Beijing City Lab

Liu L, Long Y, 2013, Planning policy scenario analysis based on BUDEM: A case study of Peixian County during industrial transition. Beijing City Lab. Working paper #19

Planning Policy Scenario Analysis based on BUDEM: A Case Study of Peixian County during Industrial Transition

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ABSTRACT

CA (cellular automata) models have achieved much progress in urban simulation since the 1980s. However, most relevant researches are from the field of geography and thence are not ready for application in urban planning, especially as a support tool for planning policymaking. Therefore this research explores this application of CA by proposing Peixian Urban Spatial Development Model as a planning support tool for a mining city Peixian in East China. The model is based on Beijing Urban Spatial Development Model (BUDEM) developed by Long (2008) and is focused on the specific influencing factors of Peixian's urban growth. The simulation result indicates that the urban spatial development in BAU scenario is quite different the master plan. Further simulation in three policy scenarios, which are industrial development scenario, urban development scenario and environmental protection scenario, shows that implementation of the master plan could be improved by setting development promotion zones, strengthening certain policies, government-led development, setting no-development zones, etc. Then the value of urban models to practical urban planning work is discussed.

KEY WORDS Cellular automata, Urban simulation, Planning support, Peixian County, Industrial transition

1 Introduction

Cellular automata (CA), the bottom-up urban modelling method, has made remarkable progress both in theoretical and practical fields since the 1980s. However, existing researches are conducted mostly in geography, which differentiates much from urban planning in the focus of urban modelling research. Therefore, the accomplishments in urban modelling can’t perfectly meet the needs of providing planning support yet. There have been several attempts in the combination of CA and urban planning. White and Engelen (1997) developed a planning support system by integrating constrained CA and GIS, which takes socio-economic constraints into consideration. Wu (1998) developed an MCE-CA model applied to Guangzhou based on multi-criteria evaluation, which is capable of simulating various development regimes by taking multi-dimensional and multi-level influencing factors. Clarke and Gaydos (1998) set an exclusive layer in their SLEUTH model to represent urban growth control in planning, which was applied to Washington Baltimore. Both What if? (Klosterman，1999) and UrbanSim (Waddell，2002) included zoning factors. Li and Yeh (2002) proposed a PCA-CA model based on principal component analysis and simulated the land use change of Dongguan under five distinct planning goals. In another Urban Density CA model, the urban development of Dongguan is examined under different density control schemes. Barredo et al. (2003) compared the urban growth outcomes of Dublin in diverse planning scenarios with CA model. Zhao and Murayama (2007) considered zoning status in their Tokyo Metropolitan Urban Growth Model. He et al. (2008) and Long et al. (2010) both incorporated land use policies and planning goals in their Beijing Urban Expansion Dynamic Model (UED) and Beijing Urban Spatial Development Model (BUDEM). However, the above researches are a bit sketchy in the setting and interpretation of planning scenarios, which do not usually provide direct answers to the questions of “when, where and what planning policies are needed”. Moreover, there are few discussions about specific types of cities at a specific developmental stage. This research will hence explore the potential of CA models in providing detailed and practical planning policy suggestions.

With promotion of the “building a resource-conserving, environment-friendly society” policy, many Chinese cities are faced with industrial transition. However, industrial transition strategies, which are devised at a macro level, are frequently confronted with various obstacles in their “landing”. For example, land parcels reserved for public purposes, such as green spaces and parks, might end up with commercial developments; areas with low development suitability might be hard to be developed; new cities might undergo a really slow start-up. The above are common problems in the implementation of all types of planning. This paper will therefore explore how CA model can provide support for planning policy making during industrial transition through its application on Peixian County, a transforming mining city. First, the characteristics of Peixian's urban development will be analyzed and imported into the model. Second, possible problems in the implementation of Peixian industrial transition plan will be detected through model simulation. Finally, the influences of various planning policies on Peixian's urban development will be simulated and compared, from which policy suggestions can be drawn.

Despite of a lot of space for improvement for urban CA models in respect of cell status, transition rules, etc., the simulation capacity of existing mature models can well meet the requirements of this research. Therefore, this research will take advantage of existing urban CA models and focus on the selection of model constraints, which aim at corresponding well with characteristics of the studied area. Through a comprehensive search and comparison of existing models, Beijing Urban Spatial Development Model (BUDEM, Long et al., 2008) is selected as the basis of Peixian Urban Spatial Transformation Model, which is to be developed in this study. The advantages of BUDEM lie in that its model constraints covers all major influencing factors of urban spatial development, including neighborhood constraints, socio-economic constraints, location constraints and planning constraints, and that it proposes a set of transition rules for the spatio-temporal complexity of model constraints. Hence, BUDEM performs well in simulating the urban spatial development of Chinese cities, with its constraints reflecting the influence of various developmental policies. Based on the model framework and algorithm of BUDEM, this study further explores the setting of model constraints, which represent the characteristics of the urban spatial transformation of Peixian during industrial transition and relevant development policies, such as joint development of main city, sub-city and new city, establishment of economic zones, development restriction on coal-mining areas, etc.

Moreover, the application of urban CA models has been focused on metropolises and regions, such as San Francisco Bay Area, Washington Baltimore, Guangzhou, Dongguan, Beijing, etc., while application on medium and small cities is scarce. To tackle the gap, this research will also discuss this application of CA models through the Peixian case study.

The second chapter explains the basic modelling ideas and specific transition rules of Peixian Urban Spatial Transformation Model. Then the third chapter is about the setting of model constraints and the calibration of model parameters, as well as the simulation of three policy scenarios. Finally, the fourth chapter concludes and discusses the value of urban models to urban planning practice.

2 Methodology

2.1 Modelling Ideas

1) Basic idea: Analysis of urban spatial dynamics----Model building----Scenario simulation

The first step of model building is to collect first-hand documents of Peixian's urban development and urban planning through field survey, interviews with local planning bureau and major state-owned-enterprises, etc., as well as TM and ETM remote sensing images of Landsat, from which Pexiain's urban spatial transformation and corresponding influencing factors can be analyzed. Based on the analysis, model constraints are set and model parameters are calibrated with historical data, which is the second step. Finally, future spatial transformation scenarios of Peixian central city are simulated and compared, from which planning policies in favor of Peixian's industrial transition and urban development can be drawn.

2) Location constraints: an integration of bottom-up and top-down processes

Urban growth of Chinese cities is a dual-process of bottom-up development from the private sector and top-down planning from the government. Therefore, the construction of Peixian Urban Spatial Transformation Model takes both sides of the process into consideration. Bottom-up factors include the location of land parcels and interaction between neighboring parcels, while top-down factors mainly comprise of land use master plans, urban growth control, etc. However, bottom-up and top-down factors are not exclusive of each other, but instead are mutual inclusive. For example, land parcels close to city centers have a stronger tendency to be developed, which could be partly explained by the attraction of fine infrastructure provided by the government; while the location and the corresponding land value are also considered when land use master plan are devised. Hence, the model will take a comprehensive consideration of both processes in selecting model constraints. Moreover, new top-down factors will be introduced or original factors will be adjusted in scenario analysis to simulate policy changes.

2.2 Conceptual Model

Considering the similarity between the modelling idea and model function of BUDEM and Peixian Urban Spatial Transformation Model, this study will refer to the model framework and algorithm of the former. However, model constraints and the scale of simulation require further adjustment to cope with the study area. The model framework of BUDEM comes as follows. There are four types of model constraints in BUDEM, which are location constraints (distance to the nearest road, distance to the nearest water body, distance to the nearest development zone, etc.), neighborhood constraints (development intensity within neighborhood), planning constraints (planned land use, development restriction), socio-economic constraints (urban growth rate) (Long, 2008). And Multi-Criteria Evaluation is employed to derive model parameters from historical data (long et al., 2008, 2010). There are two major differences between BUDEM and Peixian Urban Spatial Transformation Model: first, the cell size is smaller to adapt to the scale of the medium-to-small city; second, the model constraints are adjusted to represent characteristics of Peixian's urban spatial transformation during industrial transition.

The basic elements of Peixian Urban Spatial Transformation Model are as follows

(1) Lattices: Peixian central city, 117.1 km^2;

(2) Cells: In order to achieve the highest accuracy within capacity of PC, a cell size of 60m×60m is chosen as a balance between accuracy and running speed (the running speed declines sharply with a cell size of 50m×50m);

(3) Cell State: Only the transformation from non-construction land (State=0) to construction land (State=1) is considered, while the reverse process and urban redevelopment are not considered;

(4) Transition Rule: The transition rule is a combination of neighborhood influence, socio-economic constraint, and development suitability, which is decided by development location constraints and planning constraints. The expression goes as

follows:

$P_c^t = P_g * con\ (s_{ij}^t = suitable) * \Omega_{ij}^t$;

P_g is development suitability derived from Multi-Criteria Evaluation of historical data. Ω_{ij}^t is neighborhood influence. *Con* is socio-economic constraint. The joint development probability of each cell is an integration of the above factors;

(5) Neighborhood: Moore neighborhood.

3 Model Application

3.1 Research Area

The modelling area is the central city of Peixian County, with an area of 177.1km^2, located between E116° 41'～117° 09', N34° 28'～34° 59'. Peixian locates at the northern of Jiangsu Province and northwestern of Xuzhou City.

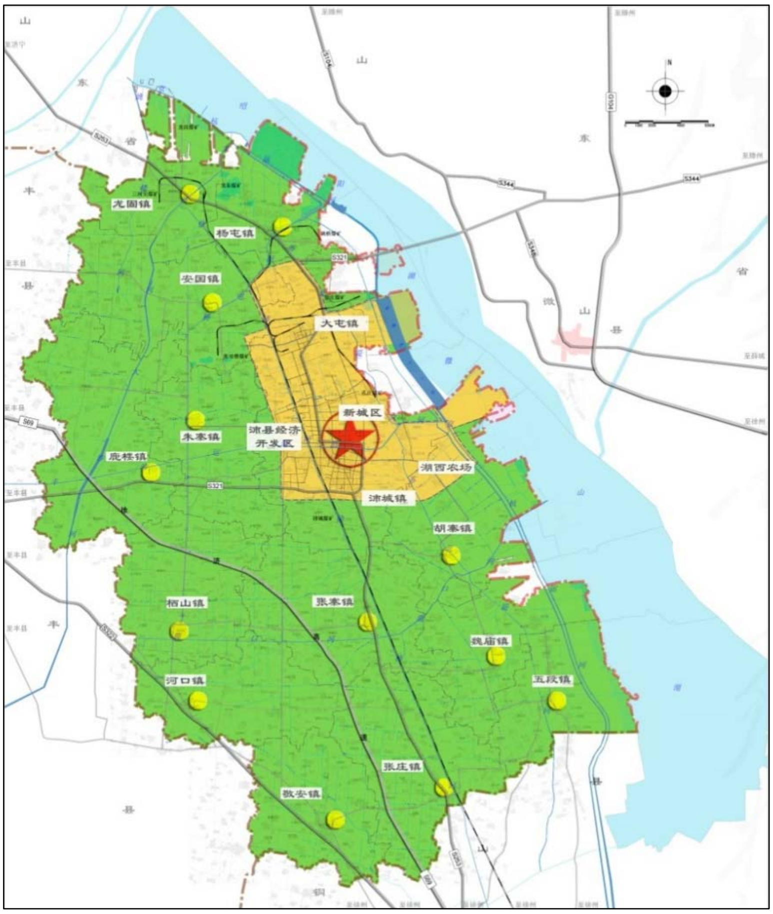
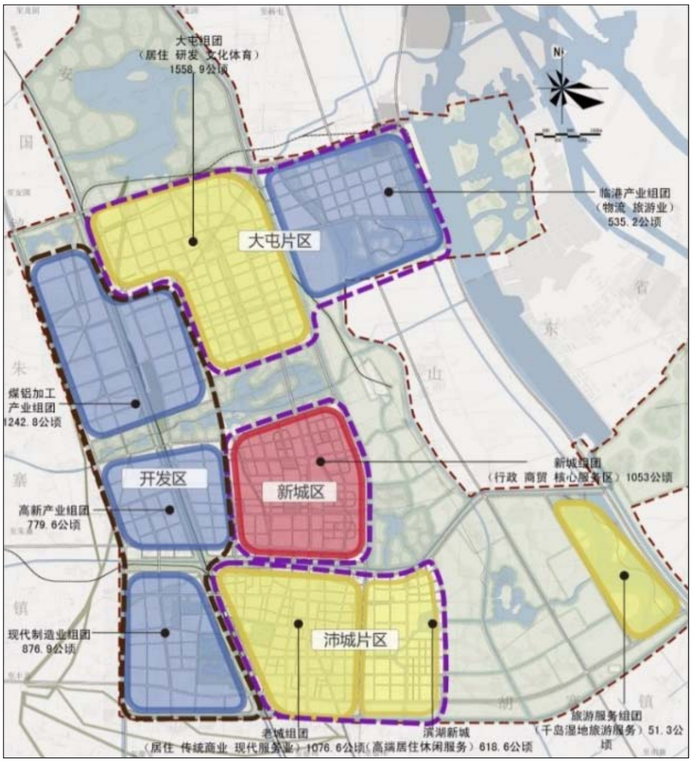


Figure 1 The modelling area (yellow)

Topping the list of coal production in Jiangsu Province, Peixian is a typical coal mining city. According to the statistics of China Mining Association (2004), 55 of the 178 Chinese mining cities (county level and above) have entered their failure stage because their urban economy has long been over-dependent on the mining industry and fails to develop a sustainable urban economic structure. The coal mining production statistics of Peixian indicates that it is currently at its "mature stage" and



might also enter the failure stage without proper industrial transition. To tackle with this threat, the local government has proposed a series of transition strategies in Peixian's 12th Five Year Plan and 2011 Master Plan. These strategies can be categorized into three aspects: industrial development, urban development, and environment protection. In respect to industrial development, mining-based new type of industrialization will be the key strategy for Peixian's industrial development in the coming period, which will be carried out through a series of industrial parks. In respect to urban development, the vision for Peixian central city is to develop into a medium-sized city of 50km^2 with 480,000 population, which expands northwards, westwards and eastwards. As to environment protection, the plans propose a central city ecological network with Peigong Wetland Park as the core component, together with construction restriction policy in mining areas and construction prohibition policy in mined-out areas.

Figure 2 Spatial Planning of Peixian Industrial Transition (2011)

3.2 Model Constraints

The urban spatial development of Peixian since the foundation of People's Republic of China can be generalized into four phases through analyzing its four master plans, county annals, statistical yearbooks, Landsat images, etc. The first phase, 1949 to 1978, witnessed a gradual urban expansion southeastwards, with the urban economy dominated by light industry. The second phase, 1979 to 1992, was featured by the forming of the sub-city and renovation of the old city, with the mining industry beginning to emerge. The third last from 1993 to 2003, during which the old and the sub city expanded towards each other and the mining industry dominated. The fourth phase is from 2004 on, as Peixian enters this new developmental stage of industrial transition, with a "three districts" urban structure composed of old city, sub-city and new city beginning to take form.

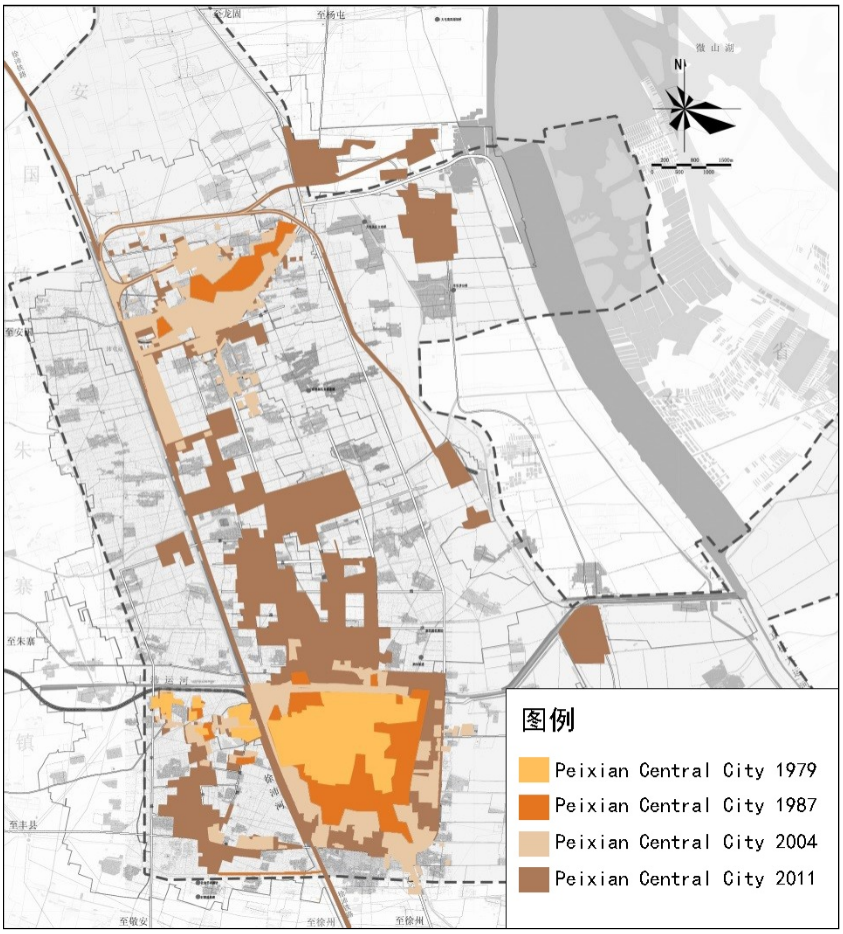


Figure 3 Urban expansion of Peixian central city from 1949 to 2010

It can also be summarized that its urban spatial development is mainly influenced by four factors, which are mineral resources, urban economy, geographical features and planning policies. Mineral resources refer to the avoidance of mined-out areas. Urban economy is reflected as the total area of urban growth. Geographical features are mainly about the influences of canals flowing through, the Weishan Lake, railways, and city main roads. Planning policies include the land use plan, attraction of the old city, the sub-city, the new city, the west Economic Development Zone, the sub-city EDZ, the new city EDZ and the lakeshore EDZ. Model constraints can be derived from these 14 influencing factors, together with Neighbor Constraint, which reflects the interaction of neighboring plots.

Table 1 Model constraints

Type	Name	Number	Description	Relevant Policy
Macroeconomic constraint	*num_con*	≥0	Total area of urban growth	Planning policy
Location constraint	*dist _river*	≥0	Distance to canals	Waterfront development policy
Location constraint	*dist _lake*	≥0	Distance to Weishan Lake	Lakeshore development policy
Location constraint	*dist _rail*	≥0	Distance to railways	Railway corridor development policy
Location constraint	*dist_road*	≥0	Distance to main roads	Roadside development policy
Location constraint	*dist _coal*	≥0	Distance to mined-out area	Mined-out land protection policy
Planning constraint	*p_type*	0,1	Land use type	Planning policy
Planning	*dist_oldcity*	≥0	Distance to the old city	Old city

constraint				development policy
Planning constraint	*dist_subcity*	≥0	Distance to the sub-city	Sub-city development policy
Planning constraint	*dist_newcity*	≥0	Distance to the new city	New city development policy
Planning constraint	*dist_edzrw*	≥0	Distance to the west EDZ	EDZ policy
Planning constraint	*dist_edzsub*	≥0	Distance to the sub-city EDZ	EDZ policy
Planning constraint	*dist_edznew*	≥0	Distance to the new city EDZ	EDZ policy
Planning constraint	*dist _edzlake*	≥0	Distance to the lakeshore EDZ	EDZ policy
Neighbor constraint	*neighbor*	0~8	Number of urban construction land cells in the neighborhood	Smart growth policy

The average annual expanding rate of Peixian central city between 2004 and 2011 was 2.76 square kilometers, which was much faster than that between 1979 and 2004 (0.6 square kilometers). The difference indicates that the urbanization of Peixian has also entered a new stage as China's urbanization began to accelerate since 2004. Since the rate and mode of Peixian's urban growth after 2011 would be more similar to the latter period, the model parameter calibration is based on historical data of 2004 to 2011. The data sources are listed as following:

(1) Land use data are from the 2004 and 2011 master plan, with the original 30 land uses reclassified into construction land and non-construction land;

(2) Mined-out area data are from Peixian Mining Resource Plan (2008-2015) and Xuzhou Mining Resource Management System;

(3) Location constraint data (except for mined-out area data) and planning constraint data (except for planned land use data) are derived from the 2004 land use map. The distances from each model cell to city centers (centers of the old city, the sub-city and the new city), EDZs (the west EDZ, the sub-city EDZ, the new city EDZ

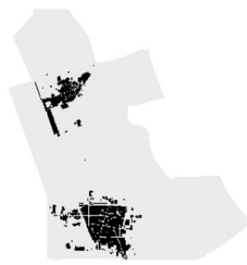
and the lakeshore EDZ), roads (railways and city main roads), and water bodies (Weishan Lake, Xupei River and Fengpei River) are calculated and normalized with Euclidean Distance tool of GIS Spatial Analyst module;

(4) Planned land use data are from Peixian 2004 master plan and 2011 master plan, which are also reclassified into construction land and non-construction land;

(5) Macroeconomic constraint is introduced to the model as an exogenous constraint.

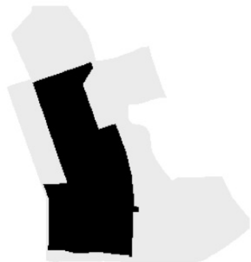
The historical data that are used in model calibration are shown as following.

Table 2 Model location constraints

Name	Description	Location constraint
con04	Construction land in 2004	
con11	Construction land in 2011	
dist_oldcity	Distance to the old city	

dist_subcity	Distance to the sub-city	
dist_newcity	Distance to the new city	
dist_edzrw	Distance to the west EDZ	
dist_edzsub	Distance to the sub-city EDZ	
dist_edznew	Distance to the new city EDZ	

dist_edzlake	Distance to the lakeshore EDZ	
dist_river	Distance to canals	
dist_lake	Distance to Weishan Lake	
dist_rail	Distance to railways	
dist_04road	Distance to main roads in 2004	

dist_coal	Distance to mined-out area	
p_type	Planned land use type	

All 13 location constraints are significant in logistic regression (the neighbor constraint is not included in logistic regression but calibrated through Monoloop). Then the 13 parameters are imported to the model and the urban growth from 2004 to 2011 is simulated based on the actual land use in 2004. The neighbor constraint is adjusted between 1 and 100 through Monoloop and the simulation results are compared with the actual land use in 2011. When the value takes 2, the Kappa index reaches the peak, which is 72.8%, indicating that the simulation result is highly consistent with the reality.

Table 3 Regression result of model parameters

Constraint	**Parameter**	**Significance**
p_type	1.367	.000***
dist_rail	-1.019	.000***
dist_river	5.853	.000***
dist_edzlake	35.564	.000***
dist_edznew	7.064	.000***
dist_edzrw	4.990	.000***
dist_edzsub	5.825	.000***
dist_coal	-2.514	.000***
dist_lake	2.190	.000***

dist_newcity	3.491	.000***
dist_04road	1.031	.000***
dist_oldcity	5.451	.000***
dist_subcity	4.199	.000***
Constant	-9.987	.000***

3.3 BAU Scenario

First, the urban growth of Peixian central city in BAU (business as usual) scenario is simulated. The iteration with 22286 cells is taken as the simulation result, which equals the area of urban construction land (80.3km^2) in 2030 according to the 2011 master plan. The Kappa index between the simulation result and master plan is 63.8% (the initial value is 17.8%), indicating that there exists a significant gap between BAU scenario and the development target.

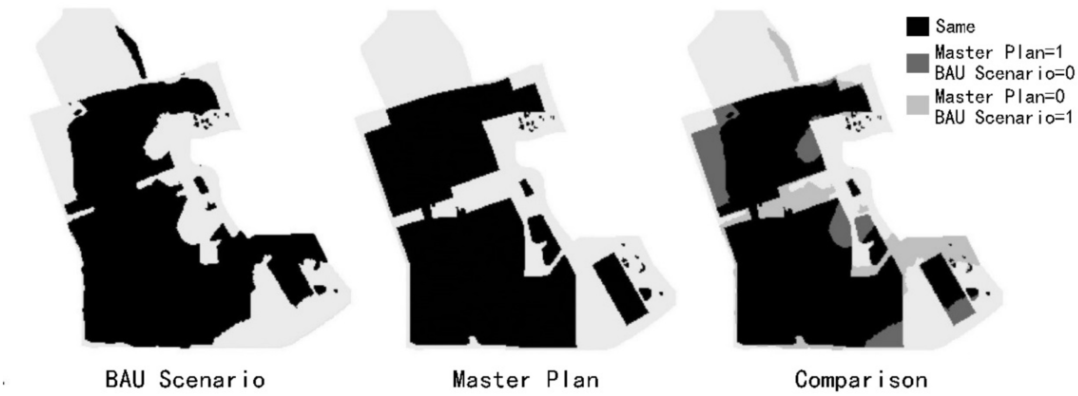


Figure 4 Comparison between BAU scenario and the master plan (2010-2030)

3.4 Planning Policy Scenarios

There are six major differences between BAU scenario simulation result and the master plan by 2030, which are shown as following. In order to adjust the differences, three policy scenarios are set according to the three aspects of Peixian's industrial transition strategies, which are industrial development strategies, urban development strategies and environment protection strategies. The tendency, path and result of Peixian's urban growth from 2011 to 2030 under each scenario will be simulated and analyzed, from which policy recommendations can be drawn to promote the implementation of Peixian master plan during its industrial transition.

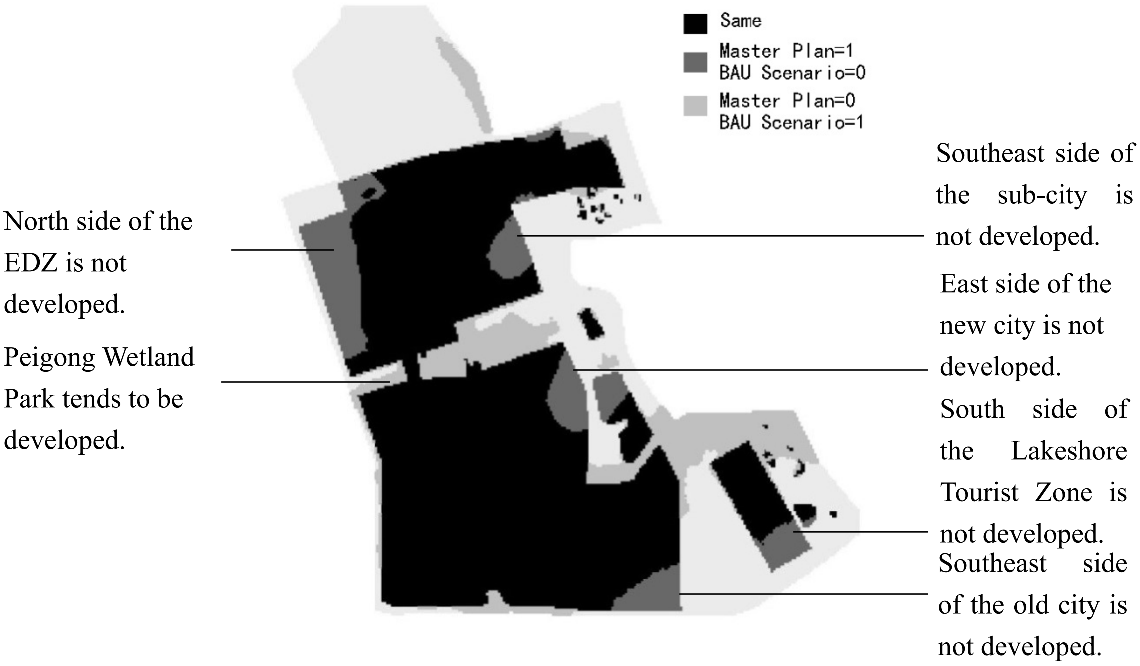


Figure 5 Comparison between BAU scenario and the master plan (2010-2030)

Table 4 Settings and input methods of policy scenarios

Difference	**Policy**	**Input**	**Type of Policy Scenario**
North side of the new city EDZ is not developed	EDZ development promotion policy	Introduce a new constraint *dist _edznorth*	Industrial development
Southeast side of the sub-city is not developed	Sub-city development promotion policy	Raise the parameter of *dist_subcity*	Urban development
East side of the new city is not developed	New city development promotion policy	Raise the parameter of *dist_newcity*	Urban development
Southeast side of the old city is not developed	Old city development promotion policy	Raise the parameter of *dist_oldcity*	Urban development
South side of the Lakeshore Tourist Zone is not developed	Lakeshore Tourist Zone development promotion policy	Add construction land cell number in the relevant area at the beginning of simulation	Urban development
Peigong Wetland Park tends to be developed	Ecological land protection policy	Set development forbidden area	Environment protection

1) Industrial development policy scenario

According to the BAU scenario simulation result, the north side of the new city EDZ is hard to be influenced and driven by other EDZs. Therefore, a new location constraint *dist_edznorth* is introduced to the model to simulate the influence of development promotion policy aimed at that area. The parameter of *dist_edznorth* is adjusted while the parameters of the original 13 location constraints are kept. The Kappa index reaches the peak, 68.4%, when the parameter value takes 10. Comparing with the other EDZ location constraints, the parameter of the new constraint is relatively high, indicating that the development promotion policy intensity should be stronger than that of other EDZs.

Figure 5 Comparison of the parameters of EDZ location constraints

Location constraint	**Parameter**
dist _edznorth	10
dist _edzlake	35.564
dist _edznew	7.064
dist _edzrw	4.990
dist _edzsub	5.825

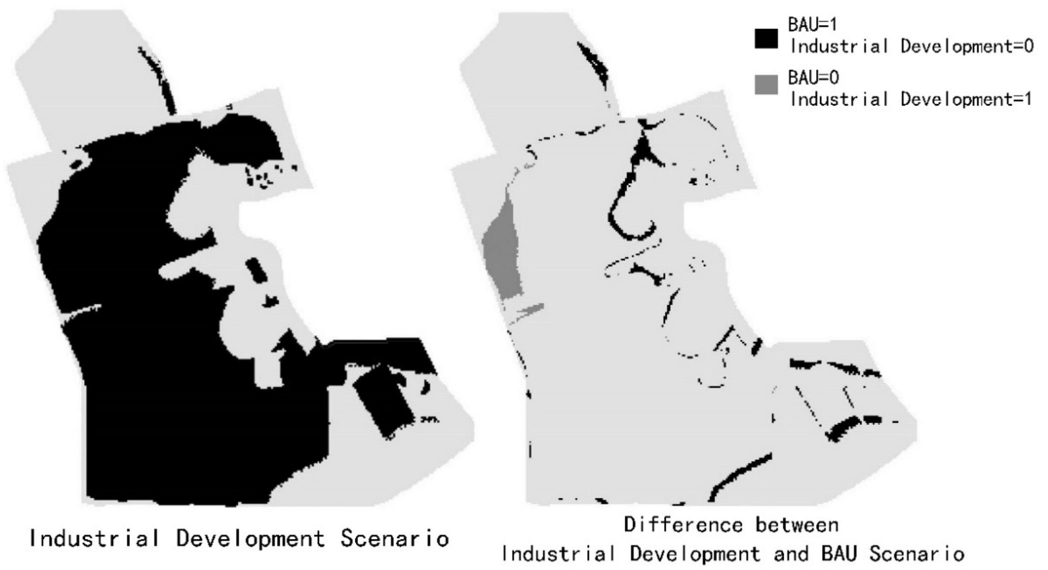


Figure 6 Simulation results of industrial development scenario and BAU scenario

2) Urban development policy scenario

First, the parameter of *dist_subcity* is adjusted to simulate the influence of stronger development promotion policies. The corresponding Kappa indexes between scenario simulation result and the master plan are shown as following. It can be observed that the Kappa index is at the highest (69.5%) when the parameter takes 70, while the original model parameter is only 4.199. Therefore the intensity of sub-city development promotion policy should be greatly enhanced. It can also be observed that the Kappa index rises relatively fast before the parameter reaches 30 and slower afterwards, indicating that it is more reasonable to increase the policy intensity moderately.

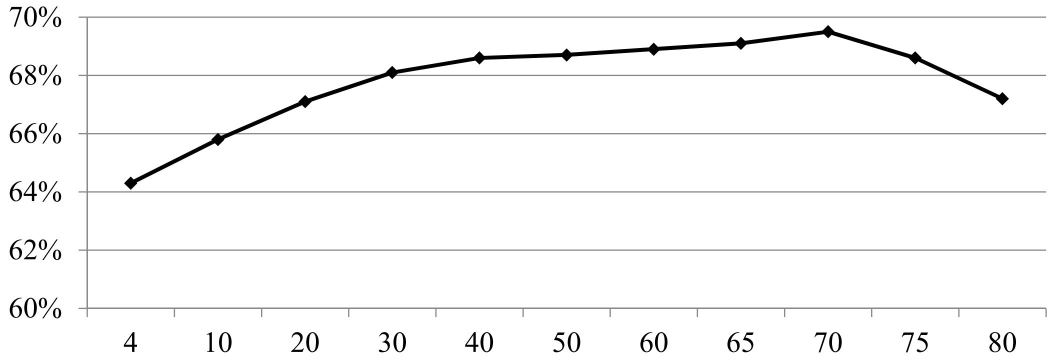


Figure 7 Parameters of *dist_subcity* and corresponding Kappa indexes

Second, the parameter of *dist_newcity* is adjusted to simulate the influence of stronger development promotion policies aiming at the new city. The corresponding Kappa indexes between scenario simulation result and the master plan are shown as following. The Kappa index is at the highest (65.7%) when the parameter takes 35 but the rise is rather moderate. The result suggests that new city development promotion policies are not quite effective. The main reason lies in that the new city is adjacent to the main city, thus much of its development is stimulated and driven by the latter.

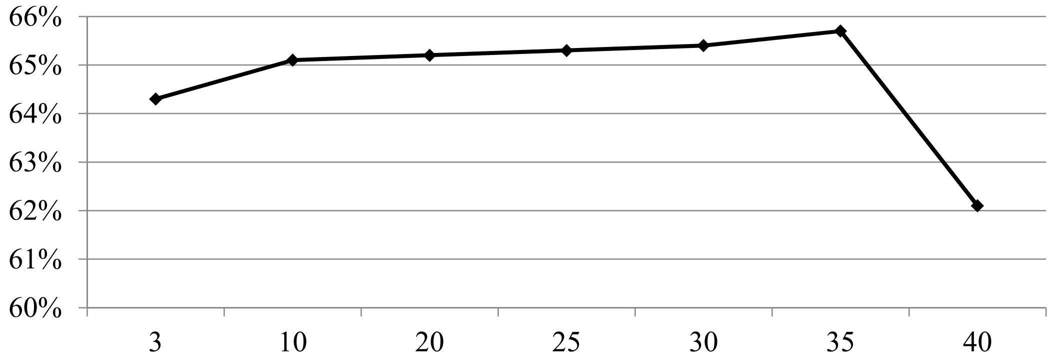


Figure 8 Parameters of dist_newcity and corresponding Kappa indexes

Third, the parameter of *dist_oldcity* is raised to deal with the lack of development in southeast part of the main city. The corresponding Kappa indexes between scenario simulation result and the master plan are shown as following. However, higher parameters don't lead to higher Kappa indexes in this case. It is probably because the southeast part of the main city is at the edge of the central city so that is hard to be influenced by development promotion policies.

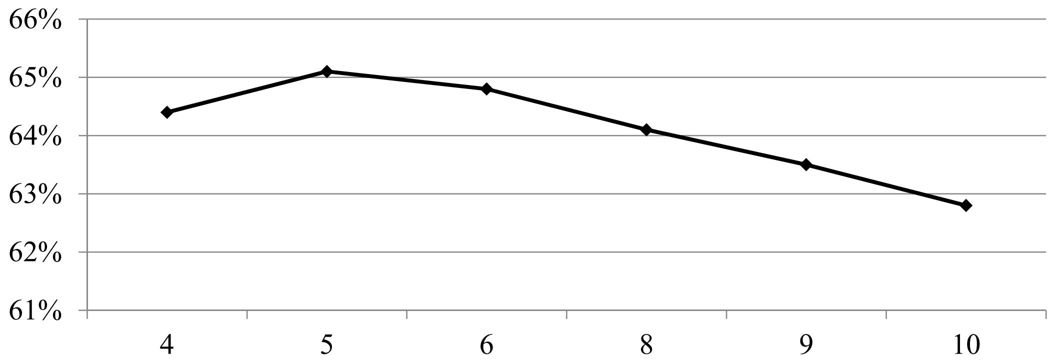


Figure 9 Parameters of dist_oldcity and corresponding Kappa indexes

Fourth, south part of the Lakeshore Tourist Zone is not developed in BAU scenario. However, the undeveloped area is too small to be designated a specific development promotion policy. Therefore government-led development is considered in this case. The inputting method is to add one square kilometer of construction land at the south end of Lakeshore Tourist Zone to simulate government-led development in that area. The result shows that the tourist zone can be completely developed with the Kappa index rising up to 66.7%.

3) Environment Protection Policy Scenario

According to Peixian Master Plan 2011, the Peigong Wetland Park, which is located between the new city and the sub-city, will function as the core area of Peixian's ecological network, while this area is very tend to be developed due to its central location according to the simulation result of BAU scenario. Therefore, an "exclusive" layer is imported to set the wetland park area as a no-development zone. The relevant Kappa index then increases to 68.2%, which is obviously higher than that of the BAU scenario.

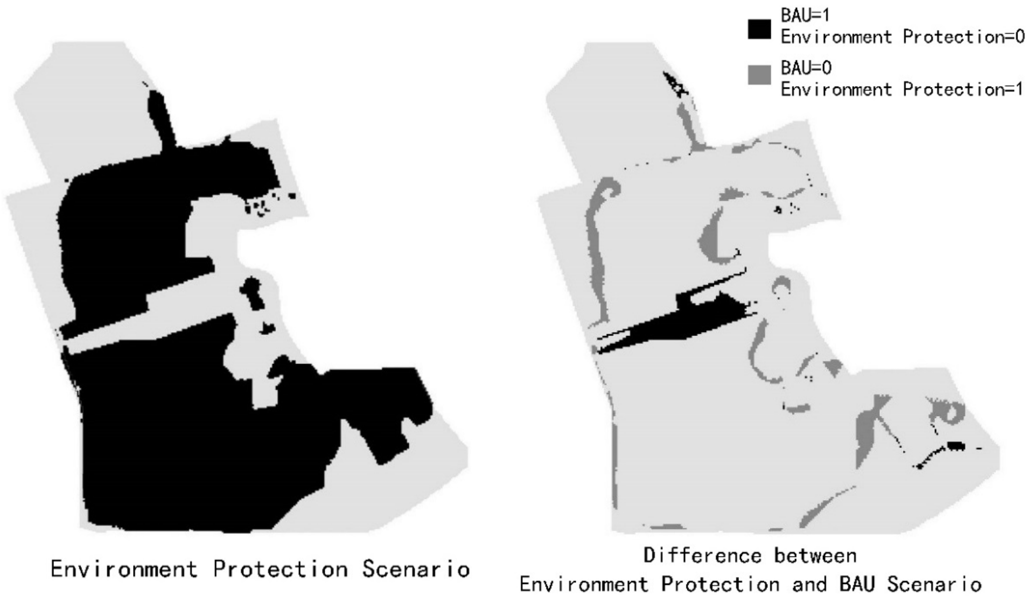


Figure 10 Simulation results of environment protection scenario and BAU scenario

In conclusion, the above scenario simulation results could help put forward more detailed policy suggestion so as to enhance the coordination between master plan and planning policies during Peixian's industrial transition. In respect to industrial development, it is necessary to make targeted development promotion policy aiming at the north EDZ, which should also be stronger than that of the existing EDZs. In respect to urban development, the development promotion policy of the old city, the sub-city and the new city should all be intensified to achieve the planned scale of development. Specifically, that of the sub-city and the new city need to be greatly strengthened while that of the old city could be moderately enhanced. Among them the sub-city should be allocated the most policy resources, because it is hard to benefit from or to be driven by the development in other areas. Moreover, government-led development is necessary for the Lakeshore Tourist Zone, which is suggested to initiate from its south part with the lowest development suitability. As to environment protection, Peigong Wetland Park, Peixian's eco-core, should be designated as no-development zone or restricted development zone to be protected from inappropriate development.

4 Conclusion and Discussion

This paper explores into the design and application of CA model from the perspective of master plan implementation and urban development policy-making. The proposed Peixian Urban Development CA Model is built on the basis of a comprehensive constraint CA model BUDEM, in which four types of major influencing factors of Peixian's urban development are considered. It could help indicate the difficulties in the master plan implementation by comparing simulation results and the plan. Furthermore, the model could also help put forward policy suggestions to promote the plan implementation by simulating the influences of various policies through adjusting model parameters. This research, to a certain degree, meets the shortfalls of existing researches that few discussions are made about the actual meanings of simulation results, thus expanding the application of CA model in urban study. Moreover, by applying CA model on Peixian County, this research also verifies the suitability of CA model for middle to small-sized cities which is also seldom discussed in existing researches.

However, the evolvement of various land uses, such as residential, industrial and commercial, is not included in this research. Optimization of model algorithm will be conducted to extend BUDEM to multi-land uses in the future, with which more detailed and more meaningful policy suggestions could be drawn. Moreover, a vector version of this model, in which model cells are actual land parcels instead of grids, could be developed to achieve more accurate simulation.

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