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Urban Expansion Simulation and Analysis in Beijing-Tianjin-Hebei Area Based on BUDEM-JJJ

Cuiling Liu and Ying Long

Abstract: The Beijing urban development model (BUDEM), based on prevalent urban growth theory and constrained cellular automatic, has been developed in 2008 for analyzing and simulating urban growth for the Beijing Metropolitan Area（BMA）. It is proved that the model is capable of analyzing historical urban growth mechanisms and predicting future urban growth for metropolitan areas in China. In this chapter, we extend the study of BUDEM from the BMA to Beijing-Tianjin-Hebei Area (JJJ), via replacing the datasets of the model and adjusting necessary parameters. In BUDEM-JJJ, the parameters include the minimum distance to the center of Beijing (f_ctr_bj), the minimum distance to the center of Tianjin and Shijiazhuang (f_ctr_tjsjz), the minimum distance to the center of prefecture-level city (f_ctr_other), the minimum distance to the center of town (f_ctr_cty),the minimum distance to the railway (f_rail), the minimum distance to the highway (f_r_hig), the minimum distance to the national road(f_r_nat), the minimum distance to the provincial road (f_r_pro), whether in the forbidden zone (constrain), neighborhood development intensity (neighbor). The model BUDEM-JJJ is used to identify urban growth mechanisms in two historical phases from 2000 to 2005 and from 2005 to 2010 , to retrieve urban growth policies needed to implement the desired (planned) urban form in 2020,and to simulate urban growth scenarios for 2049 based on the urban form and parameter set in 2020. Seven urban growth scenarios are put forward, such as the trend scenario, high-speed growth scenario, low-speed growth scenario，highway finger growth scenario, urban promoting growth scenario, developing forbidden area growth scenario, and traffic leading growth scenario. BUDEM-JJJ considers the heterogeneity of driving force and model parameters, and fulfill accurate simulation in large-scale. In addition, BUDEM-JJJ is the first applicable urban growth model in the Beijing-Tianjin-Hebei Area and has been applied in several plan projects.

Key Words: cellular automatic；BUDEM-JJJ；urban growth；simulation

Introduction

At present, the world is experiencing an unprecedented process of urbanization. The developed countries and developing countries are more or less facing the huge pressure of urban expansion, thus a lot of researches on urban expansion driving force are under way. In China, one of the fastest-developing and most-populous country in the world, the negative impact of urban expansion has emerged, such as farm land occupation, ecological environment destruction(Lu 2007; Kahn 2007). JJJ is one of the main areas of China's economic development, which is in the core status of north regional economic development pattern. Therefore, by simulating the urban expansion by establishing a model, analyzing the urban expansion driving force, and analyzing in depth the spatial layout and spatial integration direction, there will be a very important theoretical and practical meaning for promoting the regional economic strength and enhancing the overall competitiveness of our country.

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It has been a long history to analyze and simulate urban expansion. The researches mainly concentrated on the process detection of time and space, analysis of driving mechanism, process characterization and simulation, macro ecological effect evaluation, etc.(Liu and Deng 2009). The urban model which used for evaluating the urban expansion mainly experienced four stages: urban form and structure model represented by central region, static urban model represented by spatial interaction model, dynamic urban model represented by system dynamics and Laurie model, and dynamic city model represented by cellular automata and multi-agent systems(Zhou et al. 1999). CA, as an important research tool of complexity science, is suitable for simulating urban expansion a space-time dynamic process. In recent years, many researches on CA are conducted on going, For example, Batty and Xie(1994,1997) simulated the suburb expansion process of Buffalo, New York city, by CA model; White(1993,1997) simulated the land use change in the city of Cincinnati. CA model, in the aspect of urban simulation, has the following advantages: Firstly, it is simple and natural; secondly, based on spatial interaction, rather than the interaction relationship between economic and social indicators, so it can reflect the change of urban spatial pattern and the further feedback effects; Thirdly, the unit in the model can be divided into more smaller units, so the change of urban spatial structure can be found on the fine scale; In addition, the model can reflect the urban change from generation , development to the demise on a longer time scale; Finally, as an important research tool of complexity science, CA model can well simulate the urban complex phenomena, such as mutation, self-organization and chaos ,as an open dissipative system(Zhou et al. 1999; Chen 1999;He et al. 2002).

Because the urban system is a complex system and CA model also has certain limitation in itself, urban simulation based on CA is facing the following problems (He et al. 2002): As the interactions and feedback mechanism of the microcosmic individuals considered by CA model is usually simple defined by urbanization density of the neighborhood pixels, it has certain randomness; Urban form simulated under different resolution is different. Aiming at the limitations of traditional CA, some scholars began to add constraints into CA model(namely,constraint CA) to control the simulation process of the model(Ward et al. 2000; White et al. 1997),which improved the model precision and achieved good simulation effect. Long Ying(2009) developed the Beijing Urban Development Model (BUDEM) in which the space constraint, institutional constraint, and neighborhood constraint were as the constraint condition, and also simulated the urban form of Beijing at the end of 2020 and 2049(the 100th anniversary of the founding of the People's Republic of China). Some other scholars combined CA model with other models as complementation, developing models more suitable for simulating the urban dynamic change, such as combining CA model with GIS(Yeh and Li 2001; Wu 1998), studying how to put forward a best urban sustainable development mode for urban planners; He etc. (2005)developed Land Use Scenarios Dynamics Model（LUSD）based on system dynamics model and cellular automata Model, simulating land use change of 13 provinces in northern China over the next 20 years and making a research on the land use change on a large spatial scales.

JJJ has attracted a large number of experts and scholars to research because of its important strategic position. Integrating artificial neural network (ANN) model and cellular automata (CA) model, Kuang Wenhui etc. (2011) have developed urban growth dynamic model, which is suitable for different scenarios at regional scale and he also simulated urban dynamic growth in the Beijing-Tianjin-Tangshan region. He Chunyang' team studied urban expansion process under the double pressure of drought and earthquakes. He also put forward the optimal urban expansion layout and suggestions for urban expansion to adapt to disasters pressure. Xie etc.(2011)studied the earthquake disaster and risk assessment in the Beijing-Tianjin-Tangshan region. Wu Liangyong (2002, 2002) from Tsinghua university, Fan Jie (2008) from Institute of Geographic Sciences and Natural Resources Research, China Academy of Urban Planning & Design(2007) ,etc., have done a lot of researches on JJJ region.

This paper, on the basis of summarizing predecessors' work, learning from the experience of BUDEM(Long et al. 2009), makes use of JJJ spatial data, and develops the JJJ Urban Development Model (BUDEM - JJJ) using restraint CA model and logistic regression analysis method. The model scientifically analyzes the change of JJJ urban spatial development pattern under different development scenarios, forecasts JJJ urban growth under different scenarios, evaluates and analyzes the simulation results. It can provide a decision-making basis for urban plan, construction and management.

This paper is organized as follows. In Section 2，the study area and data are described in detail; In Section 3，BUDEM - JJJ model’s conversion rule is mainly introduced; In Section 4，the method to identify the model parameter is introduced, and the model accuracy is verified by the identified parameters as the basis of scenario analysis; In Section 5, construction land layout of JJJ at the end of the plan 2020 is simulated, and then compare it with the planed land layout; Seven scenarios are set up to analyze JJJ urban construction land layout in 2049; In Section 6, the research is summarized and the future research consideration is put forward.

Study Area and Data

The study area for BUDEM-JJJ model is JJJ area, as shown in Fig. 1. It locates between 113.15 and 119.70 degrees east longitude and between 36.04 and 42.56 degrees north latitude, with an area of $21.71*10^4 km^2$（16410 km^2 for Beijing,11919 km^2 for Tianjin,$18.88*10^4$ for Hebei province）, whose north and west is mainly mountainous, east and south is plain , and faces the gulf of Bohai Sea in the east.

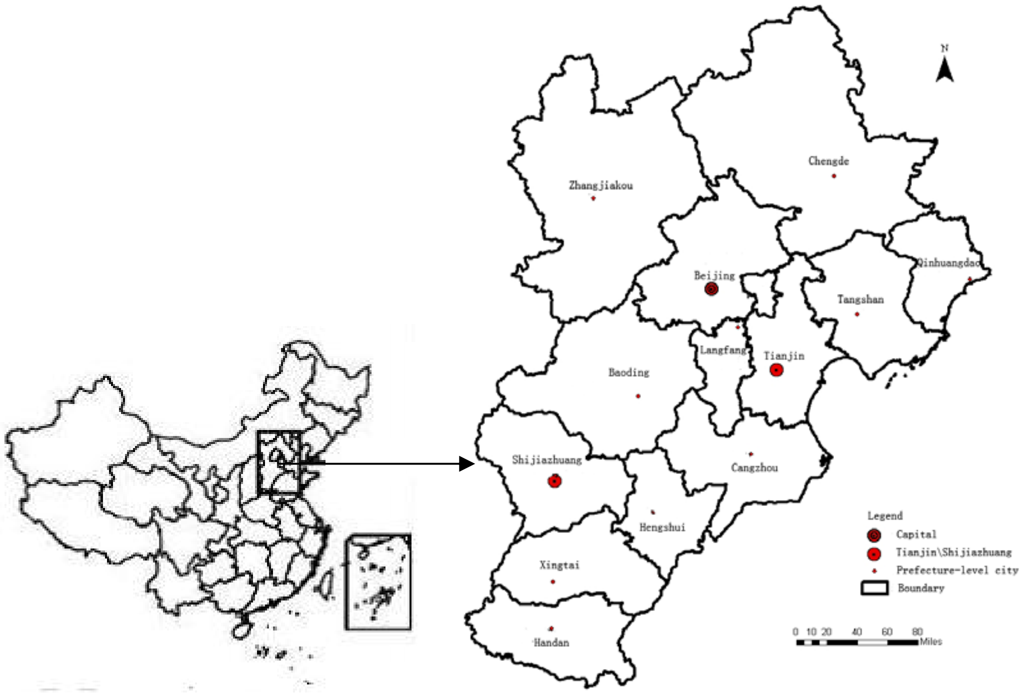


Fig. 1 Location of JJJ Area

The data required for BUDEM-JJJ model is shown in Tab.1, including land use data in the year of 2000, 2005 and 2010; topographic map 1:50000 containing information for administrative centers at all levels; topographic map 1:250000 containing information for railway, highway, state road, provincial road; JJJ master plan data for 2020; the construction forbidden areas data; urban statistical yearbook of 1995-2008, etc.

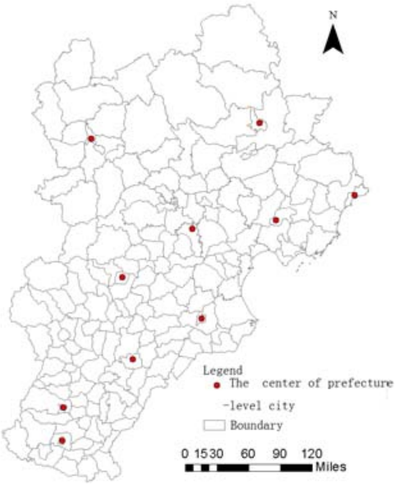
The data of administrative centers at all levels can be extracted from topographic map 1:50000, and all kinds of road and boarder line information can be extracted from topographic map 1:250000.They are as the location variable; The construction forbidden areas data is as the institutional variable; All the data is normalized to 0~1.The nearer to 1,the more probable to be developed ,and the nearer to 0,the less probable to be developed. The value of neighbor variable can be acquired by logistic regression method.

Tab. 1 Dataset of the BUDEM-JJJ model

Type	***Variable***	Min	Max	Mean valve	Standard	Description	Data	Data resource
	f_ctr_bj	0．0000	1.0000	.0029	.0269	Attractiveness of Beijing	Fig.2a	1:50000 Topographic map
	f_ctr _tjsjz	0．0000	1.0000	.0059	.0380	Attractiveness of Beijing and Tianjin	Fig.2b	1:50000 Topographic map
	f_ctr _other	0．0000	1.0000	.0254	.0767	Attractiveness of prefecture-level	Fig.2c	1:50000 Topographic map
LOCATION constraint	*f_ctr _cty*	0．0000	1.0000	.2082	.1931	Attractiveness of the town	Fig.2d	1:50000 Topographic map
	f_rail	0．0000	1.0000	.3797	.3141	Attractiveness of railway	Fig.2e	1:250000 Topographic map
	f_r _hig	0．0000	1.0000	.2662	.3043	Attractiveness of highway	Fig.2f	1:250000 Topographic map
	f_r _nat	0．0000	1.0000	.3690	.2925	Attractiveness of state road	Fig.2g	1:250000 Topographic map
	f_r _pro	0．0000	1.0000	.5519	.2711	Attractiveness of provincial road	Fig.2h	1:250000 Topographic map
INSTITUTIONAL constraint	*constrain*	0	1	.1300	.3350	Construction forbidden areas	Fig.2i	Beijing Municipal Institute of City Planning &Design
NEIGHBOR constraint	neighbor	0.0000	1.0000	--	--	The neighbor cell number /8	--	Model calculation

a. the downtown center of Beijing

b. the downtown center of Tianjin and Shijiazhuang



c. the center of prefecture-level city

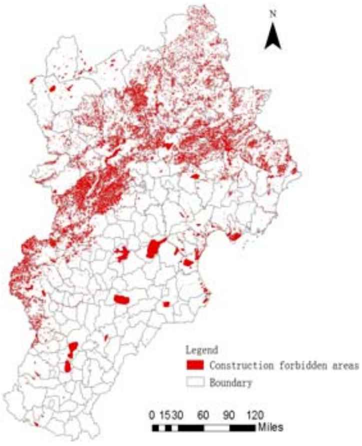
d. the center of towns

e. the railway

f. the highway

g. the national road

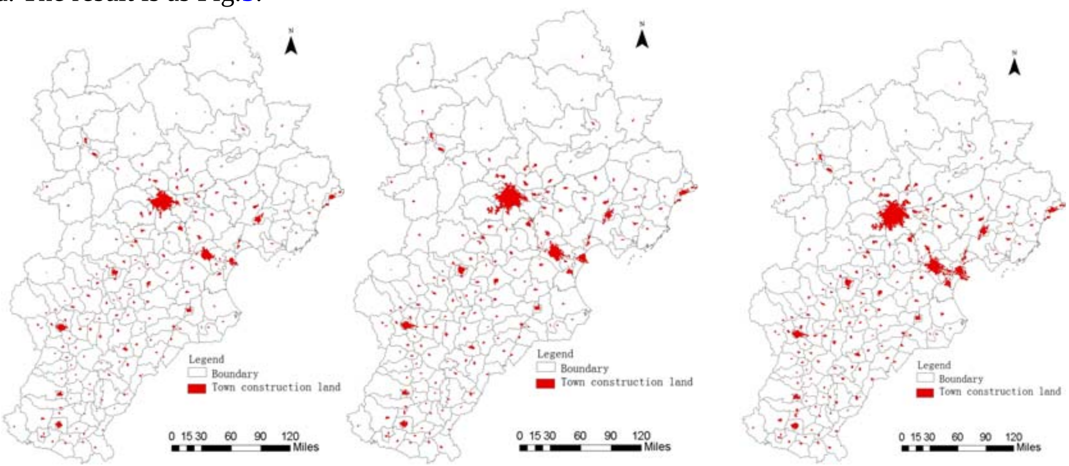
h. the provincial road



i. construction forbidden areas

Fig. 2 Spatial data for the BUDEM-JJJ model

The land use data includes mainly urban construction land, rural construction land, forest land, grassland, farmland, water area and unused land. The simulation at this time is just the change of urban construction land, therefore the research needs only two kinds of data: urban construction land and non-urban construction land. The rural construction land, forest land, grassland, farmland, water area and unused land will be amalgamated into non-urban construction land. The result is as Fig.3.



a.The year of 2000 b. The year of 2005 c.The year of 2010

Fig.3 Land use reclassification based on multi-temporal remote sensing data

The Build of BUDEM-JJJ Model

Because of the complexity and dynamic nature of spatial system, the development of urban has a "bottom-up" self-organization characteristic (Long et al. 2008), which is similar to CA' "bottom-up" self-organization evolution characteristic, therefore it is available to simulate the urban expansion by BUDEM - JJJ model which is based on CA model.

The BUDEM-JJJ Model

A standard CA is composed of cell、cell space、neighborhood state and conversion rules, which can be expressed as a formula: A= (L_d ,S ,N ,f)(Amorosos and Patty 1972), in which L_d stands for the cell space, *S* stands for a set of finite and discrete cell states, *N* stands for all the cell muster within neighborhood, and *f* stands for a conversion rules. BUDEM-JJJ is also composed of these elements, because it is converted from standard CA model.

The cell size for BUDEM-JJJ model is 500 m * 500 m.

The aim to build BUDEM-JJJ model is to simulate the conversion from the non-urban construction land to urban construction land, so two states need to be set up: urban construction land and non-urban construction land. A collection of two states is defined as S:={ urban construction land, non-urban construction land}, in a mathematical set:S = {1, 0}, in which 1 stands for urban construction land, and 0 stands for non-urban construction land.

BUDEM-JJJ model's Neighborhood uses Moore neighborhood(3*3, eight adjacent cells).

The BUDEM-JJJ model acquires Multi-criteria Evaluation (MCE) as conversion rule.

The Status Transition Rule for BUDEM-JJJ

BUDEM-JJJ Model is developed from the idea of Hedonic Model. Hedonic model(Lancaster 1966) considers that commodities consist of various different characteristics or qualities (e.g., the area of the real estate, floor, orientation and whether there is a security service, etc.), and the price is the reflection and performance of all these characteristics. Commodities with different characteristics or qualities, would have different price. For example, Butler(1982) thinks that housing prices can be decided by three key factors: location factors, the structure of the building and neighborhood environmental factors. Therefore, the housing price can reflect the consumer's preferences for these factors, and the development of urban construction land can also reflect the developers' preferences for land attributes. Referring to the theoretical framework of Hedonic model, considering the availability of data at the same time, the following elements are selected as spatial variable of BUDEM-JJJ model:

（1）LOCATION constraint:

The shortest distance to the administrative center at various levels(the center of Beijing, the center of Tianjin and Shijiazhuang, the center of prefecture-level cities, the center of towns) ,the distance to raiway(*f_rail*) ,the distance to highway(*f_r_hig*)、the distance to national road(*f_r_nat*), the distance to provincial road(*f_r_pro)*.

（2）NEIGHBOR constraint:

The neighborhood development intensity (*neighbor*).

（3）INSTITUTIONAL constraint:

Due to the restriction of data resource, only abrupt slop, wet land and blood-proof land should be considered as constrain area.

Urban growth not only be controlled by government on macro level, but also be spontaneous on microcosmic stratums. Hence, the simulation is divided into two steps: First, the government determines at the macro-level the amount of land development in different phases according to socio-economic conditions. Then at the micro-level,constrain CA can be used to simulate the urban growth, and allocate the cell number according to the simulation result.

The simulation process of BUDEM-JJJ is as follows:

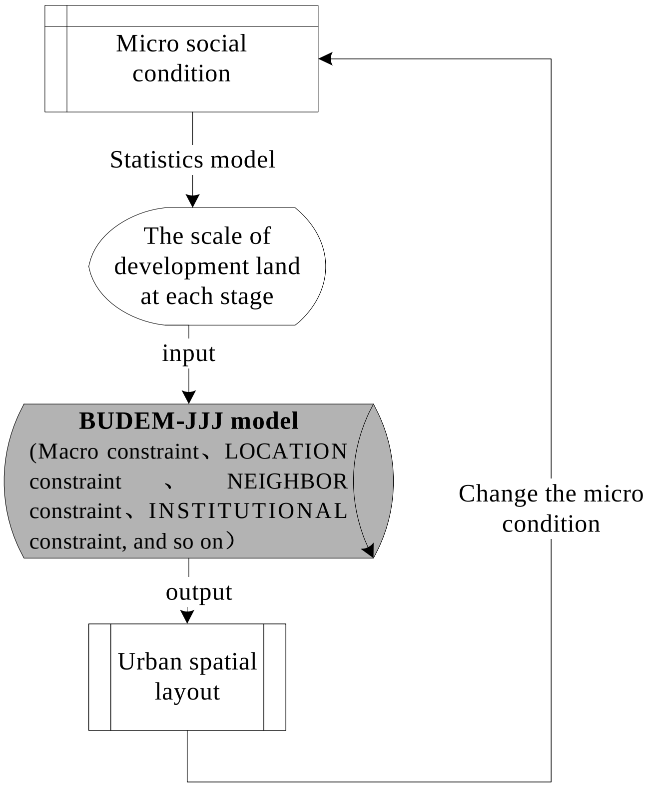


Fig. 4 BUDEM-JJJ model simulation process

In this research, BUDEM-JJJ model only simulates the translation from non-urban construction land to urban construction land, without regarding to the opposite process , urban redevelopment, and urban degeneration process.

Based on the above constraint factors, Multi-criteria Evaluation is considered as the transition rules of CA:

$$V_{i,j}^{t+1} = \{V_{i,j}^{\ t}, LOCATION\ constraint, INSTITUTION\ constraint, NEIGHBOR\ constraint\}$$

$$= f\begin{Bmatrix} V_{i,j}^{\ t}, \\ f\_ctr\_bj_{i,j}, f\_ctr\_tjsjz_{i,j}, f\_ctr\_cty_{i,j}, f\_ctr\_other_{i,j}, \\ f\_rail_{i,j}, f\_r\_high_{i,j}, f\_r\_nat_{i,j}, f\_r\_pro_{i,j}, \\ constrain_{i,j}, \\ neighbor^{t}_{\ i,j} \end{Bmatrix} \quad (1)$$

In the formula, $V_{i,j}^{t}$ *is* the cell status at *i,j* at time *t*, $V_{i,j}^{t+1}$ *is* the cell status at *i,j* at time *t+1*， and *f* is the transition rule of the cell status.

The status transition function based on status transition rule is expressed as follows:

$$\begin{aligned}
&1.\ LandAmount = \sum_t stepNum^t \\
&2.\ s^t_{i,j} = w_0 + w_1 * f_ctr_bj_{i,j} + w_2 * f_ctr_tjsjz_{i,j} + w_3 * f_ctr_cty_{i,j} \\
&+ w_4 * f_ctr_other_{i,j} + w_5 * f_rail_{i,j} + w_6 * f_r_high_{i,j} + w_7 * f_r_nat_{i,j} \\
&+ w_8 * f_r_pro_{i,j} + w_9 * constrain_{i,j} \\
&+ wN * neighbor^t_{i,j} \\
&3.\ p^t_g = \frac{1}{1 + e^{-s^t_{i,j}}} \\
&4.\ p^t = \exp[\delta(\frac{p^t}{p^t_{g\max}} - 1)] \\
&5.\ for\ instepID = 1\ to\ stepNum \\
&if\ \ p^t_{i,j} = p^t_{\max}\ then\ V^{t+1}_{i,j} = 1 \\
&p^t_{i,j} = p^t_{i,j} - p^t_{\max} \\
&p^t_{\max}\ update
\end{aligned} \tag{2}$$

In the formula: *LandAmount* stands for the total increased cells number; $stepNum^t$ stands for the increased cells number in each cycle; $s^t_{i,j}$ stands for the land use suitability; w stands for the weight coefficient of spatial variable; p^t_{gx} stands for the global probability after conversion; p^t_{gmax} stands for the global probability maximum at each cycle; δ stands for the diffusion coefficient (1 ~ 10); p^t stands for the ultimate probability; p^t_{max} stands for the maximum probability for each sub-cycle at different loop, constantly updating the value in the cycle.

As for the total land development parameter *stepNum* at each phase, the traditional demographic method has been used to predict the urban construction land. According to the formula $stepNum=P\times A/10000$, P stands for the urban population(person) and A stands for the per capita urban construction land indicators (m^2 / person). Urban population at each phase obtains by time trend extrapolation method. According to the model $P = a + bY$, Y stands for the time (year), a and b stand for constants obtained by regression analysis.

The weight coefficient w_{1-8} of 8 spatial constrain variables can be obtained by logistic regression analysis of historical data. Logistic regression analysis is a probabilistic nonlinear regression model, which is a multivariate analysis method to study the relationship between classification observations result *(Y)* and certain influence factors *(X)*. Medical science often researches whether the certain result will happen under certain factors, and what is their relationship. For example, it can be used to judge whether the coronary heart disease (CHD) has something to do with the presence of hypertension history, history of hyperlipidemia and smoking history. If the value Y is defined as the result, $Y = 1$ means yes, $Y = 0$ means no, and number between 0 and 1 means the probability of happening.

Its concrete form is shown in the formula (3): It is a semi-logarithm equation, the regression coefficient b reflects the sensitivity of the variables, namely the impact of the variable changing 1 unit on the overall probability, the larger its absolute value, the more sensitive the corresponding variables.

$$\begin{aligned}
p_{logistic} &= \frac{1}{1 + e^{-z_{ij}}} \\
z_{ij} &= a + \sum_k b_k x_k
\end{aligned} \tag{3}$$

In the above formula: a is the constant in the logistic regression model; b_k stands for the model coefficient; x_k stands for spatial variables; $p_{Logistic}$ stands for transition probability based on logistic regression.

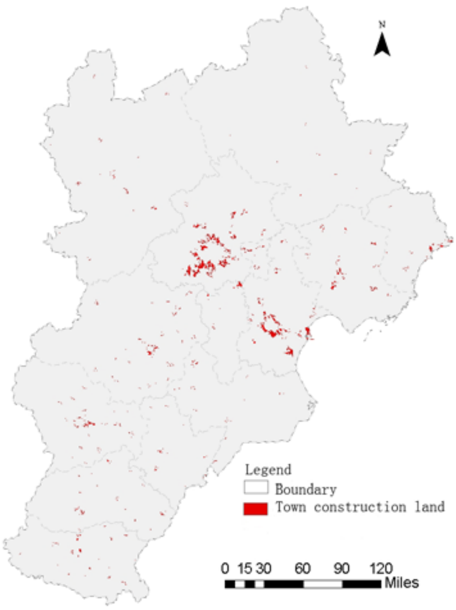
w9 is binary coefficient : $w9 = \{0, 1\}$, if $w9 = 0$, this cell cannot be developed; on the contrary, if $w9 = 1$, this cell can be developed.

When $w9 = 1$, the neighbor weight coefficient wN can be obtained by MonoLoop, and the largest coefficient of goodness - of - fit(GOF) will be chosen as the weight coefficient for wN value(Butler 1982; Long et al. 2010). The MonoLoop method is as follows: Firstly, obtain the spatial variable weight parameters except *neighbor* variable by the method of logistic regression and keep these parameters unchanged; Secondly, add a loop process in the CA model and constantly adjust the weight coefficient for neighbor variable *wN*; Thirdly, compare the different simulation values and observation values for *wN*; Then choose the best match value *wN* and logistic regression value $w_{0\sim8}$ into the state transition rules of MCE; Finally, the function of urban spatial form simulation will be realized. As for the choice range of *wN* value, in order to reduce the running time of MonoLoop process, firstly try constantly various number in a larger scale, then adjust the number in a more detailed scale according to the calculation results. In the process of simulation of different *wN* values, the rest parameters and total scale of the target construction land remain unchanged.

BUDEM-JJJ Model Parameter Identification

The Urban Expansion Analysis for JJJ

The urban expansion in JJJ is very apparent in recent years. From the Fig.5 and Fig.6, we can find that the construction land in each region has an outward expansion trend with different degree from the year 2000 to 2005, and from the year 2005 to 2010.



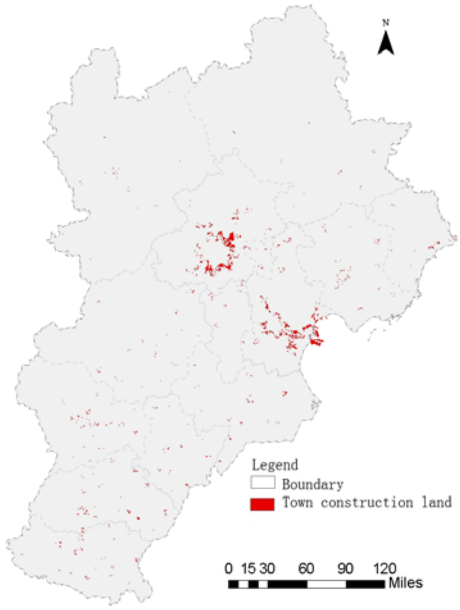


Fig. 5 Construction land expansion from 2000 to 2005 **Fig. 6** Construction land expansion from 2005 to 2010

The statistical results are as follows:

① The growth area in JJJ is 2767.25 square kilometers from the year 2000 to 2010, and annual growth area is 276.725 square kilometers.

② The growth area in JJJ is 1445.04 square kilometers from the year 2000 to 2005, and annual growth area is 289.008 square kilometers.

③ The growth area in JJJ is 1322.21 square kilometers from the year 2005 to 2010, and annual growth area is 264.442 square kilometers.

From the above statistics, we can find the urban expansion speed of the two periods is a relatively stable, but the later period is relatively lower than the former period.

History Parameters Identification

Identifying the history parameter is the key to the model prediction and the basis to forecast the future urban construction land layout. The longitudinal comparison of history parameters between the same stage can find out the main driving force for affecting urban expansion at this stage, and the horizontal comparison between the independent variable in different historical stages can find out the independent variable' influence to the urban expansion(Long et al 2008).

In this model, the parameters are identified through logistic regression method by the statistical analysis software SPSS. Due to the limitation of data source, only the parameters of the year 2000-2005 and 2005-2010 can be identified.

From the statistical analysis, we can find the date is imbalanced, for the sample number of urban construction land is far less than non-urban construction land. The regression precision will be influenced using the data directly. As shown in Tab.2, no processing the imbalanced data, all the construction land was predicted as non-construction land. It doesn't accord with the reality. Therefore the imbalanced data need to be processed before the logistic regression.

Tab. 2 Logistic classification table in the year of 2000-2005 and 2005-2010

period of time		observation （0 ）	observation （1）	total	Production precision（%）
2000-2005	observation（0）	856697	0	856697	100
	observation（1）	4942	0	4942	0
	total	861639	0	861639	
	User precision（%）	99.4	100		total precision99.4%
2005-2010	observation（0）	857661	0	857661	100
	observation（1）	3970	0	3970	0
	total	861631	0	861631	
	User precision（%）	99.5	100		total precision99.5%

At present, the research for imbalanced data's classification method mainly focuses on three aspects: the data level, the algorithm level and criterion level(Yang et al. 2008).This research adopts price sensitive approach at the algorithm level to process data, which balances the number of data by giving the small sample data greater weight, and giving the large sample data less weight. This research sets sample weight with the weight cases tool in SPSS software. Mainly 7 kinds of weight ratio are set. The weight of large sample 0 is constantly set to 1, and the weight of small sample 1 is set to 50, 100, 200, 300, 500, 1000, 10000 respectively. The matching degree and Kappa value are calculated by regression method, and the results are as follows in Tab.3:

Tab. 3 Weight variation table in the year of 2000- 2010

	weight	The number of 0	The number of 1	ratio	GOF	Kappa
2000-2005	1	856697	4942	17335/100	99.40%	0.000
	50	856697	247100	347/100	86.90%	0.613
	100	856697	494200	173/100	85.30%	0.686
	200	856697	988400	87/100	87.00%	0.737
	300	856697	1482600	58/100	88.30%	0.741
	500	856697	2471000	35/100	90.40%	0.733
	1000	856697	4942000	17/100	93.50%	0.714
	10000	856697	49420000	2/100	98.30%	0.577

	weight	The number of 0	The number of 1	ratio	GOF	Kappa
2005-2010	1	857661	3978	21560/100	99.50%	0.000
	50	857661	198900	431/100	87.60%	0.580
	100	857661	397880	216/100	85.60%	0.671
	200	857661	795600	108/100	86.70%	0.734
	300	857661	1193400	72/100	87.10%	0.730
	500	857661	1989000	43/100	89.60%	0.741
	1000	857661	3978000	22/100	93.20%	0.741
	10000	857661	39780000	2/100	98.70%	0.612

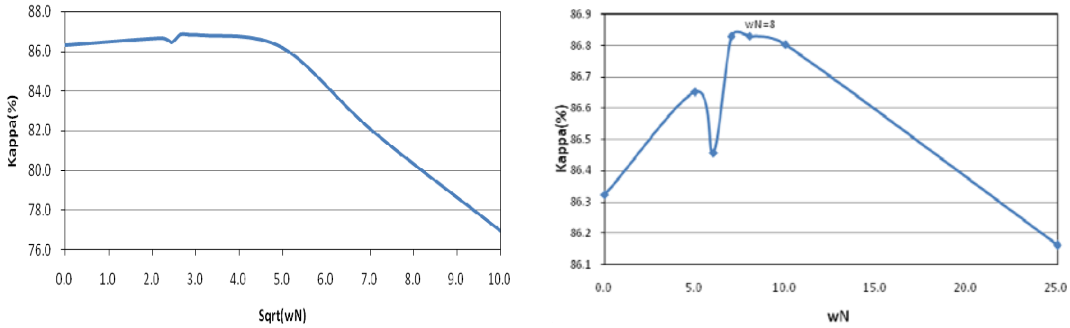
According to Tab.3, when the weight is 200, the number gap between 0 and 1 is the smallest, the data gets balanced, and the GOF and Kappa value is also optimal, so the weight 200 is chosen for regression. And all effective variables of correlation coefficient matrix are close to zero, through which we can judge the effective coefficients are uncorrelated, and the significance of all variables is at the 0.000 level. It can further prove the validity of the regression results. As shown in Tab.4.

Tab. 4 Logistic regression coefficient in different period

Varible	2000-2005	2005-2010
	B（regression coefficient）	B（regression coefficient）
f_ctr_bj	.911	-2.188
f_ctr_tjsjz	-1.989	-2.903
f_ctr_other	-.328	2.016
f_ctr_cty	1.435	1.021
f_rail	2.940	2.276
f_r_hw	3.451	4.051
f_r_nat	1.520	1.524
f_r_pro	3.981	4.025
Constrain	-1.197	-.813
Constant	-6.953	-7.485

Model Validation

By logistic regression analysis, we can acquire the model variable coefficient except neighbor constraint variables (*neighbor*). Neighbor constraint coefficient can be acquired by MonoLoop method. This study uses the urban construction land data from the year 2005-2010 to obtain the neighbor coefficient and to verify the model. By using dichotomy to take an integer value from 0 to 100 and repeating experiments, the result proves when $wN = 8$ point-to-point matching degree is highest, at 99.3% and Kappa value was 0.87,which can prove the model is of high precision and can be used to predict the urban construction land expansion in the later stages for JJJ.



a b

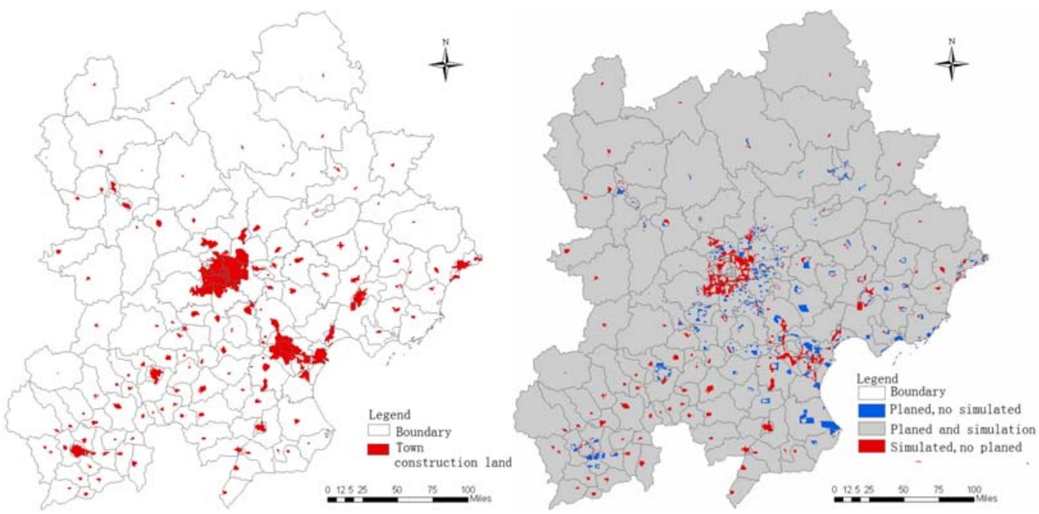
Fig7 The process curve of MonoLoop

Model Application

JJJ2020：the Urban Expansion Study for the Year 2020

The latest round of master plan is at the end of 2020 in JJJ. Simulating the urban layout in 2020 based on the present situation and comparing the simulation result with the actual plan result can help judge whether the master plan can be accomplished. Suppose the total scale of urban construction land at the end of 2020 can achieve the planned scale , and the speed of urban growth from 2010 to 2020 is the same as the speed from 2005 to 2010 (namely, all weight coefficient of spatial variables, including the neighbor variable, remain unchanged as a baseline scenario). By simulating the urban layout by BUDEM - JJJ model in 2020, and comparing the simulated result with plan data, we can make a comparison and evaluation for current policy and master plan. Due to the limitation of data source, we only simulate JJJ metropolitan circle(refer to Beijing,Tianjin and several cities in Hebei province, such as Shijiazhuang, Baoding, Qinhuangdao, Langfang, Cangzhou, Chengde, Zhangjiakou, Tangshan eight cities, excluding Handan, Xingtai, Hengshui) at this stage.

The simulated urban form for JJJ in 2020 is shown in Fig. 8a, whose comparison with the plan is shown in Fig. 8b. The kappa value is 0.54. The calculation result and contrast show there is a large difference between the simulation results and the master plan. If the trend of 2005-2010 continues, JJJ metropolitan circle will not meet the planned urban form.



a b

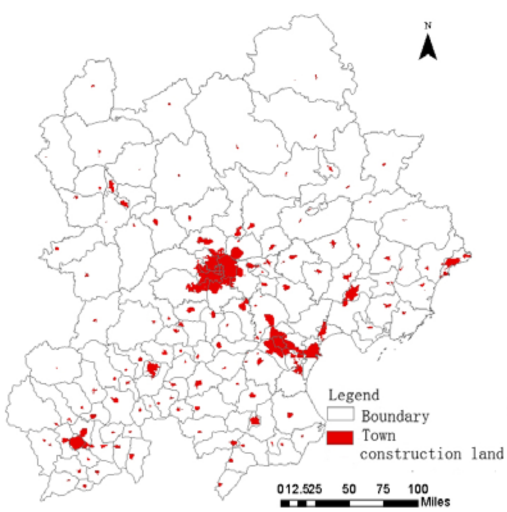
Fig. 8 Simulated urban form of 2020 (a) and its comparative image with planned form (b)

In order to achieve the planned urban spatial layout, the coefficient of the model needs to be adjusted. The dependent variable of logistic regression can acquire by the planned urban construction land scale in 2020 subtracting the urban construction land in 2010, and the independent variables keep unchanged, then the weight coefficient of independent variables can be acquired through regression analysis again. With regression results shown in Tab. 5.The correlation coefficients of effective variables are close to zero and the significant level of all variables is at the 0.000 level, so the regression results are acceptable. Comparing the regression coefficient of 2010 ~ 2020 with that of 2005-2010 horizontally, it can be seen that the driving force of affecting urban growth has significant differences: the appeal of Beijing increases apparently; Tianjin, Shijiazhuang' appeal changes from the original negative correlation to positive correlation, which is opposite to towns' appeal; The rail's appeal changes inconspicuously; The other variables' influence is reduced.

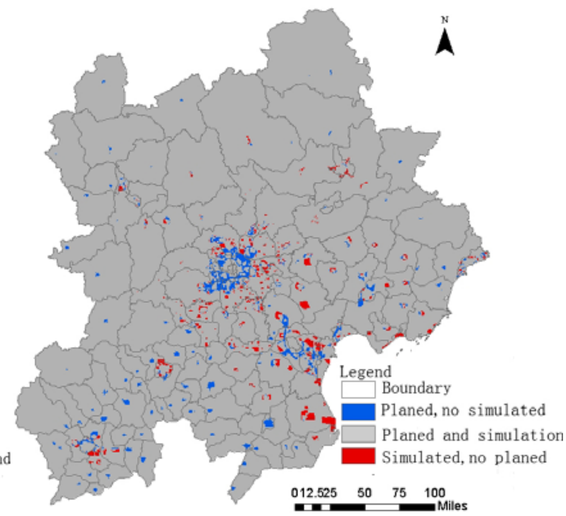
Tab. 5 Logistic regression coefficient from 2010 to 2020 and comparison with the coefficient from 2005 to 2010

Varible	2005～2010	2010～2020			
	B（regression coefficient）	B（regression coefficient）	S.E.	Wald	Df
f_ctr_bj	-2.188	-13.311	.315	1787.257	1
f_ctr_tjsjz	-2.903	2.407	.045	2858.183	1
f_ctr_other	2.016	1.699	.030	3291.351	1
f_ctr_cty	1.021	-4.079	.466	76.636	1
f_rail	2.276	2.449	.009	67087.738	1
f_r_hw	4.051	3.195	.008	157835.516	1
f_r_nat	1.524	.849	.009	9054.795	1
f_r_pro	4.025	1.436	.009	25879.339	1
Constrain	-.813	-.593	.010	3833.048	1
Constant	-7.485	-4.301	.009	214297.382	1

From the regression result, we find the matching rate between simulation result and urban form at the end of 2020 has improved, but there is still large differences (Kappa value was 0.55), as shown in Fig. 9. The result shows that the plan cannot be finished under the current policy.



a



b

Fig. 9 Optimized simulated urban form of 2020 (a) and its comparative image with planned form (b)

JJJ2049：the Scenario Analysis for 2049

Scenario Analysis

In order to prepare for the next round of master plan, it is necessary to simulate the urban spatial form from 2020 to 2049.

Simulating JJJ urban spatial form in the future, the total amount of urban construction land should be predicted firstly. In the first place, the total urban population in JJJ need to be extracted by city statistical yearbook from 1995 to 2008, then the total urban population in 1949 can be calculated by the population forecast measurement formula P=-228812+116y.The formula is acquired by regression analysis method. According to the regression result, R^2 is equal to 0.929 and Sig is 0.000, which demonstrates the formula is available. According to the formula and per capita urban land-use area, the urban construction land area for 2049 can be calculated.

This study sets up seven kinds of scenarios to analyze the urban layout in 2049. Each scenario is based on the urban construction land layout in 2010 (including all variable coefficient, per capita urban land area). By changing the enforcement strength of various policy, different spatial development scenarios will be formed.

1. The trend scenario (namely, the stable development scenario). This scenario will happen if continue the development trend from 2005 to 2010. Under this scenario, there will be not too much of development policy, and the supply of land as well as economy and population are all stable. In this situation, the urban development area in JJJ can reach 16423 square kilometers (65692 cells)in 2049. The simulation result is shown in Fig.10.

2. High-speed growth scenario. This scenario reflects that the rapid economic development leads to a large demand for urban construction land. Under this scenario, the urban development area in JJJ can reach 20000 square kilometers(80000 cells)in 2049. The simulation result is shown in Fig.11.

3. Low-speed growth scenario. Under this scenario, the economic development leads to the large increase of urban construction land, even beyond the resources and environment carrying capacity, so the supply of land will be decreased necessarily. In this situation, the urban development area in JJJ will reach 12500 square kilometers(50000 cells)in 2049. The simulation result is shown in Fig.12.

Changing different variable coefficient of the trend scenario, more scenarios can be obtained, for example:

4. Highway finger growth scenario. This scenario will improve the development along the highway. The simulation result is shown in Fig.13.

5. Town promoting growth scenario. When metropolis develops to a certain extent, it will be restrained by resources and environment, then the regional industrial structure will be adjusted to promote the development of small towns around. The simulation result is shown in Fig.14.

6. Developing forbidden area growth scenario. Due to the improvement of human productivity and the capability to convert nature, the ability to develop the forbidden area is strengthened. The simulation is shown in Fig. 15;

7. Traffic leading growth scenario. The scenario will enhance the development along the railway, the highway, the national road, and the provincial road. The simulation result is shown in Fig.16.

The conversion coefficient of each scenario is as follows:

Tab. 6 Form scenario analysis results

Type	Name	The trend scenario	High-speed growth scenario	Low-speed growth scenario	Highway finger growth scenario	Town promoting growth scenario	Developing forbidden area growth scenario	Traffic leading growth scenario
Macro constraint	*stepnum*	65692	80000	50000	65692	65692	65692	65692
	F_ctr_bj	-2.188	-2.188	-2.188	-2.188	-2.188	-2.188	-2.188
	f_ctr_tjsjz	-2.903	-2.903	-2.903	-2.903	-2.903	-2.903	-2.903
	f_ctr_other	2.016	2.016	2.016	2.016	2.016	2.016	2.016
LOCATION constraint	*f_ctr_cty*	1.021	1.021	1.021	1.021	5.021	1.021	1.021
	f_rail	2.276	2.276	2.276	2.276	2.276	2.276	2.276
	f_r_hw	4.051	4.051	4.051	8.051	4.051	4.051	6.051
	f_r_nat	1.524	1.524	1.524	1.524	1.524	1.524	3.524
	f_r_pro	4.025	4.025	4.025	4.025	4.025	4.025	6.025
INSTITUTIONAL constraint	*constrain*	-0.813	-.813	-.813	-.813	-.813	4.813	-.813
NEIGHBOR constraint	*neighbor*	8．000	8.000	8.000	8．000	8．000	8．000	8．000
CONSTANT	*constant*	-7.485	-7.485	-7.485	-7.485	-7.485	-7.485	-7.485

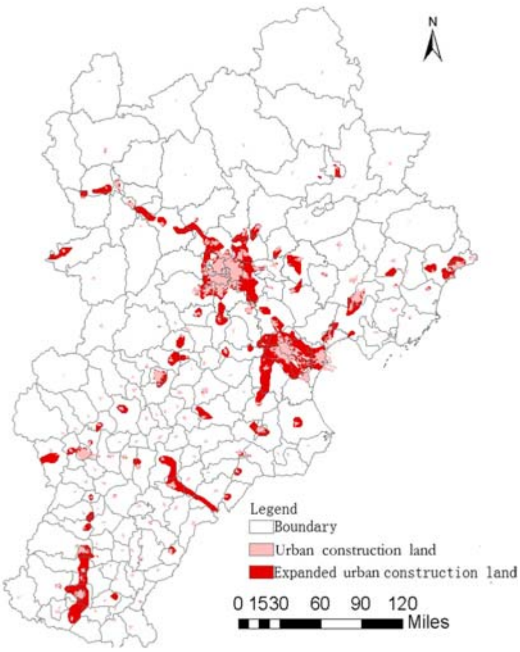


Fig.10 The trend scenario

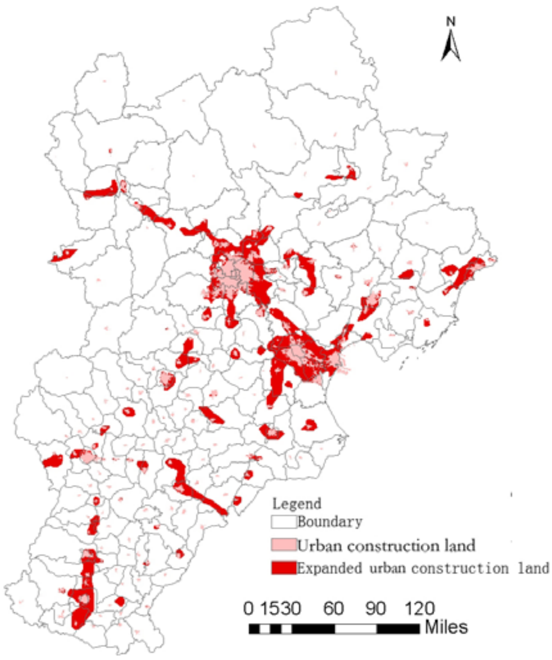


Fig.11 High-speed growth scenario

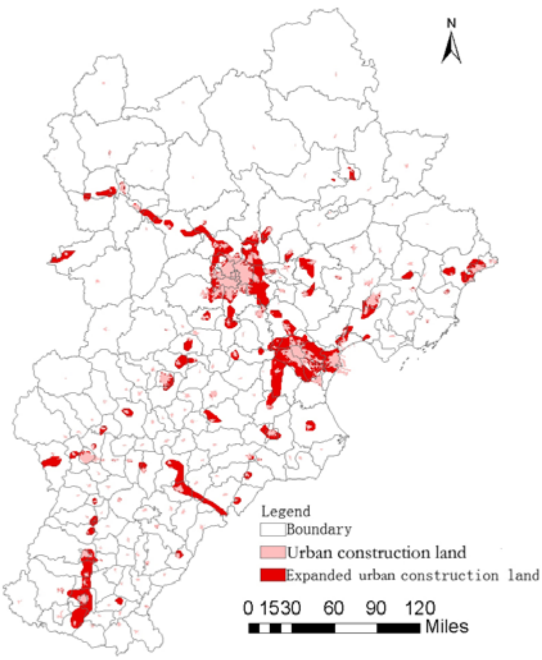


Fig.12 Low-speed growth scenario

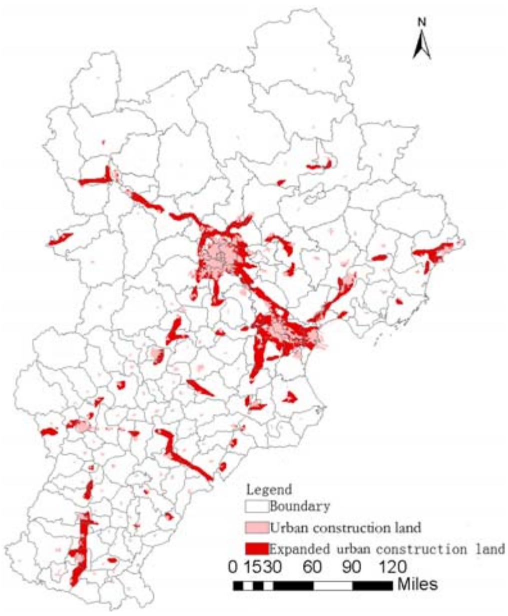


Fig.13 Highway finger growth scenario

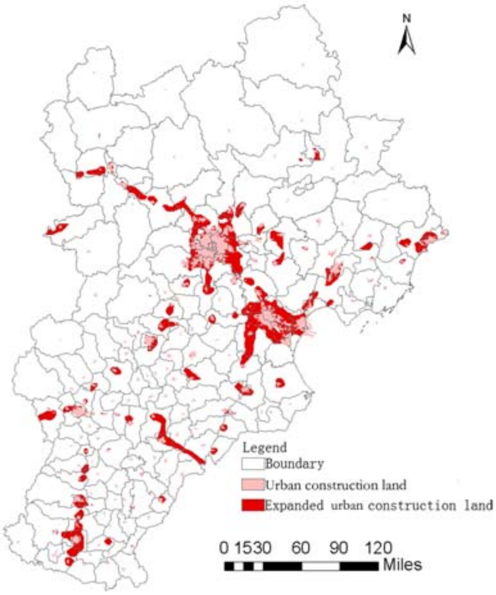


Fig.14 Town promoting growth scenario

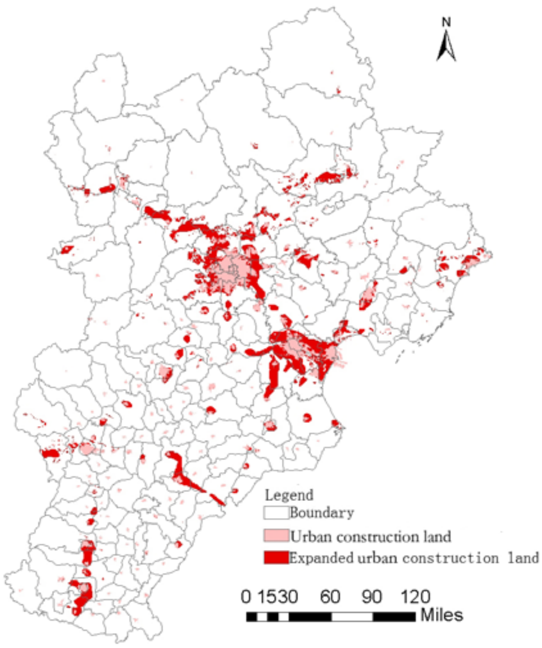


Fig.15 Developing forbidden area growth scenario

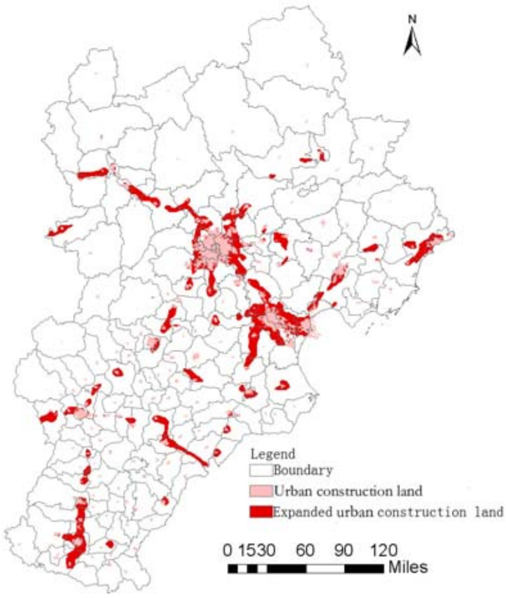


Fig.16 Traffic leading growth scenario

Scenarios Comparison

In order to compare all the scenarios for 2049, the research selects the following two ways to analyze:

(1) The cellular number and proportion of urban construction land for each municipal administrative area in JJJ: It is used to describe urban construction land spatial distribution for each scenario, as shown in Tab.7 and Fig.17.

Tab.7 Form scenarios spatial structure verification

Cities	The trend scenario		High-speed growth scenario		Low-speed growth scenario		Highway finger growth scenario		Town promoting growth scenario		Developing forbidden area growth scenario		Traffic leading growth scenario	
	cell	%	cell	%	cell	%	cell	cell	cell	%	cell	%	cell	%
Beijing	16501	25.2	18810	23.7	13781	27.7	15996	24.0	16481	25.1	18513	28.2	15754	24.3
Tianjin	15329	23.4	17877	22.5	12029	24.2	15541	23.3	15656	23.8	15035	22.9	14461	22.3
Shijiazhuang	3366	5.2	4157	5.2	2701	5.4	3505	5.3	3516	5.4	3415	5.2	3948	6.1
Handan	4504	6.9	5324	6.7	3052	6.1	3684	5.5	4089	6.2	3211	4.9	4303	6.6
Xingtai	2994	4.6	3632	4.6	2501	5.0	3013	4.5	2713	4.1	2600	4.0	2847	4.4
Hengshui	3580	5.5	4123	5.2	2771	5.6	3218	4.8	3424	5.2	2921	4.4	3012	4.7
Baoding	3689	5.6	4528	5.7	2784	5.6	3990	6.0	3720	5.7	3023	4.6	3717	5.7
Langfang	2210	3.4	2861	3.6	1451	2.9	2058	3.1	2260	3.4	2144	3.3	2218	3.4
Qinhuangdao	2205	3.4	2861	3.6	1451	2.9	2655	4.0	2331	3.6	2239	3.4	2218	3.4
Cangzhou	3499	5.4	4820	6.1	2379	4.8	4051	6.1	3558	5.4	2619	4.0	3791	5.9
Tangshan	3086	4.7	4033	5.1	2382	4.8	3569	5.4	3235	4.9	2949	4.5	3202	4.9
Zhangjiakou	3809	5.8	5126	6.5	2086	4.2	4313	6.5	4027	6.1	4485	6.8	4443	6.9

Cities	The trend scenario		High-speed growth scenario		Low-speed growth scenario		Highway finger growth scenario		Town promoting growth scenario		Developing forbidden area growth scenario		Traffic leading growth scenario	
	cell	%	cell	%	cell	%	cell	cell	cell	%	cell	%	cell	%
Chengde	615	0.9	1299	1.6	432	0.9	1002	1.5	659	1.0	2598	4.0	919	1.4

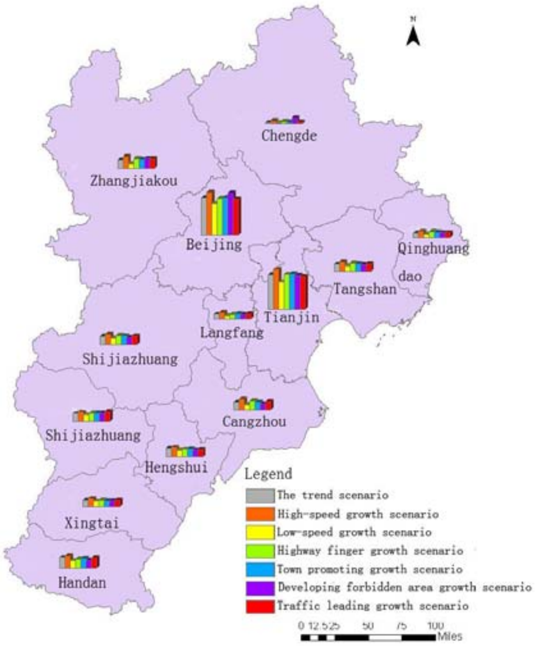


Fig.17 Urban form scenarios in JJJ Area

From Tab.7 and Fig.17, it can be seen that the quality and proportion of urban construction land in different district and different scenario are significantly different. When the total urban construction land increases, the land at each municipal administrative area will increase; The growth rate of urban construction land is directly proportional to the existing urban area; Highway finger growth scenario have a more obvious promoting effect to those area along the highway; Traffic leading growth scenario have a more obvious promoting effect to the area whose transportation is more developed; Developing forbidden area growth scenario have a more obvious promoting effect to the area in the northwest; Town promoting growth scenario have a more obvious promoting effect to the area containing more towns.

(2) Firstly, from the perspective of preventing the spatial risk, the 7 kinds of simulated scenarios are superimposed respectively with current situation layer of farmland, grassland, forest land, water area and unused land, then calculate the potential spatial risk during the process of urban growth by the spatial analysis function of GIS tools; Secondly, from the perspective of spatial form analysis, JJJ urban spatial aggregation forms are analyzed by Patch number, mean area of patch(m^2), Aggregation index, Splitting index, Contag index. Those indexes are chosen by landscape analysis method. The comparison of urban expansion is shown as Tab. 8.

Tab. 8 The comparison of urban expansion

Spatial form	The trend scenario	High-speed growth scenario	Low-speed growth scenario	Highway finger growth scenario	Town promoting growth scenario	Developing forbidden area growth scenario	Traffic leading growth scenario
Farmland occupation (km^2)	7229.54	9733.45	4654.94	7515.81	7251.04	5593.21	7327.31
Forest land occupation (km^2)	530.64	770.09	313.77	530.63	543.06	1796.59	563.18
grassland occupation (km^2)	182.99	290.72	81.84	221.73	192.12	435.64	221.66
water area occupation (km^2)	690.28	841.00	72.88	680.40	696.70	1017.73	643.07
unused land occupation (km^2)	27.02	28.32	17.49	16.62	26.82	25.05	24.03
Patch munber	237.00	217.00	255.00	255.00	238.00	836.00	234.00
mean area of patch /m^2	90890.19	99267.17	84474.41	84474.41	90508.30	25766.72	92055.45
Aggregation index	99.05	99.02	99.08	98.91	99.04	98.42	98.98
Splitting index	1.17	1.22	1.18	1.18	1.17	1.17	1.17
Contag index	77.59	74.52	81.11	76.90	77.47	75.75	77.30

It can be seen from the above comparison:

High-speed growth scenario: In this scenario, the occupation for farmland is significantly more than the other scenarios. The average patch area and Splitting index are the largest. The Contag index is the lowest. It shows that High-speed growth scenario will occupy farmland too much, which is unfavorable for the protection of farmland, and the excessive dispersive urban construction land goes against the gathered economic theory, which is to the disadvantage of the sustainable development of the society.

Low-speed growth scenario: The occupation for non-construction land is significantly less than the other scenarios. Aggregation index and Contag index are the highest in all scenarios. Therefore low-speed growth scenario is beneficial to the sustainable development of the society;

Developing forbidden area growth scenario: The occupation for forest land and water area is more than other scenarios; The occupation for farmland is less than other scenarios; Patch number is significantly more than other scenarios. Although developing forbidden area growth scenario is beneficial to the protection of farmland, it occupys more of other agricultural land and water area. From the perspective of environmental diversity, it is to the disadvantage of the sustainable development of the society;

In the trend scenario, town promoting growth scenario, highway finger growth scenario, traffic leading growth scenario four scenarios: town promoting growth scenario, highway finger growth scenario, traffic leading growth scenario occupy more farmland, forest land and grassland than the trend scenario; Town promoting growth scenario and highway finger growth scenario are lower than the trend scenario in average patch area, aggregation index and Contag index; Traffic leading growth scenario have the least number of patches, the largest average patch area and most least Contag index. All these results verify respectively the influence of different scenarios to urban layout.

Conclusion and Discussion

This research establishes BUDEM - JJJ model by adjusting BUDEM model from the parameter identification, model structure adjustment and scenario design, etc. BUDEM - JJJ model can be used to support the development of JJJ regional planning. The results are as followings:

(1)BUDEM-JJJ model, based on the constraint CA, integrates spatial constraints, institutional constraints, neighborhood constraints in the transition rules. It has more advantages than pure CA in simulating urban expansion change. BUDEM-JJJ model integrates logistic regression and MonoLoop to identify the transition rule to realize the desired urban form, which is more scientific and authentic than manual assignment.

(2)The previous researches mainly focus on regional scale or urban scale. But this research considers town as the simulation scale, which will make the simulation more delicate.

(3)BUDEM-JJJ model, based on constraint CA, is suitable for simulating the urban spatial expansion in JJJ . According to the simulation results of the year of 2005-2005, the Kappa coefficient suggests a good simulation effect, and the GOF of simulation results and the actual situation is very high, which lays a theoretical basis for BUDEM-JJJ model applying in the same scale for other area.

(4)As for the simulation inaccurate problem resulted from imbalance land use data in the same area, this reaserch puts forward a solution to balance the data by increasing the weight of small sample data, and obtains a good simulation effect.

(5) From the simulated urban layout at the end of 2020, we can find if the development trend goes on as the year from 2005 to 2010, the expected urban layout in 2020 is unable to achieve. The research provides a reference basis for adjusting the current urban development.

(6)According to the actual situation of JJJ and the requirements for our research, 7 kinds of scenarios, from different urban construction mode (The trend scenario, High-speed growth scenario, Low-speed growth scenario) to different forcing drive (Highway finger growth scenario, Town promoting growth scenario, Developing forbidden area growth scenario, Traffic leading growth scenario), are set up to predict urban spatial layout in 2049. It provides a reference and scientific basis for the next round of urban master plan.

Because urban system is a complex system, and urban expansion may be influenced by various complex factors. In this study, some of the relevant factors haven’t been taken into account: For example, in the institutional constraints aspect, the basic protection farmland constraints isn’t considered; In the spatial constraints aspect, this study is confined to Euclidean distance without considering the surface resistance, rivers and ports attraction, and also doesn’t simulate respectively the different region according to their own special cases. These questions will be paid attention to in the follow-up study. If the model is used for decision-making support, it is necessary to further improve the constraints condition and constraints variables, and verify in multiple regions so as to obtain a better simulation effect.

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