun, 2010). Its 'bottom-up' research ideas, powerful complex computing functions and spatial-temporal characteristics made it highly advantageous in the spatial-temporal aspect of simulating complex spatial systems; it thus provided an important means of analyzing and simulating complex systems (Vitabile *et al.*, 2009). Previously, Ligtenberg *et al.* (2004) proposed a land-use planning model based on the automatic combination of multi-agent, which was subsequently introduced in government plans. In addition, Monticino *et al.* (2007) established a multi-agent model that showed interactions between humans and the environment; this model was then used to evaluate the relationship between land use and the dynamic ecological environment. Chinese researchers have also undertaken related studies (Li *et al.*, 2007). Scholars in Sun Yat-sen University in China, for example, proposed a creative geographic information system framework by combining multi-agent and cellular automata, simulated land use conditions with multi-agent spatial decision-making behavior and rules in the urban development process of different planning scenarios (Liu *et al.*, 2006). To a great extent, this theory offset the deficiencies in simulation process of the geographical information system.

In summary, the multi-agent model has proven more efficient in reflecting the complexity of human factors and their interaction with the environment than a simple CA model. However, current multi-agent technology in land application and research has some drawbacks. Firstly, geographical space cannot reflect reality as space is usually represented in homogeneous form. Therefore, a more comprehensive multi-agent model is needed to simulate the process of urban expansion in small cities and towns. However, the use of game theory, remote sensing, economic models and the multi-agent model in the comprehensive analysis of urban expansion in small and medium cities remains rare. Yet, different natural, social and economic development strategies and different planning ideas could greatly influence urban land-use change and spatial distribution (Deng *et al.*, 2009). Nevertheless, many of these ideas are in the preliminary stages of exploration and thus their application to real-life city models remains very limited (Liu *et al.*, 2006).

Based on multi-agent system theory and game theory, this paper examined a dynamic game model in combination with an incomplete, complex economic model and a Repast and ArcGIS software platform. This was in accordance with different natural, social and economic development strategies and different planning scenarios. Both GIS and RS technology were utilized. The study focused on Fuyang City located in the southern Changjiang River Delta. The objectives of this research were threefold. First of all, it aimed to construct a model of urban expansion. Secondly, it aimed to simulate future urban expansion at different times, under different scenarios of spatial layout. Lastly, it aimed to simulate and analyze the operating results for a new round of land-use planning. The ensuing results could provide a basis for application in government decision-making and technical support.

2 Materials and Methods

2.1 Study area and data sources

Fuyang City (29°44′45″–30°11′58.5″N, 119°25′00″–

120°19′30″E) is a county-level city of Hangzhou City of Zhejiang Province, China (Fig. 1). It had the fastest urban growth rate of China for the last decade with a total population of 700 000 in 2009.

Data were obtained from three sources and processed as follows: First, landsat thematic mapper image data (acquired in 1996, 2004 and 2009; resolution: 10 m) were obtained for Fuyang City and processed by geometric correction, radiometric correction, and false color composition. Land use data were obtained from detailed investigations on land use and land change of Fuyang City in 1996, 2004 and 2009. Socio-economic data from the *Statistical Yearbook of Fuyang 1996*; *2004*; *2009* (Fuyang Municipal Bureau of Statistics, 1997; 2005; 2010) were also incorporated in the analyses. The vector data were transformed into consistent spatial coordinates and resolution. It was then converted into text files for subsequent analyses.

2.2 Model overview

The aim of this study was to investigate a new method of using multi-agent technology to program urban land expansion. The model consisted of a series of environmental factors and several multi-intelligent communities with motion characteristics. The research assumed that there was an existence of spatial grids in urban land space, and each spatial grid contained an agent. The term agent here did not mean a single person, but represented a group of individuals of the same type. The amount of urban land in use can be determined under different conditions of economic development through scalar game model of the urban land expansion. In this study, the characteristics of the experiment and other factors were put into account and the size of spatial grid was 10 m × 10 m (Liu, 2009). The multi-agent model of urban land expansion was summarized in Fig. 2.

(1) The first step: Determine the required agent′s amount of residents and enterprises during the planning stage according to the government′s time scheme rules, and limit the land development scale in terms of time and the amount of land used by identifying the amount of urban expansion in a certain period of time based on the game model.

(2) The second step: Calculate urban expansion probability of land use unit. Calculate location utility level of land space unit and the probability of utilized units in urban land used by resident agent or enterprise agent according to decision-making model of both the resident agent and the enterprise agent.

(3) The third step: Form the expansion probability of the land use unit according to the development probability of the city land and selection probability of the resident (enterprise′s) land.

Therefore, if it can be possible to allocate land successfully based on the macro total land requirement, then the expansion process can be terminated. Failure to

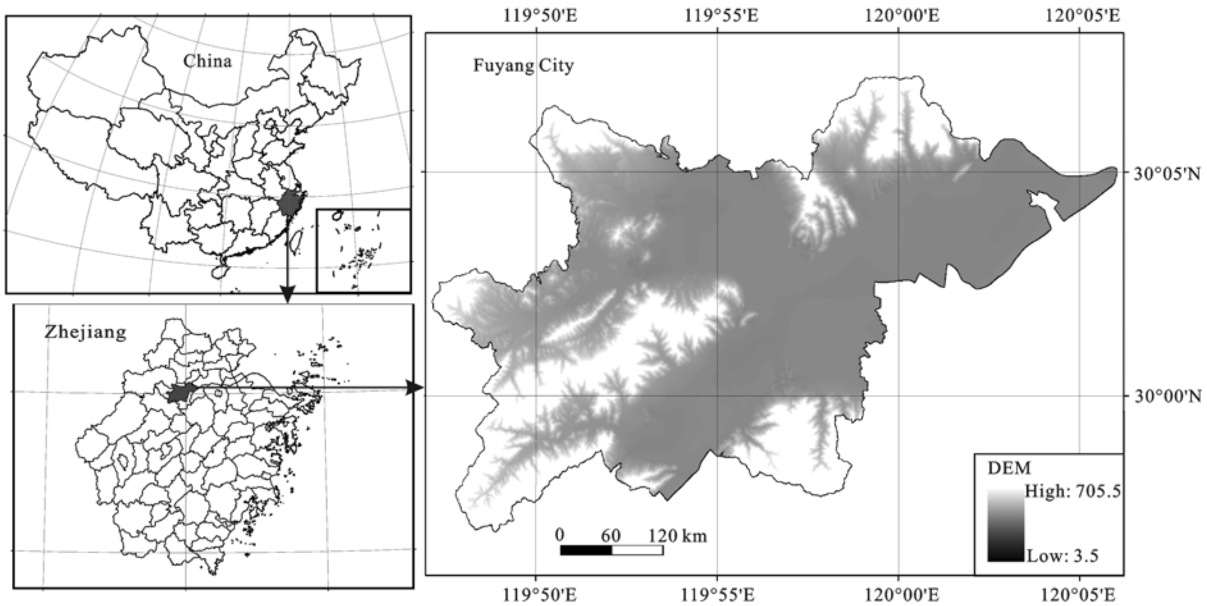


Fig. 1 Location of study area

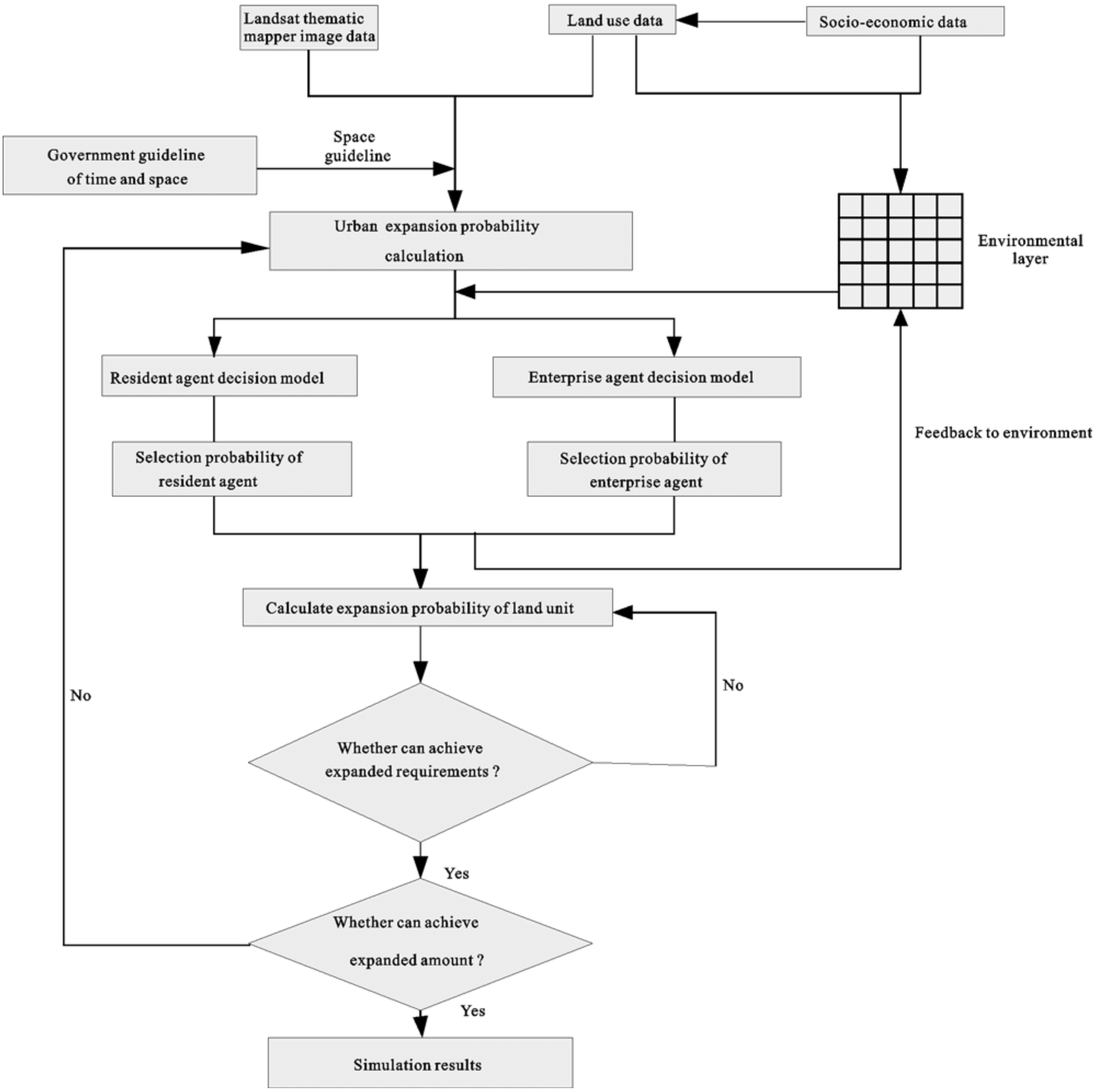


Fig. 2 Flow chart based on multi-agent model

meet the total requirement may mean returning to the integration decision-making, until the total expansion was completed under certain model, governed by game decision-making.

2.3 Methods

2.3.1 Decision rules on government agent

In the model of urban expansion, the government is a special class of agent. Unlike other spatial attributes, it is through the development of urban planning and land use planning to layout the overall planning of urban land use and to rationally allocate land resources in time and space.

According to the researches at home and abroad, first through the evaluation of land resources, the paper got the spatial distribution of the unit on both agricultural land suitability and urban land suitability, and then the probability of urban land development (P_U) and the probability of agricultural land development (P_A) was defined by linear segmentation approach (Liu *et al.*, 2006).

$$P = P_{\mathrm{U}} / \left(P_{\mathrm{U}} + P_{\mathrm{A}} \right) \tag{1}$$

where P is the index of urban expansion. Land configured by the government has proven likely to have a greater expansion index of urban land.

According to the suitability of land use types and constraints of land unit, the expansion probability of urban land can be calculated as follows (Zhang *et al.*, 2008).

$$^{t}P_{x}^{k} = \left[\left(1 + {^{t}S_{x}^{k}} \right) \times \left(1 + {^{t}N_{x}^{k}} \right) \right]^{t} V \tag{2}$$

where $^{t}P_{x}^{k}$ is the probability of land use type k on land unit x in time t; $^{t}S_{x}^{k}$ is the suitability of land use type k on land unit x in time t; $^{t}N_{x}^{k}$ is the influence factor of land use type k on land unit x in time t; and V is the random factor.

For calculating the index of the urban land expansion, it is required to determine development probability of the urban and agricultural land. Land-use development probability can be calculated as Equation (3), and its related factors include suitability of land types, influence factor of the land unit and the afterwards interference. Suitability $^{t}S_{x}^{k}$ can be figured as the followed formula (Zhang *et al.*, 2008).

$$^{t}S_{x}^{k} = \sum_{i=1}^{m} w_{i,x}^{k} Z_{i,x}^{k} \tag{3}$$

where i is suitable evaluation factor, such as terrain and transportation; m is the number of evaluation factors; $Z_{i,x}^{k}$ is the standardization suitable scores of land type k to suitable evaluation factor i on land unit x, and $w_{i,x}^{k}$ is its weight. The major land type in this research is urban land, and evaluating factors included traffic condition and gradient. The weight of evaluation factors is determined by entropy. $^{t}N_{x}^{k}$ can be expressed as follows (Zhang *et al.*, 2008).

$$^{t}N_{x}^{k} = S_{k} / S \tag{4}$$

where S_k is the acreage of land type k within window 10 × 10 where unit x is located; S is the total land acreage of window 10 × 10.

2.3.2 Decision rules on resident agent

Residents demonstrate two main decision-making behaviors, i.e. residential location behavior and re-selection residential location behavior. These behaviors not only directly affect the formation and change of the space structure, but also affect the urban social variation, spatial organization structure and urban development direction.

Under the premise of utility maximization assumption for individual residents, the dynamic random utility model was combined with the discrete choice model (Liu *et al.*, 2006) to examine the internal mechanisms of resident agent on decision-making behavior. The location utility of the resident agent for the candidate location can be expressed as follows.

$$\begin{aligned} ^{t}U_{j} = {} & a \times E_{\mathrm{traffic}} + b \times E_{\mathrm{prize}} + c \times E_{\mathrm{environment}} + \\ & d \times E_{\mathrm{labor}} + e \times E_{\mathrm{density}} + \xi_{j} \end{aligned} \tag{5}$$

where $^{t}U_{j}$ is utility of the candidate location j in time t; a, b, c, d and e are the weight of each impact factor for the resident agent; E_{traffic}, E_{prize}, $E_{\mathrm{environment}}$, E_{labor}, E_{density} are accessibility to traffic, land prices, environmental values, labor resources and building density; and ξ_j is random perturbation of candidate location j.

In time t, the expansion probability of the resident agent on unit x is calculated as follows (Zhang *et al.*, 2008).

$$^{t}Y_{x} = \frac{\exp\left(\mu {^{t}U_{x}} \right)}{\sum_{m} \exp\left(\mu {^{t}U_{x}} \right)} \tag{6}$$

where $^{t}Y_{x}$ is the expansion probability of the resident agent on land unit x in time t; m is the number of the resident agent attracted on unit x; $^{t}U_{x}$ is utility function on land unit x in time t and μ is the dispersion parameter.

2.3.3 Decision rules on enterprise agent

Enterprise is the core modern society. Land-use spatial choice behavior is closely related to the production and business activities of enterprises. The major land-use process of enterprises consists of location selection (BomPard *et al.*, 2007).

Many similar features have been found between an enterprise agent and a resident agent. Although enterprise agent location selection is based on a number of agents, the paper specifically focused on factors affecting enterprise agent such as accessibility of traffic land prices, environmental values, labor resources and building density. The equation of location utility on enterprise agent was shown consistent with the equation on resident agent Equation (5).

In the model, enterprise agents in their own space can randomly select suitable location and calculate the effectiveness of their location. In *t* time, the expansion probability of the enterprise agent on land unit *x* is calculated as follows (Zhang *et al.*, 2008).

$$ {}^{t}Q_x = \frac{\exp\left(\mu {}^{t}U_x\right)}{\sum\limits_{n} \exp\left(\mu {}^{t}U_x\right)} \tag{7} $$

where ${}^{t}Q_x$ is the expansion probability of the enterprise agent on land unit *x* in time *t*; *n* is the number of the enterprise agent attracted on land unit *x*; ${}^{t}U_x$ is utility function on land unit *x* in time *t*; and μ is the dispersion parameter.

2.3.4 Integrated decision-making rules on multi-agent urban land expansion

Urban expansion is the integrated decision-making result of the government, residents and farmers. Based on the above set of various decision rules, decision-making rules of multi-agent urban land expansion are as follows (Liu, 2009).

$$ P_x^t = \begin{cases} \exp\left(\alpha\left(R_x^t / R_{\max}^t - 1\right)\right) & \text{if} \quad R_x^t \neq 0 \\ 0 & \text{if} \quad R_x^t = 0 \end{cases} \tag{8} $$

where P_x^t is the probability of urban land on land unit *x* in time *t*; $R_{\max}{}^t$ is the maximum of the suitability scores on urban land expansion for the land units involved in the operation in time *t*; α is a discrete parameter; $R_x{}^t$ is the suitability scores of urban expansion under the combined effects of the government, resident and enterprise on land unit *x* in time *t*. The calculation model is shown below (Liu, 2009).

$$ R_x^t = k\sum_{j=1}^{L} w_j {}^{t}p_x^j \tag{9} $$

where *L* is the number of the agents; w_j is its weight of agent *j*; ${}^{t}P_x^j$ is the expansion probability of agent *j* on land unit *x* in *t* time. The expansion probabilities of government agent, resident agent, enterprise agent correspond to the previous formula of *P*, ${}^{t}Y_x$, ${}^{t}Q_x$.

2.3.5 Urban land expansion gambling model and planning scenario setting

The decision-making game of urban land expansion is not a complete information dynamic game. The balance to be achieved is the perfect Bayesian Nash equilibrium (Xuan and Zhang, 2008). Based on the game process, the total urban land development can be calculated under different probability levels in the planning period, which has conceived the multiple scene possibilities for the government in the problem of land allocation. The game focuses on changes in the amount of agricultural land. Under the different probabilities, the program idea and scene of urban land expansion also have differences, so we established general economic planning scene (planning scene 1), middle economic planning scene (planning scene 2) and high economic planning scene (planning scene 3), respectively.

Planning scene 1: Due to the low urban land expansion, generally, we should expand urban land and avoid expanding high quality arable land and take general arable land and woodland. In the initial period, there may be more space that can be selected comparatively because of the various agriculture land types around the urban constriction land. To the long-term period, the land has already displayed some form of loose degrees.

Planning scene 2: Urban land expansion increases in this period. The urban land expansion still expands land around the original constructed land, and mainly takes general arable land and woodland, which opportunely occupies high quality farmland. Similarly, in the initial period, there are various types of land that can be expanded around the urban and many positions can be selected. But on the long-term period, it will still develop to be intense. The direction of urban land expansion is absolutely limited by mountains and water, and it tends to select regions where there are convenient traffic, high-quality environment, good educational resource and perfect public infrastructure.

Planning scene 3: The local government will promote high-speed economic development strategy during the planning and urban construction land will be in great demand. In spatial expansion, land can be changed into urban land in addition to water and mountain based on the rules of government. In space expansion trend, the original arable land around urban can be used as urban land expansion area.

The government (G) chooses any of the planning scenes in its strategy space and the resident (N) immediately adopts the planning scene. The results of their interaction are showed in Table 1.

3 Results and Discussion

3.1 Model operating parameters set

According to Equation (5), traffic availability should be

Table 1 Game relation between government and resident

General economic planning scene		Middle economic planning scene		High economic planning scene	
Accept	Refuse	Accept	Refuse	Accept	Refuse
f G(1), f N(1)	f G(1), f N(2)	f G(2), f N(1)	f G(2), f N(2)	f G(3), f N(1)	f G(3), f N(2)

Note: f G(1), f N(1) represents the resident agent accepts planning scene 1 chosen by the government, which can influence the urban expansion probability in planning scene 1. f G(1), f N(2) represents the resident agent refuses planning scene 1 chosen by the government, and so on

determined firstly. Traffic availability could be calculated as follows (Liu *et al.*, 2006).

$$E_{\text{traffic}} = a_1 \times e^{-b_1 d_1} + a_2 \times e^{-b_2 d_2} + a_3 \times e^{-b_3 d_3} + a_4 \times e^{-b_4 d_4} + a_5 \times e^{-b_5 d_5} \tag{10}$$

where E_{traffic} was the accessibility to traffic and e was the accessibility to traffic of every traffic lines. In this model, traffic lines were divided into city lines and railway lines, in which city lines included urban speedway, central highway and minor highway. a_1, a_2, a_3, a_4, a_5 were spatial influence′s weight of urban speedway, central highway, minor highway, railway and urban center, respectively. The weights were 0.236, 0.278, 0.165, 0.097, 0.224 by applying analytic hierarchy method, respectively. b_1, b_2, b_3, b_4, b_5 were spatial influence′s attenuation coefficients of urban speedway, central highway, minor highway, railway and urban center. d_1, d_2, d_3, d_4, d_5 were distances from land unit x to speedway, urban central highway, urban minor highway, railway and urban center, respectively.

Additionally, it was still necessary to determine the weight of location selecting preference on resident′s agents in different income levels and family structures. In the study, resident agents were divided into six types, i.e. high income with kids, high income no kids, middle-income with kids, middle-income no kids, low-income with kids, low-income no kids in accordance with different income and family structures, and entropy method was used to determine the weights of the agent′s location selecting preference in the different types of residents (Table 2).

According to the multi-agent comprehensive decision rules, the weights of all agents were determined. From equations (8) and (9), we knew that calculating the expansion probability should firstly determine the proportion of different agents in the model, which was w_j in Equation (9). This research got the specific weight of government agent, enterprise agent and resident agent by using analytic hierarchy method, and their values were 0.408, 0.376, and 0.216, respectively.

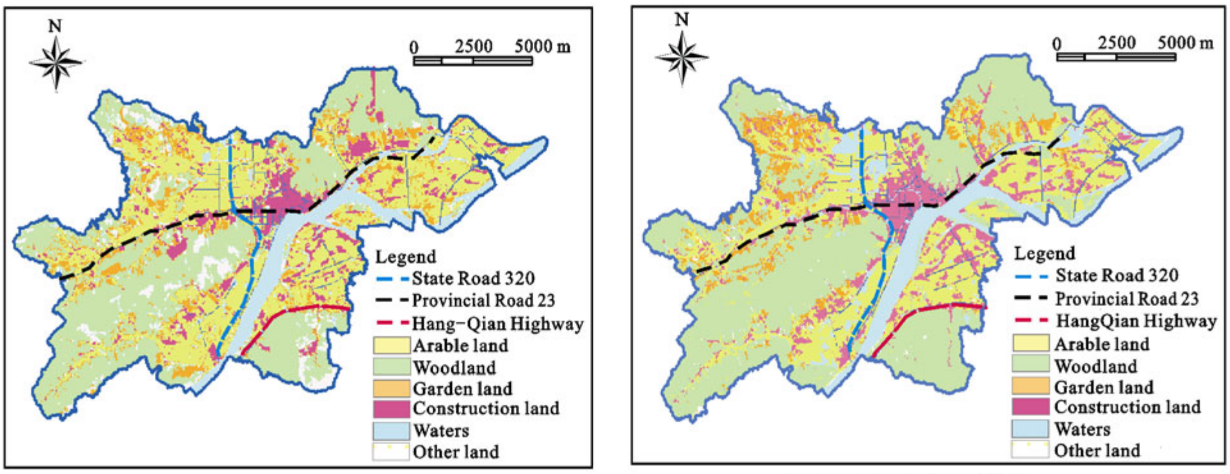
3.2 Model accuracy testing

Urban land expansion was a complex system, and was affected by many uncertainties. It was impossible to accurately simulate the dynamic change. However, when dealing with the simulation of the real urban expansion by applying multi-agent system, we need to check its inosculation with the actual situation. Overall comparative method could provide more reasonable results. What it concerns was the whole spatial pattern and did not emphasize the accurate position of each point. First, this study re-established the urban land expansion process in Fuyang City, according to the existing data and the identified model operation parameter. Then, we compared the simulation results of urban land expansion with the actual land utilization of the year 1996, 2004 and 2009, and we got the point-to-point contrast precision. The simulation accuracies of urban land expansion in the year 1996, 2004 and 2009 were 72.03%, 72.86% and 73.25%, respectively (Fig. 3).

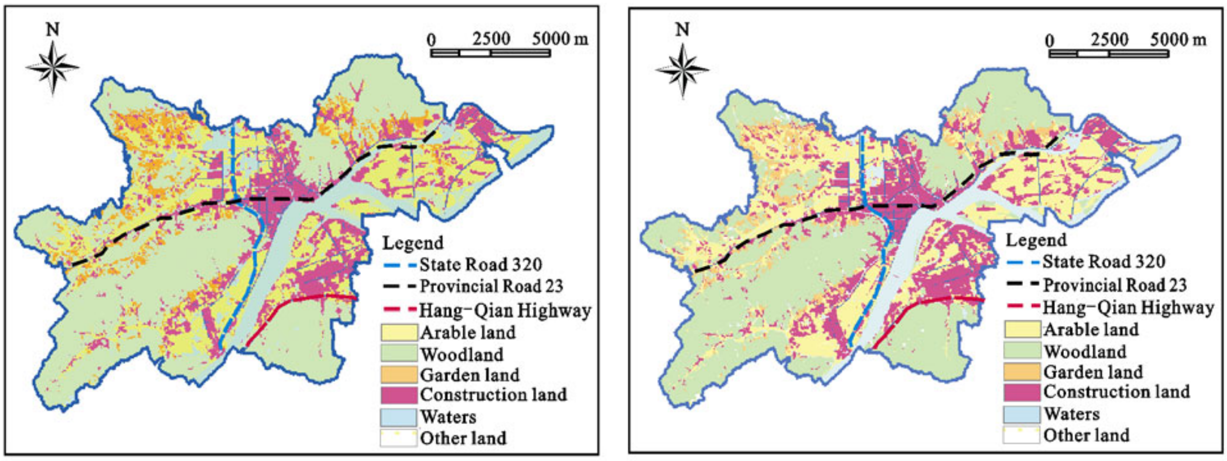
Table 2 Weights on different types of resident agents

Resident agent	Traffic	Land prices	Environmental values	Labor resources	Building density
High income with kids	0.278	0.099	0.055	0.317	0.251
High income no kids	0.340	0.061	0.109	0.414	0.076
Middle-income with kids	0.226	0.253	0.098	0.196	0.227
Middle-income no kids	0.281	0.216	0.146	0.290	0.067
Low income with kids	0.219	0.413	0.050	0.051	0.266
Low-income no kids	0.301	0.469	0.100	0.061	0.069

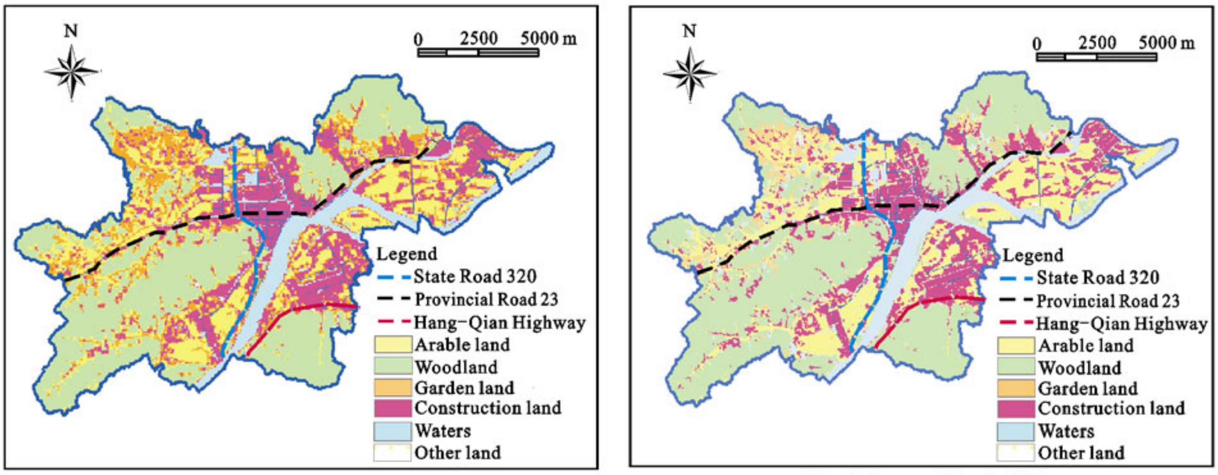
Note: high income refers to the annual income more than 100 000 yuan (RMB); middle-income refers to the annual income more than 20 000 yuan but less than 100 000 yuan; low income refers to the annual income less than 20 000 yuan



Actual condition in 1996 Simulation condition in 1996



Actual condition in 2004 Simulation condition in 2004



Actual condition in 2009 Simulation condition in 2009

Fig. 3 Comparison of simulation result with actual conditions in Fuyang City in 1996, 2004 and 2009

In addition, in order to evaluate the inosculation of simulating results and actual conditions in terms of spatial pattern, this research used compactness index (CI) and shape index (SI) (Liu *et al*., 2006). The two indexes were very important in evaluating urban land spatial pattern, in which CI represented the degree of land compact. The bigger the compactness, the higher of land use efficiency. SI reflected the complexity of the land spatial pattern (Table 3).

3.3 Simulation and evaluation of urban land expansion

Based on urban land expansion quantitative model, simulating patterns and rules of urban land expansion under different planning scenarios in different stages, 2010–2015 and 2016–2020, CI and SI under different planning scenarios in 2010, 2015 and 2020 were shown in Table 4 and Fig. 4.

Table 3 Compactness index (CI) and shape index (SI) in Fuyang City in 1996, 2004 and 2009

Year	Actual conditions		Simulation results	
	CI	SI	CI	SI
1996	0.188	16.854	0.193	15.751
2004	0.182	17.949	0.190	16.940
2009	0.175	19.172	0.180	18.434

Table 4 Compactness index (CI) and shape index (SI) in different planning scenarios

Planning scenarios	year	CI	SI
Planning scene 1	2010	0.209	18.750
	2015	0.203	19.968
	2020	0.215	21.329
Planning scene 2	2010	0.219	17.917
	2015	0.216	19.269
	2020	0.225	20.968
Planning scene 3	2010	0.229	18.705
	2015	0.225	20.116
	2020	0.234	21.890

Setting conversion probability of different land types were in different planning scenes. General economic planning scene, middle economic planning scene and high economic planning scene respectively corresponded to urban land scale of low quantity, moderate quantity and high quantity. Different development probabilities of urban expansion under general economic planning scene, middle economic planning scene and high economic planning scene were 60%, 70% and 80%, respectively.

Planning scene 1 represented scenario simulation of urban land expansion under general economic development strategy in 2010–2015 and 2016–2020. Development direction of the two simulation diagrams shown in Fig. 4 were roughly the same. They all extended to southwest along the State Road 320.

Planning scene 2 represented scenario simulation of urban land expansion under medium economic development strategy in 2010–2015 and 2016–2020. Development directions of the two simulation stages were still roughly the same, but compared to general economic development strategy of the same period, its speed was significantly much higher.

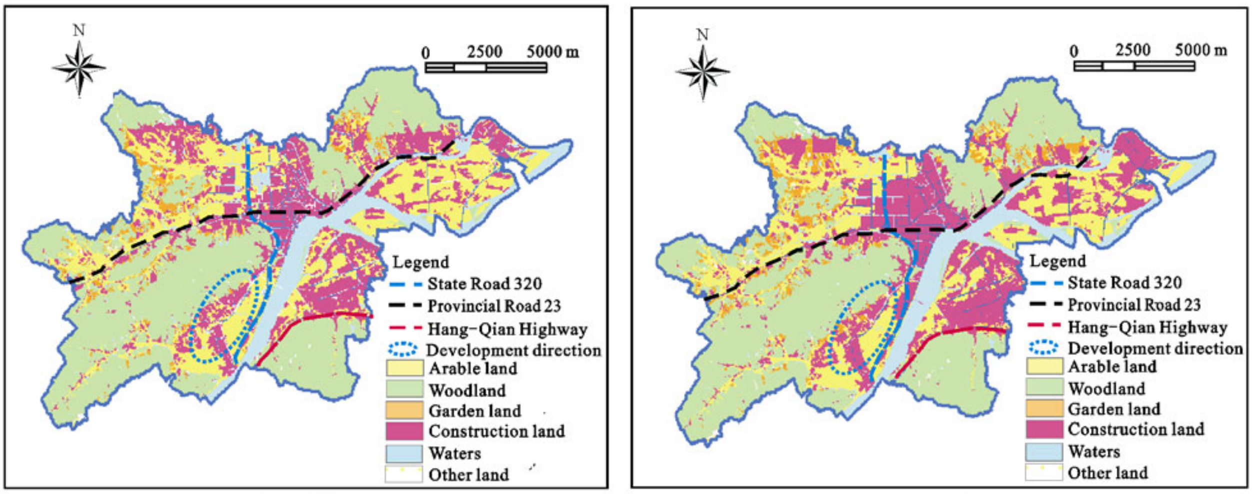
Planning scene 3 represented scenario simulation of urban land expansion under high economic development strategy in 2010–2015 and 2016–2020. In the spatial performance, in comparison with the first two planning scenes, there were three main expansion directions of urban land shown in Fig. 4. The first extended to the southwest along State Road 320 in the old city, while the second extended to the northwest along the Provincial Road 23. The third extended to the north along Hang–Qian Highway (from Hangzhou City to Qiandaohu City) in the new city. In comparison to above- mentioned two kinds of planning scenes, its expansion speed and scale were much higher, and the expansion space was more crowded with lower divergence.

It could be seen from Fig. 4 that the expansion directions under different panning periods or different development strategies were broadly similar. It indicated that when most driven and limited factors were the same or similar, urban land use quantity slightly affected the spatial direction of urban land expansion, while a series of macro and micro factors and the agent choice played a leading role.

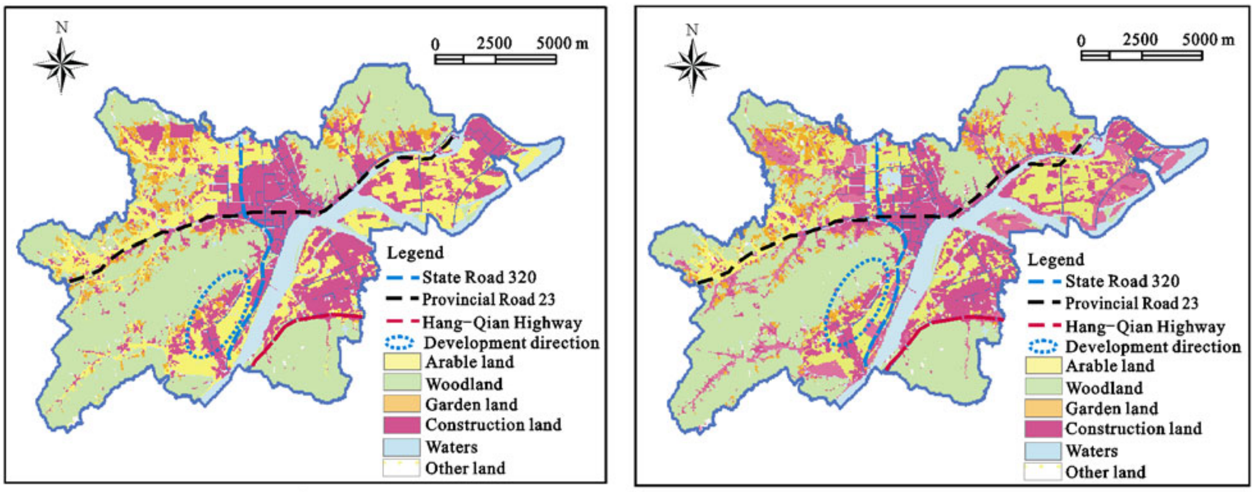
4 Conclusions

Based on complex adaptive system theory and game theory, this article explored the decision-making behavior and rules of government agent, enterprise agent and resident agent in the process of urban land expansion. Integrative multi-agent, GIS and RS were utilized in the analysis.

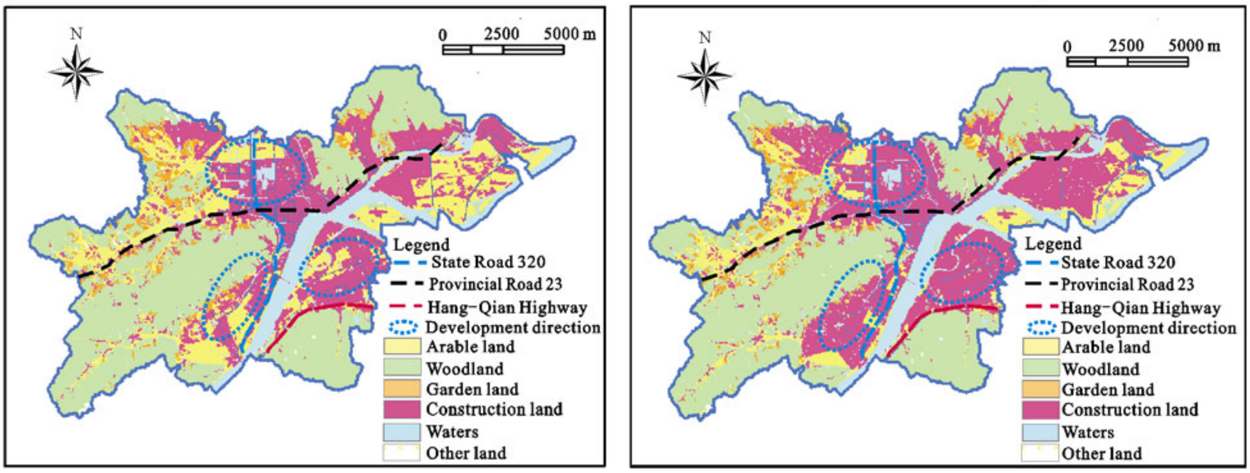
The urban land expansion process of Fuyang City in 1996, 2004 and 2009 was simulated and compared with the actual results. The subsequent cell-by-cell comparison showed that the simulation accuracy was over 72%. These results suggested that the multi-agent urban land expansion model could reflect the basic characteristics and rules of urban land expansion. The model was



Scene 1 in 2015 Scene 1 in 2020



Scene 2 in 2015 Scene 2 in 2020



Scene 3 in 2015 Scene 3 in 2020

Fig. 4 Different scenarios of simulation in Fuyang City

shown to be diverse, dynamic and capable of describing the relationship between small and medium micro-agents in the process of urban land expansion. As a result, the reasoning behind urban land expansion and the influence of agent's behavior towards urban land expansion could be easily examined. On basis of the model, a simulation of urban planning space and decision-making for Fuyang City could be formed. Relevant non-structured problems arising from urban planning management could then be identified, and the process and logic of urban planning spatial decision-making could be improved. The model could thus prove useful for auxiliary policy-making support for government and urban planners.

The multi-agent land expansion model was also used to simulate the urban land expansion of Fuyang City for the period 2010–2020. The results showed that land use in Fuyang City was likely to intensify in the future. Urban land was likely to gradually expand from the suburbs to outlying villages and towns where traffic was more convenient. As a consequence of urban land expansion, agricultural land would be vastly decreased. The government should therefore adopt positive measures to control the excessive expansion of urban land.

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