

Chapter 2

A Planning Tool for Simulating Urban Growth Process and Spatial Strategy of Urban Development in Chuandong, China

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Introduction

This century is marked by rapid urbanization. Some statistics predict that the world's urban population will reach five billion by 2030 (United Nations 2007). This rapid urbanization not only has resulted in expanded land-use, but also has led to population increases in urban areas and development-related environmental impacts. Researchers, therefore, have begun to be concerned about the relationships between urbanization, population dynamics, and development-related environmental impacts (Lambin and Geist 2001; Fontaine and Rounsevell 2009). In this chapter, we introduce a simulation tool, spatial strategic plan support system (SSP-SS), to support local decision-making of urban development, which includes two separate parts for urban growth simulation and total amount of household energy consumption and waste discharge. To represent the process of urban growth, the constraint cellular automata (CA) approach is utilized, and an agent-based model is employed for calculating the total amount of household energy consumption and waste discharge.

Nowadays, urbanization is taking place at an unprecedented pace in China, and it will continue over the next decades. According to some statistics, the total migration into urban areas during 1995–2000 amounted to 128 million and the amount of

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built-up urban area almost doubled from the 1990s to the 2000s (National Bureau of Statistics et al. 1996–2005). This rapid urbanization will lead to the problems of landscape deterioration and unexpected urban spatial change. Therefore, some prior researchers have represented the process of urban growth in the past in order to predict its possible spatial changes in the future (Catalán et al. 2008; Han et al. 2009; He et al. 2008). Meanwhile, some researchers began to focus on simulating the phenomenon of segregation and suburbanization in order to better analysis the spatial pattern of urban areas (Jayaprakash et al. 2009). Additionally, some other researchers concentrated on revealing the relationship between landscape change and household residential location (Fontaine and Rounsevell 2009; Brown et al. 2008). Meanwhile, it is a challenge to develop practical and effective planning tools to support local governments in making decisions about planning policies. In this *chapter*, we propose a planning support tool to investigate the impacts of strategic spatial plans on urban growth.

In China, local governments attempt to determine future urban characteristics, spatial development, and industry distribution by implementing strategic spatial plans aimed at achieving objectives such as sustainable economic growth, land reclamation, infrastructure construction, and urban development. Making a strategic spatial plan will involve at least three local government planning departments, namely the local economic and social development planning department, the land-use planning department and the urban planning department. The planning work they do is implemented independently by the economic and social development commission, the land-use planning and management bureau and the urban planning and management bureau. Local governments should have an integrated process for making strategic spatial plans that integrates all three planning functions. Additionally, when considering environmental issues arising from urban development, work done by the environmental protection department cannot be ignored. Thus, how to combine the work proposed by the four departments into a sensible overall plan is a key factor in supporting local government decision-making.

In the Chuandong area of China, the local strategic spatial plan includes development of a new city. The proposed new system, SSP-SS, is intended to assist local government decision makers by enabling them to produce a visible, pellucid model of the effects of local strategic spatial plans. As mentioned above, this system simulates urban growth and integrates the economic and social development plan with the land-use plan and urban plans while taking into consideration environmental issues, such as the total amounts of natural resources used and waste discharged. In this *chapter*, we use the cellular automata (CA) approach to represent the process of urban growth. Moreover, we employ an agent-based model to simulate population change, resource use, and waste discharge. Much research has demonstrated that the CA approach has advantages over other methods and can simulate urban growth in a very realistic manner (Batty et al. 1997, 1999; Clarke and Gaydos 1998; White and Engelen 1997, 2000; Wu and Webster 1998; Sui and Zeng 2001; Li and Yeh 2002b; Fang et al. 2005; Shen and Kawakami 2008). Urban growth, however, is a complex process influenced by many macro-scale driving forces. The pure CA model is inadequate to take these political, economic, and cultural forces into

account (White and Engelen 1997, 2000). To improve the CA model so that it can represent the spatial complexity of the urban growth process, a constrained CA model has been developed (Li and Yeh 2000). It can simulate urban growth as influenced by local, regional, and global sustainability constraints. Despite its advantages in spatial representation, the CA approach also has its own drawbacks. CA models are arrangements of individual automata over tessellated space, where automata in neighboring cells influence each individual automaton. Neighbors transfer information by diffusion (Torrens and Benenson 2005). This results in one shortfall in the CA approach; cells cannot move and make their own decisions (Torrens 2007). Therefore, urban growth simulations tend to depend too much on how cells are assigned using predefined neighborhood rules. Although CA-based models are good for representing and simulating the spatial processes of urban growth that underlie decisions related to neighborhood interactions (Batty et al. 1997), agent-based models (ABMs) are much better at handling individual decisions.

For these reasons, we employ both constrained CA and ABM methods in the SSP-SS simulation of urban growth and in calculating the total amount of resources used and waste discharged in the Chuandong area. Moreover, work proposed by different planning departments can be integrated in the SSP-SS, aiding local governments in their strategic spatial planning and decision-making processes.

The whole *chapter* comprises five sections. In Sect. “[A Systematic Approach for Supporting Local Government Decision Making](#)”, we introduce a systematic approach for supporting local governments’ decision making. In Sect. “[Description of SSP-SS](#)”, we give details about the models used to build the SSP-SS. In Sect. “[SSP-SS Implementation](#)”, we describe SSP-SS implementation, and then an analysis of the experimental results and conclusions are presented in “[Conclusions](#)”.

A Systematic Approach for Supporting Local Government Decision Making

As mentioned above, in China, a strategic spatial plan will involve the work of urban planning, land-use planning, and local economy and social development planning departments. Moreover, related environmental assessments conducted by the department of environmental protection should also be considered to take into account the environmental consequences of implementing the plan. In planning practice, however, these four departments are independent from each other, and their work is always carried out under different frameworks.

In China, local development and reform commissions authorize large-scale investment projects in urban areas in accord with local economic and social development plans. The department of land management devises land-use plans to be implemented in both urban and rural areas based on the land use demanded by these large-scale investment projects. Then, the department of urban planning takes its turn, planning and managing urban development. Obviously, this is a top-down

relationship between the local economic and social development planners, land-use planners, and urban planners. Ideally, these three planning divisions should cooperate with each other instead of working in sequence. Moreover, to achieve local sustainable development targets, the total amount of resources used and waste discharged should not exceed the local resource supply and environmental carrying capacities determined by the environmental planning department. Thus, a practical strategic spatial plan should bring factors from across all four functions together. The current situation, in which the four departments operate independently, results in difficulty in coordinating planning work and analysis of the impacts the plans have on urban development. Hence, it is necessary for local governments to develop an integrated planning system for making decisions about their strategic spatial plans.

To find a solution for the problems noted above, we have developed the SSPSS decision-making tool, which targets full integration of land-use planning, urban planning, and economic and social development planning on the same platform. To achieve this, we employed a constrained CA model to simulate the process of urban growth driven by land development potential in the Chuandong area of China. Economic investment is the direct driving force for urban growth, and we therefore chose the locations of investment projects as the seeds (initial areas) for our urban growth simulation. According to Chuandong's local economic and social development plan, there are two types of investment projects for new urban development in the area. One is for highway construction and the other is for new urban center construction. Based on this division, we generate two scenarios corresponding to the two projects in order to reveal the different urban patterns resulting from the types of investment projects recognized in the local economic and social development plan. Evaluation of whether developments are a suitable use of land is a precondition for local government's production of a land supply plan. In this *chapter*, we assume that local governments make land supply plans based on land-use suitability evaluation. The spatial process of urban growth, then, can be evaluated using the probability of land development using CA transition rules. Meanwhile, urban planning controls related to each cell are employed to regulate development projects in urban spaces. The factors of land-use types, population density, and landscape that are determined by urban planning are regarded as institutional constraints for our urban growth simulation. Hence, the three types of planning work conducted by the different departments are integrated into the SSPSS to allow visualization of the spatial process of urban growth based on the strategic plan.

Finally, numbers of households or business owner are assumed to be consistent with the population density as controlled by urban plans for the Chuandong area. Correspondingly, the total resources used and waste discharged can be simulated through an agent-based model. In this model, the interactions between local government agents and other agents are defined by rules that adjust individual resource use and waste discharge to satisfy the total amount of resources used and waste discharged. These total control demands are predefined as proposed by the department of environmental protection.

As mentioned above, the urban growth simulation can be used to predict resource use and waste discharge amounts that reflect the impact of implementing

a spatial plan. It is possible for local governments to use urban growth simulation a tool to assist in making decisions about strategic spatial plans.

Description of SSP-SS

Simulation of Urban Growth Using Constrained CA

As mentioned above, we assume that areas that have high development potential, based on land-use suitability evaluations, urban plans, and economic and social development plans, will be developed. In order to visualize the possible spatial process of urban growth in the Chuandong area, reflecting a dynamic balance between land supply and land-use demand that results from implementing strategic spatial plan, we applied the constrained CA model built by Wu (1998) and Li and Yeh (2000). In this model, the constraints include spatial constraint A_s reflecting the land-use suitability evaluation, macro-social economic constraint A_{mac} , reflecting urban development projects outlined in the economic and social development plan, institutional constraint A_{ins} , and neighborhood constraint A_{nei} (Long et al. 2008, 2009). In this simulation, the institutional constraint can be understood to be urban planning. Investment projects for urban development determined by local economic and social development plan can be taken as the macro-social economic constraint. Additionally, the Moor Neighborhood scheme is utilized for this simulation and each cell is defined as having four neighbors. The four spatial constraints can be as expressed as

$$\begin{aligned}
 V_{ij}^{t+1} &= f(V_{ij}^t, A_{mac}, A_{spa}, A_{ins}, A_{nei}^t) \\
 V_{ij}^t &: \text{cell status at time } t \text{ and in location } ij \\
 V_{ij}^{t+1} &: \text{cell status at time } t + 1 \text{ and in location } ij \\
 f &: \text{transition rule of cell status}
 \end{aligned} \tag{2.1}$$

Equation 2.2 details the rule governing transitions of cell status V_{ij} as follows:

$$\begin{aligned}
 s_{ij}^t &= x_0 + \sum_{k=1}^{n-1} x_k \times a_k + x_n \times a_n^t = s_0 + x_n \times a_n^t \\
 p_g^t &= \frac{1}{1 + e^{-s_{ij}^t}} \\
 p_{ij}^t &= \exp \left[\alpha \left(\frac{p_g^t}{p_{g \max}^t} - 1 \right) \right] \\
 \text{if } p_{ij}^t &\geq p_{threshold}(p_{ij}^t, Developmentstage^{t+1}) S^{t+i}(ij) = \text{Developed} \\
 \text{otherwise } &S^{t+i}(ij) = \text{Un Developed}
 \end{aligned} \tag{2.2}$$

Among the variables, s_{ij}^t reflects the development potential of cell (i, j) at time t as influenced by the land-use suitability evaluation and the urban, economic, and social development plans. In addition, x_0 is a constant and s_0 is the static part of development potential during each simulation step. $S^{t+1}(ij)$ is the status of cell (i, j) at time $t + 1$. x_k is a parameter set reflecting institutional policies other than neighborhood rule, such as land-use suitability. x_n is a parameter reflecting neighborhood impacts, a_n represents the spatial features of the neighborhood, a_k reflects spatial features excluding the neighborhood, and p_g^t is the global probability for transition. $p_{g_{\max}}^t$ is the maximum global probability during each step. α is a diffusion coefficient ranging from 1 to 10, p_{ij}^t is the final probability, $p_{\text{threshold}}(p_{ij}^t, \text{Developmentstage}^{t+1})$ is the neighborhood of the cell and controls development speed, which can change depending on p_{ij}^t and $\text{Developmentstage}^{t+1}$ in order to make the development speed in $\text{Developmentstage}^{t+1}$ match the settings.

The basic principle of this transition rule is as follows. First, simulation initial areas are determined. Then, the final probability of one cell will be employed to decide if the cell can be developed or not by comparing with the threshold, which is expressed as $p_{\text{threshold}}(p_{ij}^t, \text{Developmentstage}^{t+1})$.

As determined in the strategic spatial plan, the development periods in the Chuandong area are divided into initial, mid-development, and mature stages.

Resource Use and Waste Discharge Amount Calculations

Simulation of Agent Generation

Urban growth inevitably leads to population centralization in the urban area. Using the constrained CA approach, urban growth can be visualized to aid local governments' strategic decision-making. It is consider how the spatial changes will impact population growth in the Chuandong area. To answer this question, we assumed that the total population that will become concentrated in the new urban area will come from the surrounding countryside and that the urbanization objectives of the local socio-economic plan will be achieved. However, we do not simulate the process of moving the population from the surrounding countryside and only generate agent numbers based on the density proposed by urban plan. Therefore, if the simulation shows that the total population scale can meet government urbanization objectives while satisfying density requirements and the total inhabitable space in the Chuandong area, the local government can gain insight on how implementation of the strategic spatial plan can impact urban development. Simulating the movement of the population from the countryside to the city in the urbanization process remains as a further task that should be carefully investigated in the future.

Recently, the agent-based modeling approach has been applied extensively to mimic individual behaviors in virtual societies. We use our SSP-SS tool, which employs an agent-based approach, to generate agents and simulate resource use and waste discharge. Agents, including households and business owners, are assumed to migrate to each developed residential and commercial cell. Their numbers are

controlled by the density proposed in the urban plan. According to the Chuandong area urban plan, there is only one small industrial area where a single industrial agent is located. Among the formulas in (2.3)–(2.5), N_r , N_c , N_i , and N_h , respectively, stand for the number of households in residential, commercial, and industrial areas and the number of households all developed areas. D_{rn} and D_{cn} are the population densities in residential and commercial areas, respectively. ε is the error term (a random value with a mean of 1 and a standard deviation of 0.5) used to generate each area's population density. S is the area of each different land type, and S_{cell} gives the real area of each cell. $\sum NumCell$ represents the total number of developed cells for each land-use type.

Based on the predefined population densities for the different types of land use zones, the number of households in residential areas is calculated using (2.3) as follows:

$$\begin{aligned} N_r &= \sum_{n=1} (D_{rn} \cdot \varepsilon_{rn}) \times S_{rn} \\ S_{rn} &= S_{cell} \times \sum NumCell_r \\ N_r &= \sum_{n=1} (D_{rn} \cdot \varepsilon_{rn}) \times S_{cell} \times \sum NumCell_r \end{aligned} \quad (2.3)$$

The number of company owners in commercial areas is expressed as

$$\begin{aligned} N_c &= \sum_{n=1}^2 (D_{cn} \cdot \varepsilon_{cn}) \times S_{cn} \\ S_{cn} &= S_{cell} \times \sum NumCell_c \\ N_c &= \sum_{n=1}^2 (D_{cn} \cdot \varepsilon_{cn}) \times S_{cell} \times \sum NumCell_c \end{aligned} \quad (2.4)$$

Consequently, the total number of agents in all developed areas is expressed as

$$N_h = \sum_{x=r,i,c} N_x \quad (2.5)$$

Residential Resource Use and Waste Discharge

Local governments attach great importance to the principle of sustainable development and environmental protection. The implementation of a strategic spatial plan will lead not only to urban growth but also to population concentration in developed urban areas. Thus, the great amounts of resources used and waste discharged by agents should not be neglected when making strategic decisions. We utilize the SSP-SS tool to reveal agents' resource use and waste discharge while taking into

account the interaction between local government agents and other agents under the assumption that all agents achieve a consensus and cooperate to comply with the planned total amounts of resources used and wastes discharged.

Some basic principles governing these calculations are: First, the initial values of agents' resource use and waste discharge are set for each agent based on the different land-use types proposed by the local environmental department. Second, limits on total resource use and waste produced proposed by the environmental department are used in the initial step. Accordingly, the total amount of agents' resource use and waste discharge will be calculated in each simulation step, and adjustments will be made by each agent when the total resource use and/or waste discharge amounts exceed control values proposed by the local government. A flow diagram for this calculation is shown in Fig. 2.1. The model for calculating resource

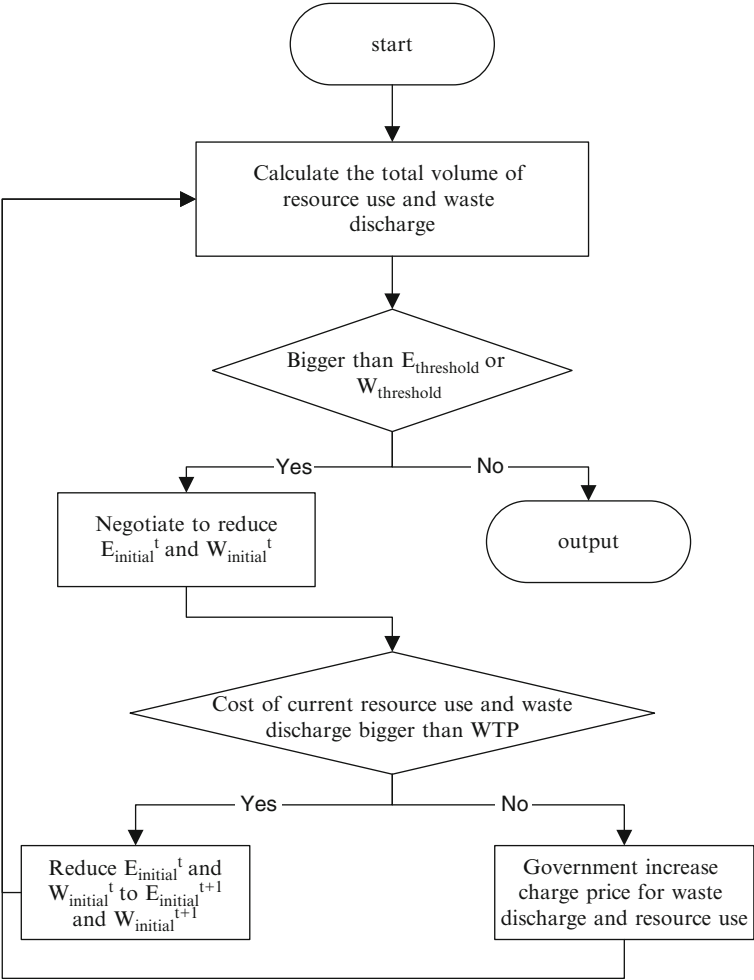


Fig. 2.1 Calculation of resource use and waste discharge

use is shown in (2.6). E_i^t stands for the resources consumed in industrial areas in step t , E_r^t stands for resources used by households in residential areas in step t and E_c^t stands for resources used in commercial areas in step t . E^t is the total amount of resources used in step t ; E_{initial}^t is the initial value of resources used by each agent in step t ; E_{initial}^{t+1} is the updated value for each agent's resource use, which has been adjusted by agents' interactions and governed by the control policy; and $E_{\text{threshold}}$ is the value to which the total amount is limited.

$$\begin{aligned}
 E^t &= E^t i + E^t r + E^t c = N^t i \times E^t \text{initial} \times \varepsilon i \\
 &\quad + N^t r \times E^t \text{initial} \times \varepsilon r + N^t c \times E^t \text{initial} \times \varepsilon c \\
 &= E^t \text{initial} \times (N^t i^* \varepsilon i + N^t r^* \varepsilon r + N^t c^* \varepsilon c) \\
 &= E^t \text{initial} \times \sum_{x=i,r,c} N^t x^* \varepsilon x \\
 \text{if } E^t &\geq E_{\text{threshold}} \\
 E^{t+1} &= E^{t+1} \text{initial} \times \sum_{x=i,r,c} N^t x^* \varepsilon x (E^{t+1} \text{initial} - E^t \text{initial} < 0) \\
 \text{otherwise } E^t &= E^t \text{initial} \times \sum_{x=i,r,c} N^t x^* \varepsilon x
 \end{aligned} \tag{2.6}$$

The model for calculating waste discharge is shown in (2.7). W_i^t stands for the waste discharged by industrial agents in step t , W_r^t is household waste discharged from residential areas in step t , and W_c^t stands for waste discharged from commercial areas in step t . W^t stands for the total amount of waste discharged in step t , W_{initial}^t is the initial value for waste discharged by each agent in step t , and W_{initial}^{t+1} is the updated value for each agent's waste discharge, which has been altered by agents' interaction based on agreement that the total waste to be discharged will be controlled. $W_{\text{threshold}}$ is the value to which the total amount is limited.

$$\begin{aligned}
 W^t &= W^t i + W^t r + W^t c = N^t i \times W^t \text{initial} \times \varepsilon i \\
 &\quad + N^t r \times W^t \text{initial} \times \varepsilon r + N^t c \times W^t \text{initial} \times \varepsilon c \\
 &= W^t \text{initial} \times (N^t i^* \varepsilon i + N^t r^* \varepsilon r + N^t c^* \varepsilon c) \\
 &= W^t \text{initial} \times \sum_{x=i,r,c} N^t x^* \varepsilon x \\
 \text{if } W^t &\geq W_{\text{threshold}} \\
 W^{t+1} &= W^{t+1} \text{initial} \times \sum_{x=i,r,c} N^t x^* \varepsilon x (W^{t+1} \text{initial} - W^t \text{initial} < 0) \\
 \text{otherwise } W^t &= W^t \text{initial} \times \sum_{x=i,r,c} N^t x^* \varepsilon x
 \end{aligned} \tag{2.7}$$

SSP-SS Implementation

Implementation Area

The Chuandong area belongs to Tongren City, which is in northeast Guizhou Province, southwest China. The whole area is located in the middle of the Lingwu Mountains next to Hunan Province. According to Tongren City’s latest local economic and social development plan, it is going to develop a new urban area in Chuandong. The new urban area will be located in the vicinity of 108° 23’ to 108° 26’ east and 30° 80’ to 30° 83’ north. The whole planning area covers about 18.7 km². It is just 5 km from the local airport, Daxing Airport, and 10 km away from the local railway station. The route for Provincial highway N201 crosses the planning area. The spatial pattern of this new urban area was designed by the local government’s department of urban planning. Its configuration is as shown in Fig. 2.2 with the whole urban area to be divided into industrial, landscape, residential, and commercial zones. Meanwhile, the planned highway will play an important role in the new urban development. Traffic conditions provide Chuandong area with special development opportunities and challenges.

According to the local economic and social development plan, the total population is planned to be 800,000 in the Chuandong area, and development will cover about 20 km². There are two development proposals for this new urban area that have been permitted by the local government. One proposal is intended to accelerate new urban development through investment in specific projects in Chuandong’s new business district, as well as construction of two university campuses in the urban center. As shown in Fig. 2.2a, the new urban area comprises the locations of educational organs (T4), residential areas (T5), and commercial areas (T6). The other development proposal is targeted to accelerate land-use development through construction of the provincial highway, which already under way. The site of the highway is shown in grey in Fig. 2.2. We will, therefore, introduce two urban growth scenarios for the Chuandong area corresponding to these development proposals. The first will take the urban centers in Fig. 2.2b as the initial area for

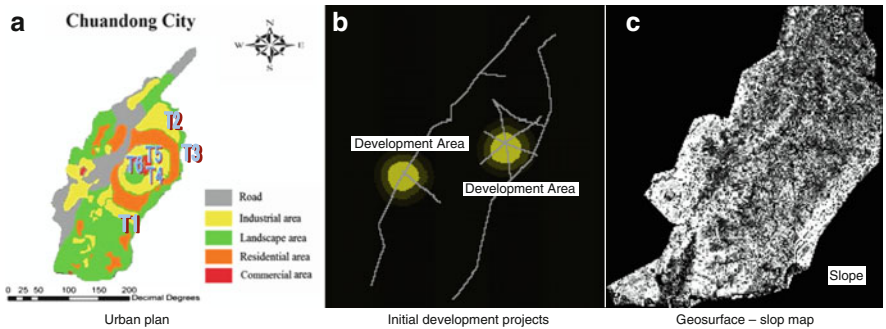


Fig. 2.2 Spatial pattern of land-use zoning in urban plan of Chuandong area

development, and the second will take the highway construction site as its initial land-use development area.

SSP-SS Framework

As shown in Fig. 2.3, SSP-SS fits into a three-part framework of data importing, data processing, and output.

In the first phase of the urban growth simulation, spatial patterns, geo-surface information, and initial development zones within the Chuandong area must be imported from GIS data. Among these data, the spatial patterns are plan drawings as shown Fig. 2.2a, which is a plan proposed by VBN design Inc. but not the final approved urban plan for the Chuandong area. Geo-surface information includes the

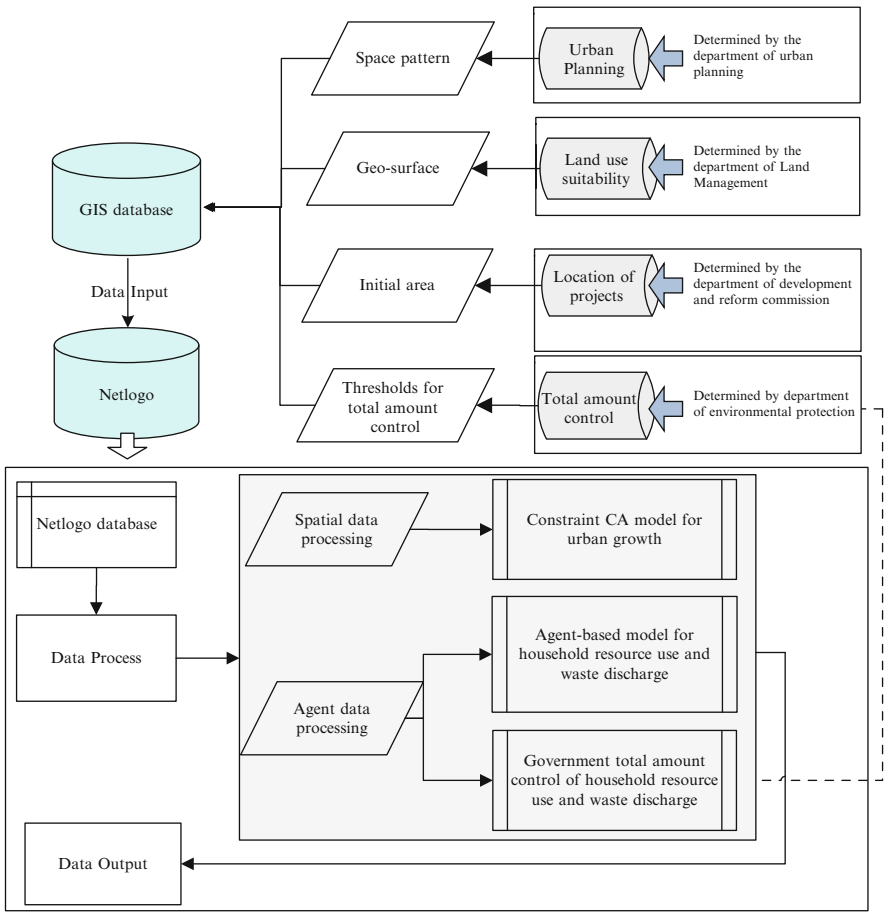


Fig. 2.3 SSP-SS framework

results of land-use suitability evaluations, which we generated using remote sensing data (Fig. 2.2c). The initial development areas (Fig. 2.2b) for our simulation are based on the locations of the investment projects discussed above, for which consensus was gained through deliberation among local officers, and abiding by the local economic and social development plan. We believe that all the data can be prepared by local urban planning, land-use management, and development departments. As a case study, we prepared these data ourselves in order to be consistent with planning practices in China for possible future application of this model by local governments.

There will be two choices of how to launch investment projects in the initial development phase in the Chuandong area, and therefore two urban growth scenarios can be simulated, based on the different locations of areas to be developed in that initial phase. One of the scenarios is that urban growth will be spurred by construction of the highway (the gray in Fig. 2.2a). In the other scenario, growth is promoted by developing the city centers, as shown in Fig. 2.2b.

As shown in Fig. 2.4, the constrained CA model can simulate Chuandong's urban growth process. Based on the simulated urban growth, resource use and waste discharge can be calculated. Moreover, threshold values for controlling resource use and waste discharge should be based on values determined by the local environmental protection department.

Figure 2.4 details the flow of the simulation. First, data can be imported through the "setup" procedure. Then, the simulation is implemented through the "urban growth" and "environmental assessment" processes. Next, the results of the simulation can be saved and output in the "display statistics" procedure. Users can then analyze the results displayed on the system interface.

SSP-SS Implementation and Results

SSP-SS is implemented in the Netlogo platform authored by Uri Wilensky in 1999. It is a programmable modeling environment suited for simulating natural and social phenomena. It allows users to carry out experiments by changing parameter values and observing updated results. The SSP-SS interface is shown in Fig. 2.5.

Sliders and switches in the interface allow users to change the values of parameters. The sliders on the left from the top are respectively threshold of development potential, agent numbers, a density parameter used to generate density values in different land-use zones, average resource use, average waste discharge, and the total limits on resource use and waste discharge. Sliders in the middle from the top are respectively a slider permitting selection of one new initial development area (*developX* and *developY*) and set policy parameters. Sliders from the top right are global demand (developed cell numbers), development years, and other policy parameter settings. There are some settings that allow the user to choose different results that they want to display. These settings, as shown in Fig. 2.5, include space potential, geosurface, and environment assessment.

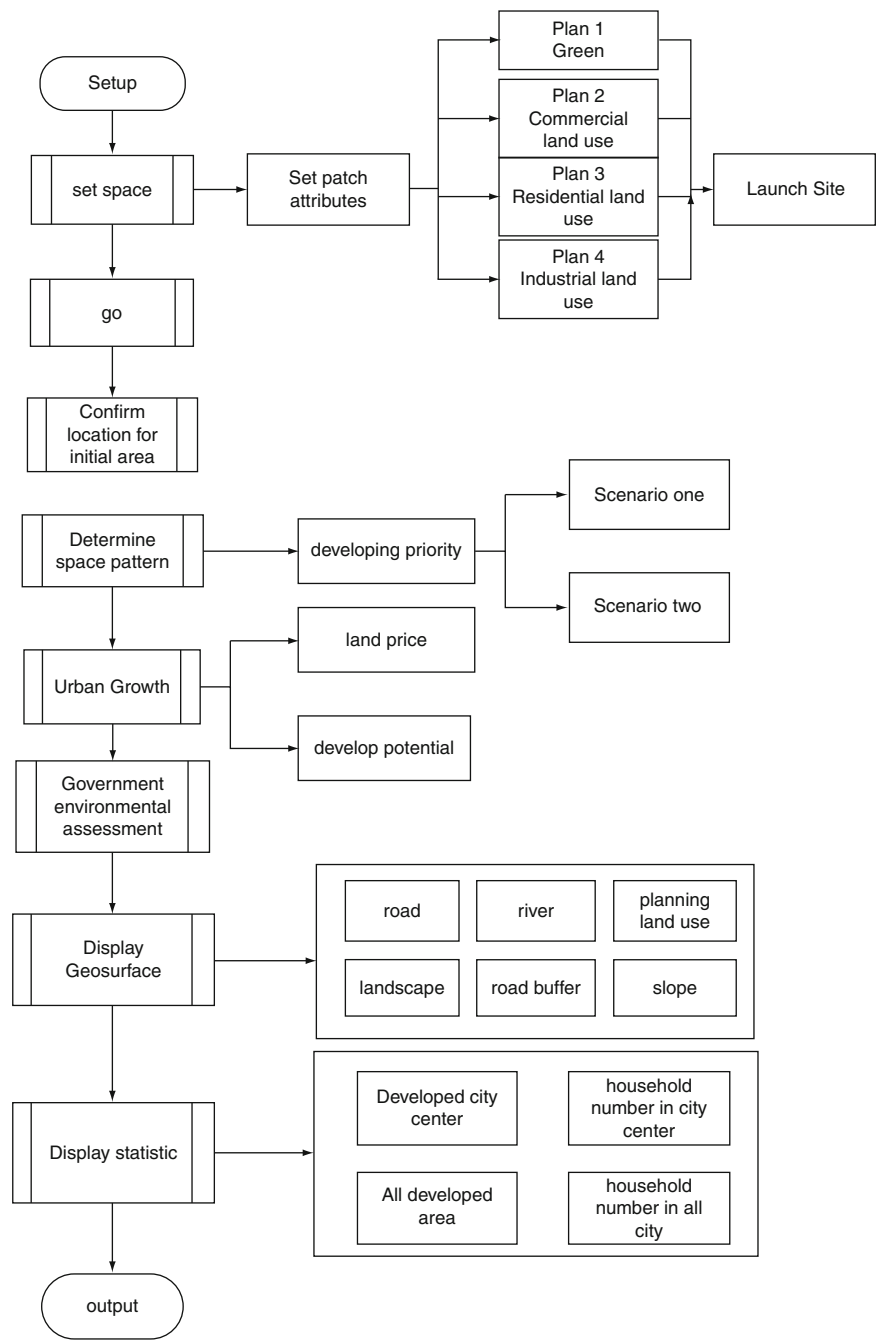


Fig. 2.4 Flow of urban growth simulation for the Chuandong area

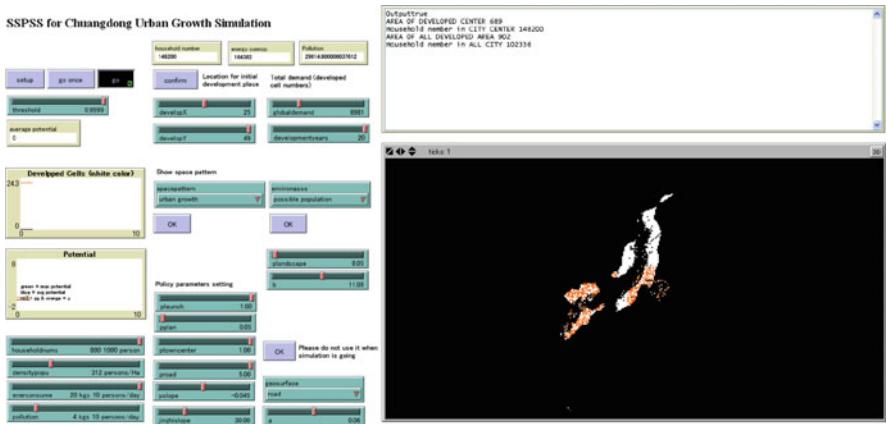


Fig. 2.5 SSP-SS interface in Netlogo

Results of First Scenario Simulation

Under the urban growth scenario characterized by urban center development, the region formed by T4, T5, and T6 land-use categories is determined to be the area where initial development will occur. According to the strategic spatial plan, investment in urban center development will be divided into three stages, and we therefore implemented the simulation in three stages as well: initial development, mid-stage development and the mature stage where development is complete.

According to local social-economic conditions given in the strategic spatial plan, there will be a population demand of 800,000 people in the Chuandong area. However, because the strategic plan does not explicitly describe economic demand with regard to industrial structure or commercial use at this stage, we took only simulated household resource use and waste discharge estimates for our analysis. The standard daily household waste discharge is about 14.6 kg/10 persons according to the statistics from the city of Statistic Bureau of Shanghai (2000). We assumed a standard daily household resource use of 20 kg/10 persons. Due to a lack evaluation data judging the environmental carrying capacity and energy supply capability in the Chuandong area, we assumed that the total resource use and waste discharge thresholds are respectively 1,470,000 kg and 30,000 kg. If the total resources used or wastes discharged exceed these thresholds, household will reduce their daily resource use and/or waste discharge in order to meet the total limit prescribed in the simulation. The results of the initial stage simulation are shown in Fig. 2.6.

As shown in Fig. 2.6, promotion of city center development induced rapid growth in the number of households, which increased from 30,000 to 200,000 over the total urban area. This occurs even though, except for the development of university campuses in the urban center, there is no explicit development potential determined by the strategic spatial plan. Thus, the developed cells tend to be



Fig. 2.6 Simulated urban growth in the initial stage under the first scenario



Fig. 2.7 Simulated urban growth at mid-stage under the first scenario

centralized in the urban center area. In Fig. 2.6, areas shown in red and orange are the regions with high population density and large resource use and waste discharge.

As the simulation continues we assumed that a population of 300,000 would be needed at the beginning of mid-stage development. As shown in Fig. 2.7, formation of the new urban center has been basically achieved. The more colorful areas in the T4, T5, and T6 zones show that the population is higher there than in the areas promoted for T2 and T3 land uses. This means that households are mainly centralized in the urban center.

When the simulation reached the mature stage, the number of households rapidly increased to more than 800,000 over the whole area. As shown in Fig. 2.8, urban development in the urban center area has improved even more and the population density has increased to 600 persons/ha. Moreover, the city center is connected with



Fig. 2.8 Simulated urban growth in the mature stage under the first scenario

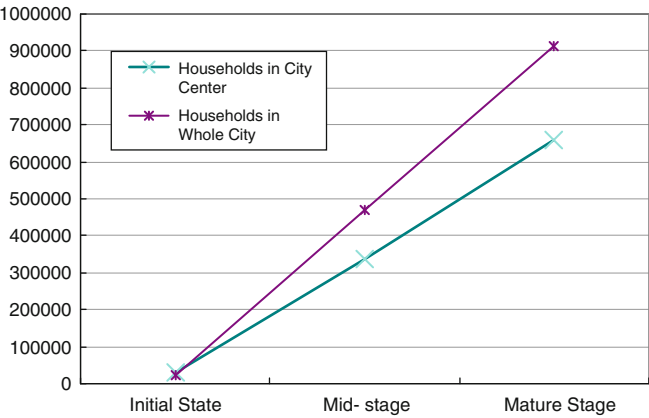


Fig. 2.9 Household numbers in the first scenario

Daxing Airport via the highway. At this stage, the development of the new urban area in Chuandong has been achieved. Compared with Fig. 2.2, it can be seen that the simulated space patterns of Chuandong's new urban area basically match the planned space pattern.

The simulation also shows that if the developed area in Chuandong were increased to 24 km² the population density would increase to 500 persons/ha in the T4, T5, and T6 land-use areas, and would reach 400 persons/ha in the T2 and T3 areas. The population would reach 650,000 in the city center and more than 800,000 over the entire area (Fig. 2.9). As shown in Fig. 2.10, the total daily household resources used and daily waste discharged are respectively more than 1,000,000 and 200,000 kg, which do not exceed the total control limits.

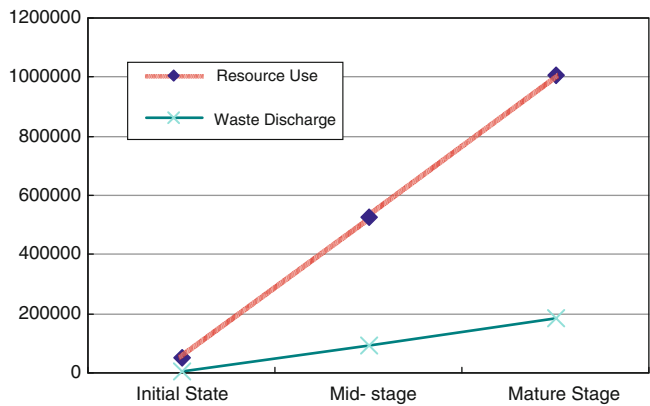


Fig. 2.10 Total daily household resource use and waste discharge at each simulation stage



Fig. 2.11 Simulated urban growth in the initial stage under the second scenario

Results of Second Scenario Simulation

Under the urban growth scenario characterized by the development of the highway, we took the areas shown in gray in Fig. 2.2 as locations where initial development would occur. Except for the initial area, all other simulation conditions and parameters were the same as in the first scenario.

In the simulation’s initial stage, areas around the highway developed first, with people attracted to the area because of the road. Meanwhile, households gradually centralized into areas along the highway as shown in Fig. 2.11. Population density increased to 600 persons/ha in the urban center and 350 persons/ha in the surrounding areas. Although the number of households around the highway nearly doubled by the end of the initial stage, the spatial pattern in the urban center is still not clear. Thus,



Fig. 2.12 Simulated urban growth at mid-stage under the second scenario

we see that construction of the city centers, should be strenuously promoted to induce formation of the urban center and growth of the entire urban area.

By stressing the city center construction, we were able to induce the spatial pattern of the urban center to become clearer by the end of the simulation's mid-stage. Meanwhile, since urban growth was promoted by both highway development and the city centers construction, urban development sprawled across the entire area. Figure 2.12 shows that most of the areas near the highway and the urban center have been developed. Moreover, in the mature stage, the colored areas became even more aggregated, showing that the number of households, as well as the amount of resources they use and waste they discharge, will have increased even further there. The local government should be sensitive to urban development near the highway and should separate the urban area from the highway with a green belt.

Figure 2.13 shows that, compared with Fig. 2.11, Chuandong's spatial pattern becomes more compact as development proceeds. Displaying aggregation of developed urban areas, the colored areas are more intense than in the previous two stages. This indicates a boom in household mobility and increased household resource use and waste discharge. Urban growth under the second scenario can be summarized by noting that the spatial pattern tends to be different (as shown in Fig. 2.11) from the pattern devised for the strategic urban plan if development of the urban center is not strenuously promoted.

Through last stages of the simulation, the purpose of urban development in Chuandong area, namely meeting population and land-use demands, have been basically achieved through the promotion of highway development and campus construction. In order to make the spatial pattern of the Chuandong area more compact, development around the highway should be restricted in a rational way, inducing newly developing areas to aggregate around the city center (Fig. 2.14).

The simulation also showed that if the developed area in Chuandong reached 20 km^2 the population density would increase to 600 persons/ha in the T5 and T6 areas, while in the surrounding T2, T3, and T4 areas, densities of 350 persons/ha



Fig. 2.13 Simulated urban growth in the mature stage under the second scenerio

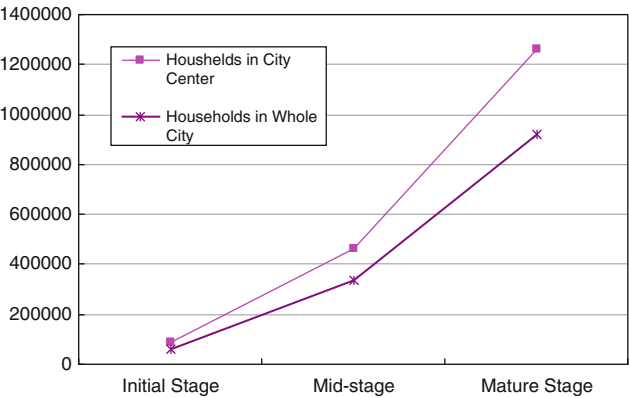


Fig. 2.14 Numbers of households in the second scenario

could be achieved. As Fig. 2.15 shows, total household resource use and waste discharge are nearly 1,400,000 kg/day and 260,000 kg/day, respectively, which do not exceed the control limits.

Conclusions

The SSP-SS tool, which integrates constrained CA and ABM models, is able to describe potential spatial urban growth processes. Using this tool, the planning work proposed by local urban planning, land management, and environmental protection departments and development and reform commissions can be combined in the same platform to visualize possible spatial patterns of urban growth.

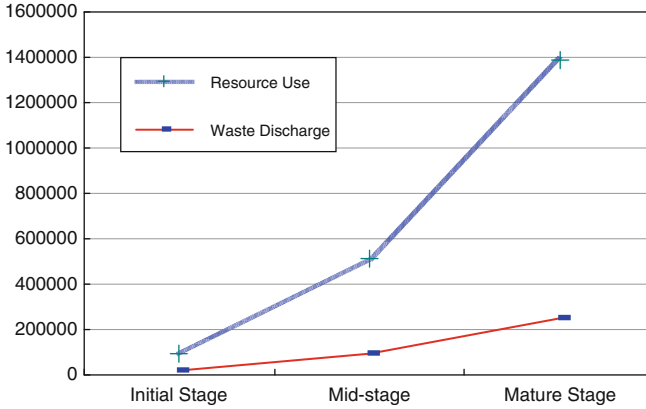


Fig. 2.15 Total daily household resource use and waste discharge at each simulation stage

In this *chapter*, we have focused on how to apply the agent-based model as a tool to aid local governments in investigating growth possibilities through urban modeling in planning practice rather than in model building and validation. We employed the SSP-SS tool to integrate urban and land-use plans with an economic and social development plan on the same platform in order to study the dynamic, interactive influences between the three plans. These influences are reflected in the different outcomes for various spatial strategy plan scenarios in the urban growth process. As a result, it is possible to bring population and land-use demand into an economic and social development plan. This allows urban regulation planning and land-use suitability evaluations found in land-use plans to be used together to gain insight into the impact urban policies laid out in strategic spatial plans can have on urban growth. We also integrated resource supply capability and waste discharge carrying capacity drawn from Chuandong’s environmental plan into the Netlogo platform for investigating environmental issues in the urban growth process.

In this research, all the data were prepared by the research team to test whether an accurate dataset could be imported into the system. With the success of this attempt, we can try to validate the model in planning practice. For this purpose, historical datasets for estimating parameters and a planning dataset including urban, land-use, and socio-economic development plans are necessary. This remains as further work in this research stream. Finally, we did not present modeled behaviors in this *chapter* nor was interaction between agents validated in the estimation of the total control amounts of resources used and wastes discharged. These should be considered carefully in future work.

Acknowledgment This research was supported by Minister of Environment of Japan (S-3 project), Grants-in-Aid for Scientific Research (No. 23404022B), Japan Society of the Promotion of Science.

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<http://www.springer.com/978-3-642-13558-3>

Geospatial Techniques in Urban Planning

Shen, Z.

2012, XIII, 393 p., Hardcover

ISBN: 978-3-642-13558-3