Form scenario analysis using constrained CA[1]

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Abstract: Future urban form is hard to be accurately predicted and simulated because of existing uncertainty in urban development. Scenario analysis has been widely applied in the realm of urban and regional planning. In most of current scenario analysis research of urban growth, developing policies are set as the input scenario conditions to generate various urban forms, which can be referred to by policy makers and urban planners. The perspective of this paper has reversed the line of current scenario analysis for urban growth, in which the term of form scenario analysis (FSA), a spatially explicit approach, is novelly defined, employing urban form as scenario condition and aiming at identifying whether any policies set can be implemented to realize the pre-defined form. If yes, what the detailed policy implications are for the scenario form will be answered. A constrained cellular automata model (CA) is developed for FSA, which is similar with constrained CA calibration using historical observed forms. Four planned schemes of Beijing Master Plan 2020 for Beijing metropolitan area are analyzed using constrained CA to test FSA approach, and corresponding required policy parameters are generated, together with policy implications. FSA is proved to be suitable for urban planning practice.

Keywords: cellular automata; urban form; desired future; urban planning; Beijing

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1. Introduction

In urban growth analysis, simulation and prediction, in order to reflect the uncertainty of future urban development, urban form is frequently investigated using scenario analysis (SA) approach as the basis for decision-making, regarding the developing policies as scenario conditions (for instance, Klosterman, 1999; Landis, 1994, 1995, 1998a, 1998b). For this, Couclelis(2005) argued that little has been done by routine land use models to investigate the future-oriented research, such as desired or feared future. The line of the paper, using future urban form as scenario condition to identify required spatial policies to realize the form, is on the contrary side of traditional urban growth SA. We bring forward the conception of form scenario analysis (FSA), which is applied to analyze the consistence between urban form and corresponding spatial policies, together with the differences of required spatial policies among various planned urban forms (Socio-economic demand is regarded as an exogenous variable in this paper).

In China, urban planners, mostly working in government-hold planning institutions, intend to keep intrinsic planned economy notion when constituting planning form, resulting in lacking of market economy factors considerations (such as location factors). They are accustomed to constitute desired planned form firstly, and then consider required spatial policies to yield the desired urban planning form. Planned urban form by planners can not be fully implemented solely via enforcing land use planning (or zoning), because except urban planning, planned urban form is also influenced by other related urban spatial policies, such as eco-sensitive land protection, infrastructure development, and other market economy factors. Hence, the practical urban growth often deviated from planned form resulting in planned form being broken through. For example, the planned form evaluation results show that more than 35% urban development was beyond the planned form in Beijing, Shanghai and Guangzhou (Han *et al*, 2009; Xu *et al*, 2009; Tian *et al*, 2008). Planning departments, lacking of policy guidance, have little knowledge of the exact policies for the planned form and their differences from current policies. From this point of view, urban policies required for planned urban form are widely concerned by the government, and therefore, FSA has important practical significance in China.

Scenario is defined as “the assumption on reasonable event with uncertainty in the next period of time” (see, Kahn and Wiener, 1967; Pearman, 1988), and scenario analysis, defined as “the entire process of predicting and analyzing the possible influences of scenario” (see, Ratcliffe, 1999), acknowledges that the future development is diversified and has a wide range of possible trend (see, Schoemaker, 1995; Ringland, 1998). Scenario analysis is widely applied in urban growth models since future urban form is often difficult to be accurately predicted. Various set of policy parameters can be employed to generate the corresponding urban form (Klosterman, 1999; Landis, 1994; Landis, 1995).

The paper brings forward FSA approach using constrained cellular automata (CA), which provides it possibility to analyze required developing policies for form scenario as to present institutional implications for urban planning practice. The novel exploration of FSA can identify the existence of required policies as well as the policies variation among planned forms, which differs from traditional applications of constrained CA. In section 2 of the paper, the methodology for FSA using constrained CA will be interpreted in detail. In section 3, we will present the application of FSA approach to validate four planned schemes in the latest urban master plan of Beijing metropolitan area, and the expression of required developing policies for each validated scenario as well as the comparison of them in parallel. We will sum up and discuss the near next steps of FSA research in the last section of the paper.

2. Approach

2.1 Form scenario analysis in math

Urban growth SA is a vision of future urban form, which in mathematics can be expressed as formula 1. It needs to be mentioned that *y*, *X* and *A* are all spatial explicit variables which in mathematical format should contain *ij* subscript to represent spatial location, but the subscript is omitted as for the simplification of the formula.

$$\begin{aligned}
&y = f(X, A) \\
&X = \{x_k{}^t \mid k = 1,2,3,\ldots,n; t = 1,2,3,\ldots,p\} \\
&A = \{a_k{}^t \mid k = 1,2,3,\ldots,n; t = 1,2,3,\ldots,q\} \qquad (1) \\
&T^p = \{T_t^p \mid t = 1,2,3,\ldots,p; T_t^p \in [T_s, T_e]\} \\
&T^q = \{T_t^q \mid t = 1,2,3,\ldots,q; T_t^q \in [T_s, T_e]\}
\end{aligned}$$

In the above formula, *A* as the term of policy, stands for urban developing policy with its spatial distribution, which is a temporal dynamic variable and can be regarded as an urban form. *X* as the term of policy parameter as well as a temporal dynamic variable, stands for the implementing intensity of the corresponding policy *A*. *X* can be regarded as the acceptable degree for the corresponded urban form of *A*. *y* stands for the urban form. y_{ij} =1 means space *ij* is developed as urban built-up, while y_{ij} =0 not developed. *k* stands for the total number of policies. T_s stands for the start point-in-time of scenario analysis, and T_e the end point-in-time (*y* is the urban form of the point-in-time T_e. *q* and *p* stand for the variation times of *A* and *X* from T_s to T_e respectively. T^q and T^p stand for the value changed point-in-time of *A* and *X* respectively. The urban form of some future point-in-time *t* is the accumulative influenced result of *A* and *X* from base point-in-time to *t*.

We draw three basic premises for urban growth scenario analysis process, considering the limitations of dataset achieving and computer calculation time consuming. (1) Function *f* is based on multi-criteria evaluation (MCE). (2) *X* and *A* keep static from T_s to T_e (in most conditions equals to the value of point-in-time T_s or T_e), so both *p* and *q* equal to 1. (3) *X* is the spatial static variable, namely its spatial distribution is homogenous. Based on the mentioned premises (THREE PREMISES), formula 1 is then transformed into formula 2:

$$
\begin{aligned}
& y = f(X \bullet A) \\
& X = \{x_k \mid i = 1,2,3,\ldots,n\} \\
& A = \{a_k \mid i = 1,2,3,\ldots,n\} \qquad\qquad (2) \\
& P = \sum_{1}^{n} x_k * a_k \\
& y = \left\langle \begin{array}{l} 1, P \geq p_{threshold} \\ 0, P < p_{threshold} \end{array} \right.
\end{aligned}
$$

THREE PREMISES are also presently applied in urban growth SA. For instance, Klosterman (1999) developed planning support system “*What if?*”, in which A are the policies of soil condition, flooding control and transportation, and X stands for the corresponding implementation intensity. Landis (1994, 1995) and Landis and Zhang (1998a, 1999b) developed CUF (California Urban Future Model) and CUF-2 respectively, in which A stands for the policies of location, environmental conditions, land-use control, zoning, existing development density, accessibility for each developing land unit (DLU), and X stands for their implementation intensity. In routine urban growth SA, *X* and *A*, the scenario analysis conditions as input, are applied to generate corresponding urban form *y*. In mathematics any parameters set, namely *X* and *A*, has the definite analysis result *y*, denoting that we can get the corresponding urban form from any developing policy. What should be mentioned here is that in most existing traditional urban growth scenario, *A* is adjusted to review the dynamic change of *y*, while *X* keeping constant, to simplify SA process.

FSA, promoted in the paper, can be regarded as the reversed process of routine urban growth scenario analysis. THREE PREMISES are also applied in FSA, which can be expressed as formula 3 in mathematics.

$$
\begin{aligned}
& (X, A) = f^{-1}(y) \\
& X = \{x_k \mid k = 1,2,3,\ldots,n\} \qquad\qquad (3) \\
& A = \{a_k \mid k = 1,2,3,\ldots,n\}
\end{aligned}
$$

In formula 3, *y*, as the scenario condition, is used to generate required developing policies (*X* and *A*). From the equation solving view, for any independent variable *y*, dependent variables, *X* and *A*, can be classified as three conditions: (1) No solution, namely there is no policies to yield *y*. (2) One solution, namely only one policies set can realize *y*. (3) Multi solutions, namely multi policies sets can realize *y*. Constrained cellular automata (CA) are adopted to solve FSA issue, which regards desired urban form *y* and confirmed policies *A* as model input to solve the equation in formula 3 in order to validate the existing policy parameters *X*.

2.2 Deriving policy parameters

Urban form as scenario condition remains vacancy in recent literatures relevant with constrained CA so far. Whether constrained CA can be adopted for solving FSA and whether urban form can be regarded as scenario condition remain unexplored. Firstly we will investigate the status transition rule acquisition method of constrained CA (model calibration), which is the core procedure of traditional constrained CA to simulate urban growth (for instance, Li and Yeh, 2000, 2002, 2004; Wu, 1998). Observed forms (*y*) and known constrained conditions (*A*), namely policies, in some historical stage are required to identify parameters for constrained conditions (*X*). FSA is aimed at acquiring *X* through *y* and *A*. In traditional model calibration process, urban form is based on historical observation, while in FSA, urban form is based on pre-defined urban form. Therefore, the two processes are identical in essence.

The key issue for FSA using constrained CA is the identification of policy parameters (*X*), which can refer to the model calibration method mentioned above. In FSA, T_s can be regarded as the start point-in-time of the historical stage, and T_e the end point-in-time. Therefore, time phase of scenario analysis, namely, T_s to T_e, corresponds with the historical stage, and FSA can be transformed into model calibration issue of traditional constrained CA, in which such approaches as logistic regression, Artificial Neural Network (ANN), Genetic Algorithm (GA), and Nested loops are widely adopted.

The evaluation standard for the consistence of form scenario (*y*) and current policies (*A*) should be confirmed in FSA. Policy parameters (*X*) can be calibrated using form scenario. As the input of constrained CA, *X* is applied to simulate urban form (y'). *Kappa* index, as the evaluation standard indicator, is applied to compare simulated form y' and form scenario *y* cell by cell. *Kappa* less than 80% stands for none solution condition (No policy parameters to realize form scenario), and greater than or equal to 80% stands for at least one solution condition, denoting that the calibrated parameters can be used to simulate designated scenario form. Generally speaking, solutions for FSA can be expressed in mathematics as $\{X \mid y' = f(X, A), Kappa(y, y') \geq 80\%\}$, which stands for the solution space of *X*.

The simulation logic of urban growth in China is influenced by the particular institutions of socialist market economy. Firstly, the government determines the land development amount of different time phases according to socio-economic conditions in macro-level. Secondly, the developers respectively acquire suitable land to develop from the government, taking into account comprehensive constraints, to develop during the allocation process in micro-level.

2.3 Constrained CA for FSA

Based on the simulation logic, the conceptual model of constrained CA for FSA is shown in formula 4. Neighborhood of CA is Moore type, with 8 adjacent cells for each CA cell, and the discrete time of CA is one month in real world. Constrained conditions in urban growth process, namely developing policies, consist of four types, including macro socio-economic constraint A_{mac} (non-spatial explicit variable, and no corresponding policy parameter *X* for it), spatial constraints A_{spa}, institutional constraints A_{ins}, and neighborhood constraint $A_{nei}{}^{t}$. Spatial and institutional constraints can be supposed to keep static during future urban growth process, and macro socio-economic constraint reflects the total number of built-up cells to be developed. Neighborhood constraint, however, keeps changing with iterations of CA. Accordingly we will adopt different model calibration methods to retrieve parameters for neighborhood constraints and others separately.

$$
\begin{aligned}
&V_{i,j}{}^{t+1} = f\left(V_{i,j}{}^{t}, A_{mac}, A_{spa}, A_{ins}, A_{nei}{}^{t}\right) \\
&V_{i,j}{}^{t}: \text{ the cell status at } ij \text{ of time } t \\
&V_{i,j}{}^{t+1}: \text{ the cell status at } ij \text{ of time } t+1 \\
&f: \text{ the transition rule of CA}
\end{aligned}
\tag{4}
$$

Expressed in formula 5 is the status transition rule in MCE of constrained CA, with *LandAmount* as the total number of cells to be developed, *stepNum* as the number of cells developed in each iteration (exogenous variable), $s_{ij}{}^{t}$ as developing suitability, $p_g{}^{t}$ as initial transition probability, $p_g{}^{t}{}_{\max}$ as the max value of $p_g{}^{t}$, α as dispersion parameter ranging from 1 to 10, indicating the rigid level of developing, p^t as the final transition probability, $p^t{}_{ij}$ (namely p^t) as final transition probability, $p^t{}_{\max}$ as the max value of p^t in each sub-loop of iteration t, x_0 as the constant item in MCE, a_n as the neighborhood policy, x_n as the parameter of a_n, a_k as the policy except neighborhood, x_k as the parameter of a_k, and s_0 as the constant part of $s_{ij}{}^{t}$ among all iterations. To simulate urban growth using constrained CA with the above status transition rule, *stepNum* can be calculated by macro socio-economic constraint, and allocation procedure is adopted to allocate the cells to be developed in each iteration with maximum development probability.

$$
\begin{aligned}
&1.\ LandAmount = \sum_t stepNum^t \\
&2.\ s_{ij}{}^{t} = x_0 + \sum_{k=1}^{n-1} x_k * a_k + x_n * a_n{}^{t} = s_0 + x_n * a_n{}^{t} \\
&3.\ p_g{}^{t} = \frac{1}{1+e^{-s_{ij}{}^{t}}} \\
&4.\ p^t = \exp\left[\alpha\left(\frac{p_g{}^{t}}{p_g{}^{t}{}_{\max}} - 1\right)\right] \\
&5.\ \text{for } inStepID = 1 \text{ to } stepNum \\
&\qquad if\ p_{ij}{}^{t} = p^t{}_{\max}\ then\ V_{ij}{}^{t+1} = 1 \\
&\qquad p_{ij}{}^{t} = p_{ij}{}^{t} - p^t{}_{\max} \\
&\qquad p^t{}_{\max} \text{ update} \\
&\quad \text{next } inStepID
\end{aligned}
\tag{5}
$$

We will discuss how to retrieve model parameters for constrained CA to investigate

FSA. The parameters needed to be calibrated include *stepNum*, x_k, and x_n, in which various approaches can be adopted. Regarding the calibration of *stepNum* reflecting the total amount of land required by economic development, it can be supposed to be uniform distributed through all the simulation period as shown in formula 6.

$$stepNum = \frac{C_{T_e} - C_{T_s}}{(T_e - T_s)/t_0} \tag{6}$$

C_T: total number of developed cells in scenario form

C_t: total number of developed cells in current form

T_e: future point-of-time

T_s: current point-of-time

t_0: real time length of one iteration

Regarding the calibration of x_k and x_n reflecting the intensity of policies, logistic regression and heuristic approaches can both be applied. In our constrained CA, we integrate the methods of Wu (2002) and Clark and Gaydos (1998), combining their benefits, to retrieve the parameters of MCE formatted status transition rule. x_k can be calibrated via logistic regression. x_n can be calibrated, with maximum *Kappa* of form scenario and simulated form, via *MonoLoop* approach (details in Long *et al*, 2008) using calibrated x_k. x_k and x_n calibrated (X^*) represent the policy implementing intensity for scenario form. The semi-heuristic approach can both identify the overall historical urban growth trend and reduce the time consumed of model calibration. *Kappa* index is calculated via comparing simulated form (y') and form scenario (*y*). X^* stands for the maximum consistence of *y* and *y'* through existing A in condition that *Kappa* is greater than or equals to 80%, and X^*, as one solution in the solution space, is not the only parameters for the realization standard of form scenario. Only X^* parameters set is considered in the paper, and other solutions in the solution space will be discussed in further research.

When parameter *X* is positive, the exact policy *A* is encouraged, otherwise *A* is rejected. The parameters for various policies can also be compared in parallel to identify the policies inclination. Meanwhile, the parameters can be compared with historical ones to “visualize” the policy implications.

Constrained CA is empirically applied in Beijing master plan of 2020 to examine the consistence of four planning scenarios and confirmed policies. Policies implications are also shown in the following application section.

3. Application in Beijing

3.1 Study area and dataset

The study area of constrained CA is Beijing metropolitan area (Figure 1) with an area of 16,410 km^2, which lies in northern China, to the east of Shanxi altiplano and south of Inner Mongolia altiplano. The southeastern part of study area is plain, with a distance of 150 *km* to the west coast of Bohai Sea. It is covered by mountainous area with an area of 10,072 km^2, which is up to 61% of the whole area.

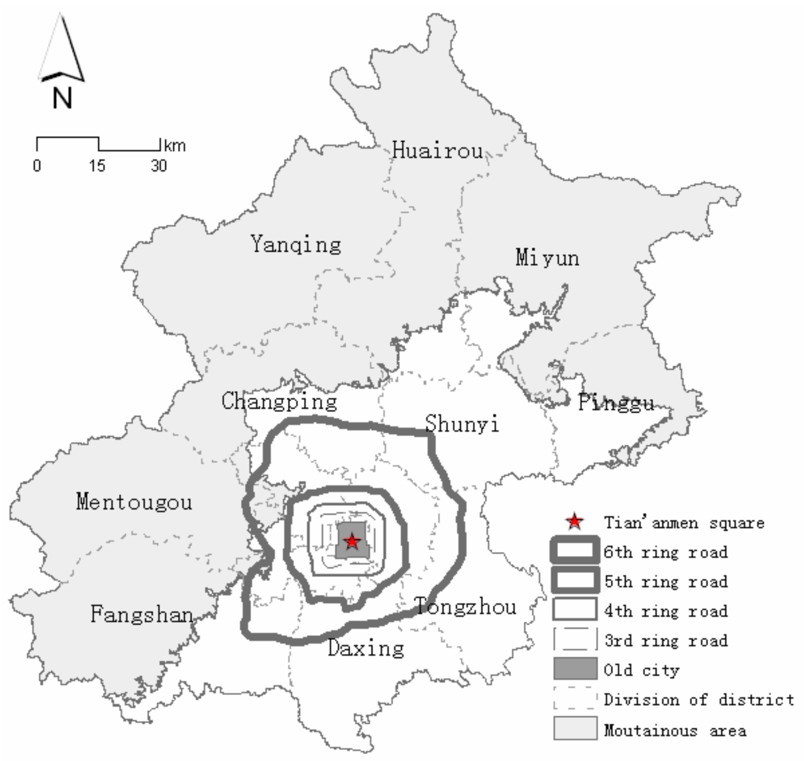

Figure 1 Study area map

Beijing has experienced a rapid urbanization period together with GDP and population amount since Reform and Opening was firstly advocated in 1978 by the central government. GDP in 2006 is 787 billions CHY, 83.7 times of that of 1976, 9.4 billion CHY. Population in 2006 is 15.81 million, 1.9 times of that of in 1976, 8.29 million (Beijing statistical yearbook, 1987, 2007). From interpreted TM images, urban built-up area in 2006 is observed as 1,324 km^2 (Figure 2), nearly 3 times that of in 1976, 495 km^2. Moreover, the urban growth is predicted to keep increasing in two decades according to the local government. Therefore, urban growth pattern is concerned by scholars and decision makers in such background, especially regarding how to develop as pre-defined planned urban form in future.

For this requirement, we tested form scenario analysis approach in Beijing metropolitan area to derive policy implications of planning alternatives. Constrained CA is proved to be suitable for simulating urban growth of Pearl River Delta, where urban growth is also quite rapid (Li and Yeh, 2000, 2002). The driven forces of urban growth of Beijing and Pearl River Delta can be regarded as similar with each other in the same socio-economy developing background. Therefore, constrained CA is introduced into form scenario analysis in Beijing. In table 1 are the policies and the corresponding dataset of constrained CA in Beijing. The spatial distribution of various policies are shown in figure 2 (Black and white denote 1 and 0 respectively in the maps). *stepNum*, the macro constraint, as one global control parameter, reflects the total amount of land development in future, and is related to the key objective of socio-economic developing plan. The spatial constraints denote the special plans or policies of city hierarchy, flood control, transportation development, etc, while the institutional constraints ecological protection, disaster prevention, and farm protection. Neighborhood constraint represents the development control policy in different scale/size.

Table 1: Dataset in constrained CA

Type	Variable	Policy	Value range	Data source
Macro constraint	*stepNum*	Socio-economic development	>0	Socio-economic Development plan
Spatial constraints	a_1	Tian'anmen (city hierarchy)	0-1	Derived from spatial dataset
	a_2	New city (city hierarchy)	0-1	Derived from spatial dataset
	a_3	Town (city hierarchy)	0-1	Derived from spatial dataset
	a_4	River (Flood control)	0-1	Derived from spatial dataset
	a_5	Road of 2006 (Transport development)	0-1	Interpreted from TM image of 2006-11-01
Institutional constraints	a_6	Construction forbidden (Ecological protection, disaster prevention)	0, 1	Beijing municipal planning committee, 2007 *
	a_7	Suitability for agriculture development (farm protection)	0-1	Beijing planning commission *et al*, 1988
Neighborhood constraint	a_n^t	Develop intensity in neighborhood	0-1	Calculated by CA

* For details of calculation approach, see (Long *et al*, 2006).

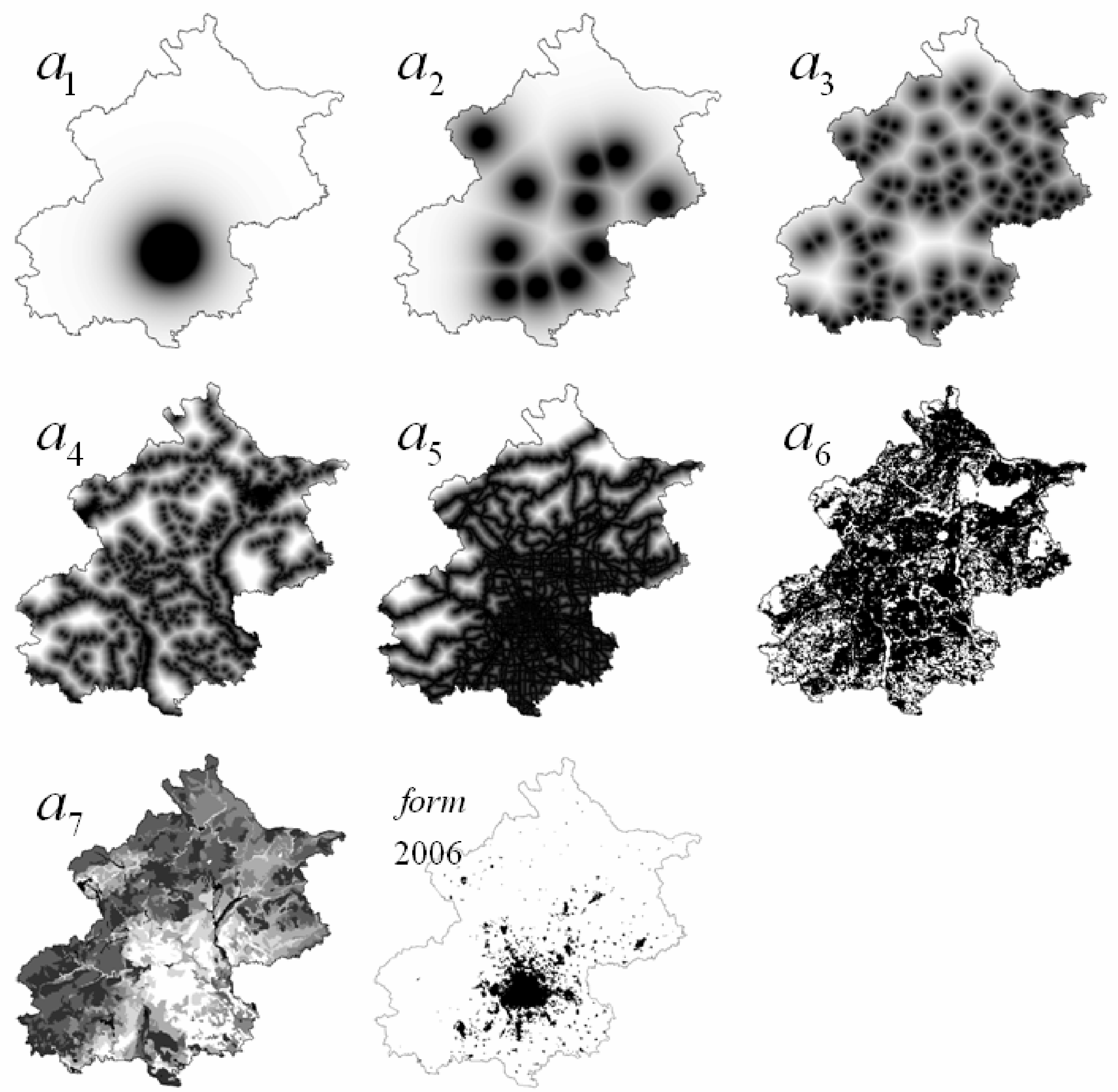

Figure 2 Maps of spatial policies and urban form of 2006

For the convenience of comparing parameters of various policies in parallel and vertical, namely across time period, policies (*A*) are standardized to range from 0 to 1, with 1 denoting the greatest probability to be developed, and 0 the least. The spatial constraint a_k, using corresponding spatial feature class as source data, is processed by "Distance/Straight Line" toolbox of Spatial Analyst module in ESRI ArcGIS family to acquire $dist_k$ followed by $a_k = e^{-\beta * dist_k}$ to calculate the attractive potential, where β=0.0001. Regarding institutional constraints, if construction forbidden policy a_6 and suitability for agriculture development policy a_7 equal to 0, there will be least probability to be developed, and if they equal to 1, there will be greatest probability to be developed. Policy parameter *X* reflects the implementing intensity of plan or policy, which, together with policy spatial distribution *A*, is correlated with the simulated urban form.

The spatial distributions of various constraints in Beijing, shown in Figure 2, play a role in influencing possible future urban growth pattern. From the perspective of every single constraint, we can directly and easily recognize corresponding urban form without taking into account other constraints. For an instance, construction forbidden constraint a_6 stands for dispersed urban form, with Miyun Reservoir, partial western mountain area, farmland in plain area, and Greatwall protection zone undeveloped. Road constraint a_5 stands for the urban form along the traffic corridors mainly in plain area due to the high density roads network in this area and low in remote mountain area. Considering combined constraints and currently existing urban form featuring central city sprawl, the future urban form in Beijing tends to be further sprawl around central city in plain area, with scattered developed patches in mountain area. For this, in the following context, we will come to set form scenarios and identify policy parameters required for scenarios using constrained CA.

3.2 Settings of form scenarios

Five versions of urban master plans for Beijing metropolitan area have been constituted since 1958, separately in the year of 1958, 1973, 1982, 1992 and 2004 (Beijing municipal planning committee *et al*, 2006). With respect to 1992 version planning scheme for 1991-2010, Han *et al* (2009) pointed out up to 51.8% urban development from 1991 to 2005, within the sixth ring road area (Figure 1), was beyond the planned urban construction boundary, It is clearly shown that the practical urban development was poor consistent with the last version planned form in Beijing. Therefore, form scenario analysis study is essentially needed for validating the new version planned form.

The planning goal of 2004 version is for year 2020, and the planning has established the population scale of 18 million, the developed land scale of 2,300 km^2, as well as the urban spatial structure of “Two ax., tow belts and multi-sub-centers”. In the plan, four schemes of planned form, shown in figure 3, are constituted with almost the same total developed land scale (see table 2) and different spatial layout. During the constitution and approval of the plan, the possibility to be realized is not considered in detail. We aim to apply FSA approach and developed constrained CA model to identify the consistence between planned form and existing policies.

Below are the detailed descriptions for each form scenario.

- Scenario A (y_A): Planned scenario, as the approved urban form by State Council of P. R. China (see, Beijing municipal planning committee *et al*, 2006), is characterized by preventing central city from over-sprawled and promoting the development of new cities.
- Scenario B (y_B): Sprawl scenario, so called Tandabing in Chinese (circle-spread), is characterized by promoting development in central city and controlling new development in new cities.
- Scenario C (y_C): Grape-cluster scenario, which is characterized by promoting development along transport corridors and of small towns.
- Scenario D (y_D): Sustainable scenario, which is characterized by preventing

construction forbidden area and high-quality farm land from been encroached, resulting in more dispersed form.

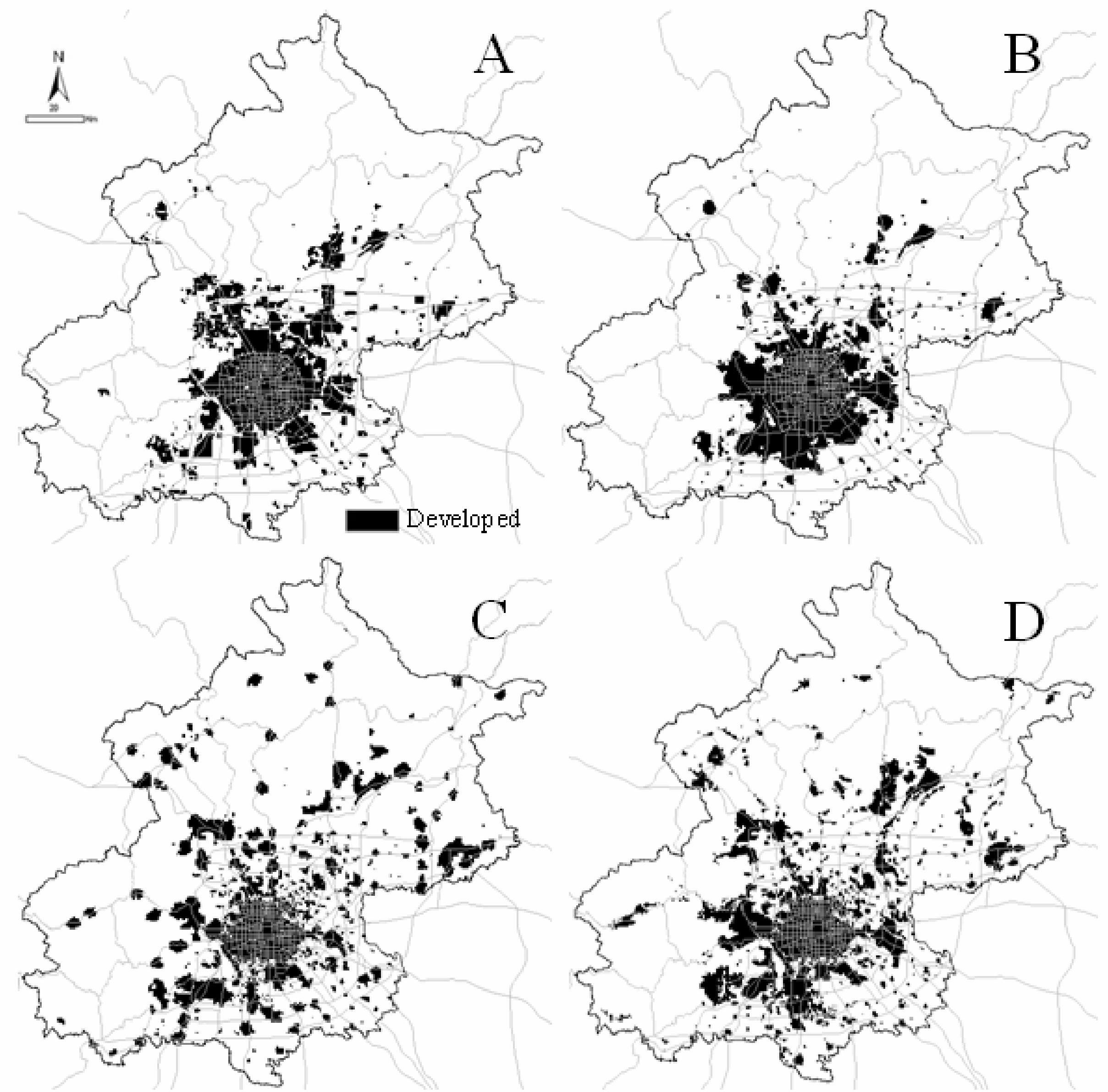

Figure 3 Form scenario maps

3.3 Identification of policy parameters

We developed the tool, a constrained CA model, for FSA using Python script language supported by ESRI Geoprocessing. The cell size of CA is 500*m* * 500*m*, then there are 65,628 cells in the study area. The total iterations number is (2,020-2,006)*12=168 in constrained CA. C_{T_s} equals to 5,011 according to the urban form of 2006 (baseline year), namely y_{2006}. In form scenario A, C_{T_e} =9,254 stands for the total number of developed cells, and *stepNum* equals to (9,254-5,011)/168=25. The identification methods of *stepNum* for other scenarios are the same.

As for the identification of parameter *X*, applied is the approach integrating logistic regression and MonoLoop. The dependent variable in logistic regression is whether one cell is developed from non urban built-up to urban built-up, 1 for developed and 0 for non-developed, and a_1 to a_7 in table 1 are independent variables, in which a_n^t is not included. Via logistic regressions, x_i (x_0 to x_7), as regression coefficients, are retrieved. Via *MonoLoop*, x_n can be identified as the parameter of neighborhood influence. The model parameters identification results, together with *Kappa* index, are listed in table 2.

Table 2: Form scenario analysis result

Variable	Scenario A	Scenario B	Scenario C	Scenario D	Historical form
Developed cells number	9254	9270	9895	10679	5011
stepNum	25	25	29	34	9
x_0	-8.700	-30.696	-63.599	-55.624	-12.263
x_1	15.268	54.558	15.106	20.849	11.782
x_2	3.575	10.294	10.046	9.701	2.490
x_3	-0.717	5.272	31.639	7.807	-1.872
x_4	4.105	8.765	24.348	11.622	7.574
x_5	1.368	6.027	7.627	8.113	0.917
x_6	1.193	3.672	4.078	23.000	1.535
x_7	-2.396	5.066	6.094	12.003	-1.179
x_n	15	17	9	7	20
Kappa	69.4	91.8	85.0	85.8	67.5
Valid	False	True	True	True	False

3.4 Validation of form scenarios

In fact, *MonoLoop* is the form scenario validation process, using *Kappa* index. When *Kappa* is greater than or equals to 80%, the form scenario is validated that the parameters identified can be used to yield the form scenario. When *kappa* index is less than 80%, the form scenario is not validated. To explain the validation process in a much more detailed approach, the simulated urban form y' can be generated using constrained CA with input parameters in table 2, namely *stepNum,* x_{0-7}, and x_n. The cell-by-cell comparison result of y' and *y* (scenario form) is shown in figure 4

Form scenarios B, C and D have relatively higher match precision respectively with the simulated forms through the *Kappa* validation and cell-by-cell comparison result. Besides *Kappa*, Moran I, separate clusters, edge cells and spatial structure (various distance zones to Tian'anmen square) methods are also applied to compare *y* and y' of form scenario B, C and D, and the consistence degree is as well agreeable high.

Form scenario A, however, has a low cell-by-cell match precision, and in this case, either y_A or A should be adjusted to reach the consistence between the scenario form and development policies.

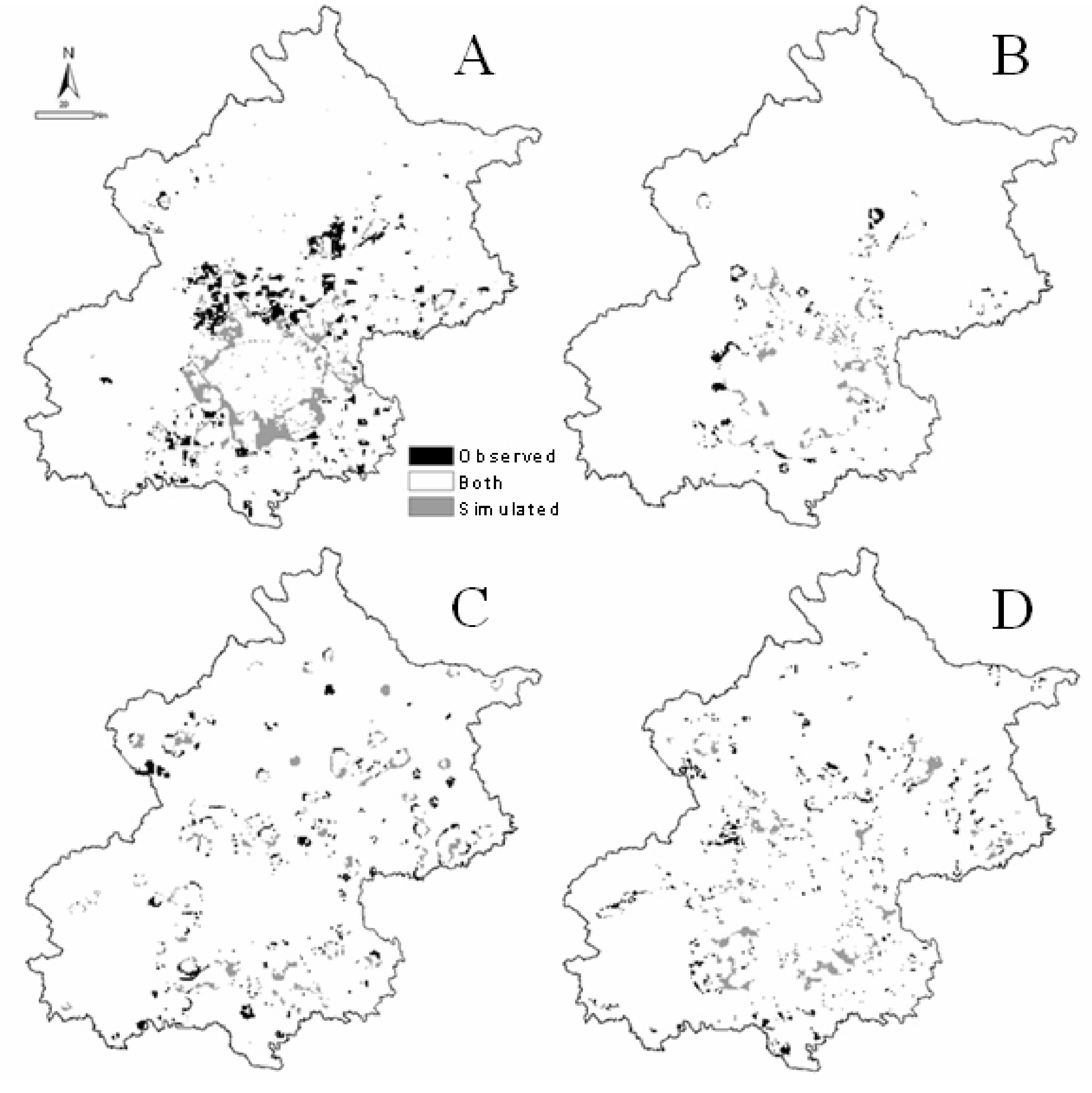

Figure 4 Simulated urban form compared with form scenario

3.5 Policy implications

Policy implications for validated form scenarios can be presented according to the result of parameter identification. Below are the three aspects of policy implications.

(1) Parallel comparison of parameters for each form scenario. For the instance of form scenario B, urban development velocity of urban built-up land is 25*12/4=75 km^2 per year from 2006-2020 according to *stepNum*. Therefore population increased one year is accordingly 750,000 with the assumption of the standard of 100 m^2 urban built-up land per person. Other parameters can also be compared in parallel, and the greater the parameter is, the more intense the policy should be implemented to realize the

form scenario. For example, scenario B should promote central city, new city and river side developing policy more than other policies.

(2) Parallel comparison of parameters across form scenarios. By comparing every parameter of various scenarios, the difference of policy implementation can be identified conveniently. For an instance, x_1 of scenario B is greater than that of scenario C, denoting that to realize scenario B, the central city developing policy should be implemented much more intensely than that of scenario C. In the same way, the construction protection intensity to realize scenario D should be largely greater than that of scenario C since parameter x_6 of scenario D is obviously greater than that of scenario C.

(3) Parallel comparison of parameters with historical phase. The policy parameters of 1976–2006, as shown in the last column in table 2, can be identified by the same model calibration approach with form scenarios, using observed forms and historical policies (Note that Kappa index for this phase is less than 80%. The reason may be the uncertainty in policy spatial distribution or parameter variation across the study area, which is not explored in the paper. Nevertheless, we suppose the policy parameters are capable to reflect the objective and true urban growth trend in history). The urban growth speed of scenario form is 2-3 times of that of historical phase 1976-2006, denoting that to realize scenario forms, urban economic and population development should be much more promoted than that of historical period. The expansion of neighborhood development should as well be controlled for scenario forms, especially scenario C and D.

4. Conclusions and Next steps

In the realm of urban growth simulation, development polices, as scenario conditions, are widely applied to analyze future urban form for decision-makers using scenario analysis method. In urban planning practices, planned urban form by the planner, however, reflects his/her preference and knowledge, lacking of global analysis of developing policies. Inconsistence between planned form and development in reality often induces that it is impossible to fulfill the planned form. In such condition, either policies or planned form should be adjusted to accommodate with each other.

The paper is the first attempt of using urban form as scenario condition to enable the discussion of the possibility of established urban form by planners within the framework of current developing policies from the perspective of development demand, geographical condition, and institutional control. FSA using constrained CA is a breakthrough of CA application, which can be adopted to solve problems faced by planning departments and planners in China. FSA is also capable of evaluating the consistence between planned form and developing policies, namely specialty plans. Nowadays in China, planning implementation evaluation (PIE) is argued as a compulsive requirement in urban planning practices to examine the consistence between the real urban spatial development and planned scheme after several years of planning implementation. The reports regarding PIE were not optimistic due to occasionally broken through of planned forms. Rather than PIE, FSA can be conducted at the very first of the planning constitution to examine the implementation possibility in integrated urban developing policies environment to bring forward the planning scheme with higher realization likelihood.

We draw THREE PREMISES to simplify FSA in the paper, such as lack of taking into account the spatio-temporal dynamic of policy and its parameter, as well as various types of urban land-use like residential, commercial and industrial. To simulate urban growth much more factually, further research should be focused on the current simplifications and set them free. Policy itself (A), besides policy parameter (X), can be taken into account in FSA to identify not only required policy implementing intensity but required policy spatial distribution. Furthermore, agent based modeling (ABM) can be applied in FSA to represent planners and other decision makers' preferences as planner agent, to study FSA in another line (Ligtenberg *et al*, 2001; Saarloos *et al*, 2005).

Time and pages limited, we did not investigate parameters sensitivity analysis of FSA in the paper. In the near future, we will undertake regional sensitivity analysis for FSA incorporating H-S-Y algorithm (Beck, 1987; Spear *et al*, 1994), which is more fitful to detect the parameters' regional dynamics than local sensitivity analysis lacking of regional watching. Policy implications can be meanwhile retrieved through regional sensitivity analysis. Furthermore, H-S-Y algorithm provides it possible to identify the parameter sets meeting Kappa index's 80% constraint, which can be applied in planning practices.

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Long's Biography

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