Understanding Residential Expansion Using MAS/LUCC Models

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by

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ABSTRACTS

Residential expansion has been the focus of the urban planners as well as the government during the past decade. Due to the complexity of the residential expansion process, it is very difficult to understand how human behaviours affect this process, not to mention how to present such relationships in fine urban models. In this research, analysis is carried out for exploring effective means to understand residential expansion, and then DPSIR framework and MAS/LUCC model are chosen for contributing to such understanding.

DPSIR is applied for its capability of analyzing in a cause-effects way and thus to answer "what" behaviours will have effects on residential growth. Then as for MAS/LUCC model, it is taken as a more effective method for understanding "when", "where" and "how" issues of residential expansion process for two components integrated within this model through specification of interdependencies and feedbacks between agents and their environment.

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Then a MAS/LUCC model is built up for understanding residential expansion with effects of human behaviors in Hongshan, Wuhan city, China. And this model is implemented by simulating residential expansion from 1996 to 2002 in study area. The result turns out to have a user precision of 52%. Although not very high a precision, this model demonstrates to be theoretically sound; and its capability in presenting spatio-temporal and behavioural complexity of residential expansion process prove it to be practically promising.

Finally, some discussions about problems in this model as well as possible solutions are given, and recommendations as well as future work are suggested. It is pointed out that this study demonstrates suitability for understanding complex urban processes. The methods put forward here represent a move toward more theoretically sound, behaviourally realistic, and ultimately more useful modelling methods. Especially for policy makers and urban planners, it can be taken as policy and management decision making support.

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Table of Contents

List of Tables

List of Figures

List of Maps

1. Introduction

1.1. Background

As a primary portion of urban growth, the residential expansion is becoming a more and more important issue. From the experiences of developed countries in North American and European world, uncontrolled residential expansion brings some problems during the process of residential suburbanization such as fast urban sprawl without control, severe residential segregation of different estates and races, hollow urban centre and environment deterioration, and many planners have expressed their concerns about the social and environmental cost of these problems in the decline of city centre and loss of farm land and open spaces (Ewing, 1997; Freilichand Peshoff, 1997; Hylton, 1995; Young, 1995; Rusk, 1993; Katz and Bernstein, 1998).

As far as China is concerned, because the conflict between residential expansion and plantation scarcity is fiercer than that in developed countries (Zhang, 1999) and the population growth brings much pressures on both residential needs and food demand, we should take measures to monitor rational[1] residential expansion to make a good balance between the need to maintain the amount of arable land and the need to accommodate the demand of urban households. That is to say, it is necessary for the government take some strategies to monitor the residential expansion process for sustainable urban development.

Chinese urban governments have long traditions of monitoring and controlling the residential expansion by means of urban master planning. Some urban researchers have carried out research on the understanding of residential expansion process as planning support. They explore questions such as: what is going on during the process of residential expansion? What are the essential driving forces of this process? How do the driving forces affect the process of residential expansion? How does the real city work?

Reviewing the literatures in China and abroad, some research has being carried out on the mechanisms of residential expansion. Some analyse from macro layers such as the economic development and policy issues. They argue that the government is "supporting" directly or at least involved indirectly in residential expansion, public spending on transportation and the personal income tax deductibility of mortgage interest are two public policies believed to contribute to residential expansion. On the other hand, some researchers analyse from micro layers, and they think residential expansion is a normal process of urbanization, in which the rising incomes of consumers and their location choice behaviours guide the growth of new urban residential territory into fringe areas (Gordon and Richardson, 1997).

[1] "*Rational*" in this thesis means a decision made by choosing the choice that satisfies all/most objectives. From the aspect of procedure, the decision should consider about solutions as many as possible. And from the aspect of objective, it should be aiming at "optimal solution". (Sharifi, 2004)

During the process of compiling urban master planning, except for planning support methods above, the planners evaluate the development actuality of the residential expansion, analyse its strengths, weakness, opportunities and threats (SWOT). Furthermore, they take public participation strategies for exploring planning more conform to the will of the urban dwellers.

1.2. Problem statement

However, actual residential development turns out to be not the same as that in urban master planning, because the behaviours of the urban households and land developers also contribute the planning implementation process. That is to say, the decision making of the government or the planner is affected by the argued proposals of other stakeholders. And the differences between reality and planning in turn result in uncontrolled residential expansion to some extent, and the interests of certain households or land developers sometimes stand for their own wills, which is contrary to that of the interests of the government.

Therefore, if the government knows the needs of different stakeholders, the resulting residential location choosing behaviours and the interactions between the behaviours as well as their effects on residential expansion process, it seems feasible to make a more rational land use planning and management. Here the interactions mean how the behaviour of one agent affects that of the others. And the stakeholders here include all the stakeholders concerned: households, land developers, the government itself, etc.

There are some means for the government to understand the behaviours and their effects on residential expansion: investigations, social analysis, and other methods. As for investigations, they show poor ability in micro spatial interactions and temporal interactions between complex human behaviours and the spatio-temporal residential expansion process, although they can represent individual behaviour quite well. Then as far as social analysis is concerned, it put more emphasis on qualitative and macro issues instead of quantitative and micro ones (Du Debin, 1997; Li Tieli, 1997).

Therefore, it is of high demand of understanding the residential expansion with human behaviours in micro scale including: what types of stakeholders take actions in residential expansion process? What are the interrelationships between their behaviours? And what are the effects of their actions on the spatio-temporal complex process of residential expansion?

Then the newly arising models—MAS/LUCC (Multi-agent system for Land use/cover change) models are particularly well suited for answering the questions. They are designed for representing complex spatio-temporal interactions under heterogeneous conditions and for modelling decentralized, autonomous decision-making, socioeconomic and biophysical complexity. And these characteristics of MAS/LUCC models are suitable for the goal of modelling interactions and feedbacks between human behaviors and physical residential expansion.

1.3. Research objective

1.3.1. The aim of the research

The main aim of the research is to make a contribution to the understanding how the process of urban residential expansion is affected by human behaviours.

1.3.2. Main objective

The main objective of this thesis is to develop a MAS/LUCC model that can represent complex residential expansion process with human behaviours for a case study in China.

1.3.3. Sub objectives

1. To analyse the residential expansion of Hongshan, Wuhan city, China from aspects of different agents.
2. To design a MAS/LUCC model for further understanding residential expansion process with human behaviours.
3. To implement the model prototype and calibrate the established prototype.
4. To achieve better understanding of complex residential expansion with this MAS/LUCC model.

1.4. Research questions

1. *To reason the residential expansion of Hongshan, Wuhan city, China from aspects of different agents.*
   - Who are the main agents of residential expansion process when reasoning about the process?
   - How to reason a cause-effect relationship with DPSIR framework?
   - How to reason residential expansion process in study area from the aspects of different agents with DPSIR framework? What responses by what agent will affect what aspect of residential expansion?

2. *To design a MAS/LUCC model for further understanding residential expansion process with human behaviours.*
   - Why to choose MAS/LUCC model and how to apply this model?
   - How to build components of the model (MAS and LUCC) by further exploring human behaviours and residential expansion based on the reasoning results of DPSIR framework?
   - How to integrate MAS and LUCC parts to make a MAS/LUCC model of residential expansion with human behaviours?

3. *To implement the model prototype and calibrate the established prototype.*
   - What is the suitable implementation platform?
   - What is the implementation flow of the model?
   - How correct is the simulation versus actual development?
   - Which aspect of the model can be changed to improve the resemblance?

4. *To achieve better understanding of complex residential expansion with this MAS/LUCC model.*
   - What might be considered when it comes to the complex of residential expansion?
   - How can the model help understanding such complexity?

1.5. Methodology

As for understanding the complex residential expansion process with human behaviours, I will mainly consider about such methodology:

1.5.1. DPSIR-towards reasoning

DPSIR (Driving Force-Pressure-State-Impact-Response) framework is an appropriate common logical framework for reasoning and it is selected for reasoning residential expansion in this study. Here state stands for actual residential land use distribution. Responses stand for the activities that agents (actors) are taking during the process of residential expansion that affect the process and in turn lead to a new status of residential land use distribution. From aspects of different agents, several DPSIR frameworks can be formed to reason residential expansion from different point of views. With this framework, we can get the idea that what contributors do each agent make to residential expansion process.

The reason that I take DPSIR framework for analysing residential expansion lies in that it enables logic way of analysing a process in a cause-effects way as well as takes into consideration of human behaviours by element of Responses.

1.5.2. MAS/LUCC -towards modelling

As the further analysis of understanding residential expansion with human behaviours based on the results got in the previous step, the behaviours of different agents and their interactions can be interpreted, thus to form a MAS/LUCC model for residential expansion process. As a matter of fact, any agent that contributes to residential expansion whether forwardly or passively should be taken as an agent of the multi-agent system. But here we simplifies agents and their activities in that:

Only several primary kinds of agents are taken into account, while neglecting the minor ones. In this study, I only take households and the government into consideration.
The usefulness of relationship or coordination can be seen in the simple situation where one agent is affected by the behaviours of the other agent.

After the study of multi-agent activities as well as their relationships with residential expansion process, the MAS/LUCC model can be formulated.

Why I use MAS/LUCC model in my research lies in that: if we want to study the relationship between activities of agents and residential expansion (as a kind of land change), we should consider about both the characteristics of activities and those of land use change. MAS/LUCC is just such a model that is newly proposed for studying the relationship between multi-agent activities and land use change. A closer look at this model will be represented by comparison to other models in chapter two.

1.5.3. Hybrid MAS/LUCC and CA-towards modelling implementation

Then the theoretical modelling claims for a suitable simulation platform for modelling implementation. There are several possible ways for this purpose, while CA-based platform in Arc/Info-GRID is adopted in this research for its strength in land use transition presentation. In fact, this is a hybrid method of MAS/LUCC theory and CA technology.

At the beginning of simulation, the data requirements will be defined and data will be collected accordingly. At the same time, from literature both in theoretical and practical aspects, a suitable simulation sequence is formed with simplified MAS/LUCC model. Whereafter the real data from case study city will be used to implement and calibrate the MAS/LUCC model.

Furthermore, the validation of the MAS/LUCC model is also very important because it gives impression of how reliable the modelling is and how good it matches the reality. While the main purpose of this research is on the construction of Multi-agent model, and there is a time limit, the calibration and validation of this model will be done in a simple way.

1.5.4. Scenarios analysis—towards understanding complex residential expansion

Owning to its micro presentation of interrelationships between human behaviours and land use change, MAS/LUCC can present not only its results in macro residential expansion but also the complexity of this process in time, space and complex human behaviours relationships. As for time, the residential development sequence is explored and analysed. Second for space, households of different incomes are taken for studying their different choices distribution in space. Third for human behaviours, several scenarios representing different human behaviours and their relationships are generated for demonstrating their different effects on residential expansion.

To integrate the methodologies utilized, a figure is illustrated in Figure 1-1 in the next page.

1.6. Structure of the thesis

The thesis focuses on designing a MAS/LUCC model that can represent the complex residential expansion process. The case chosen is residential expansion in Hongshan District, Wuhan city from 1996 to 2002. and this thesis is structured into six chapters:

Chapter 1 states the research background, problem, objectives and questions as well as methodology and theoretical framework.

Chapter 2 presents a literature review of theories of urban growth, residential expansion and their driving forces. The DPSIR framework and MAS/LUCC models are introduced as methodology of the study.

Chapter 3 describes the study area—Hongshan District of Wuhan city. With the DPSIR framework, the behaviours concerned by households and the government that contribute to the residential expansion are got.

Chapter 4 carries out the MAS/LUCC modelling work of residential expansion in study area for certain time periods based on the analysis of human behaviours with the resulting residential expansion in the DPSIR framework in chapter 3.

Chapter 5 implements the model in chapter 4 by simulating the residential expansion with the behaviours of households and the government in study area from 1996 to 2002. A further analysis is taken on the respective representation of temporal, spatial and behavioural complex of residential expansion process.

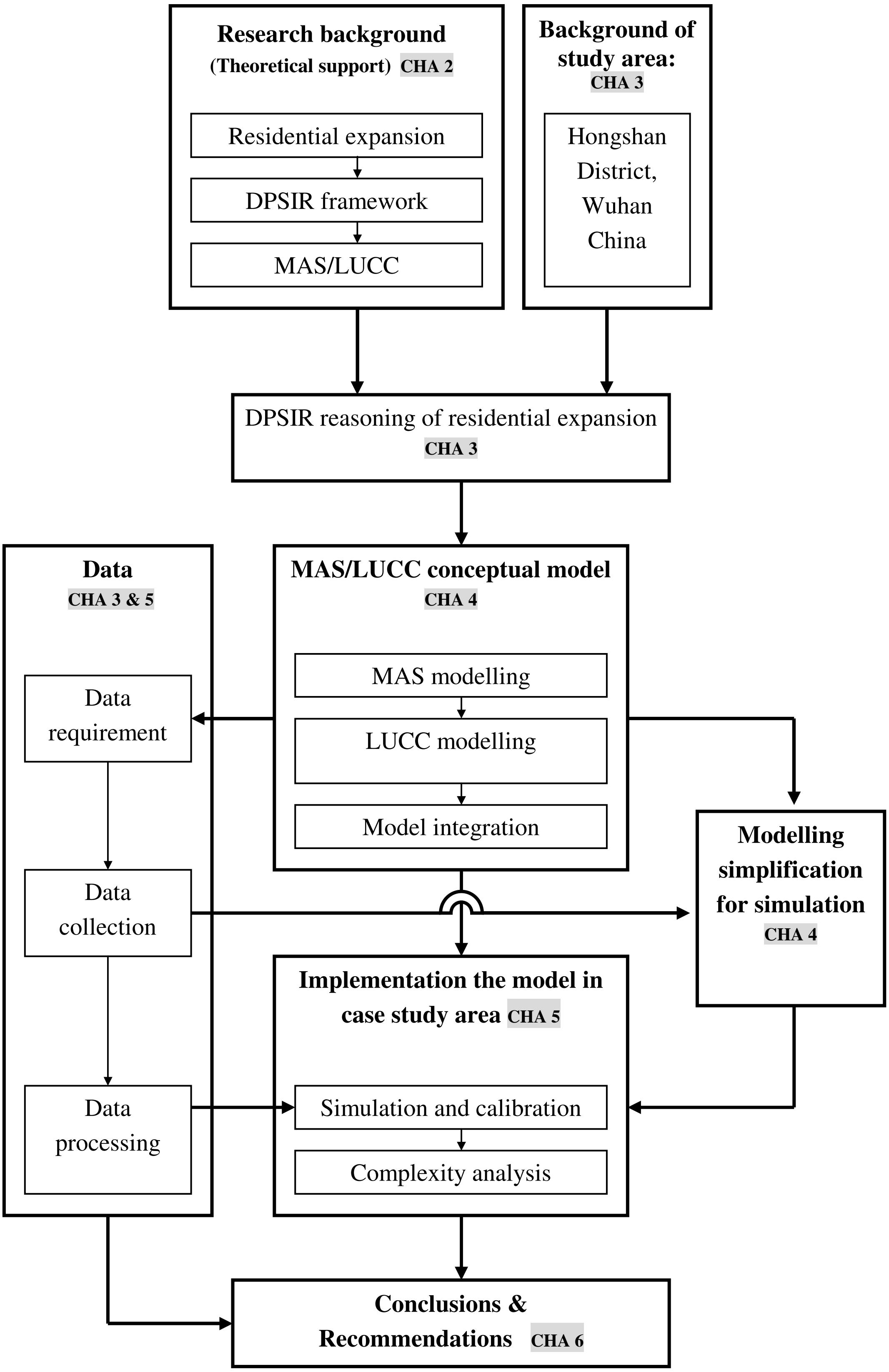


Figure 1-1 Research Methodology

Chapter 6 discusses on issues encountered in this research. Recommendations as to the future development of MAS/LUCC model for residential expansion are given. Finally, the conclusion on this research is arrived.

In appendix, the auxiliary information will be given on best-fit running results and scenarios running results in Arc/Info-GRID, the generated households database by Monte Carlo, and parts of the source code of programming in AML language.

2. Research Background: methods for understanding residential expansion

2.1. Introduction

This chapter presents a literature review of background theories of urban growth, residential expansion and their driving forces, and then introduces what methods I will take for my study and why I take those methods.

As a complex system, urban expansion can be seen as a very complex process, so does residential expansion. Although many researchers have interpreted the process from several aspects and by using various methods such as theoretical study and land use models, they seldom understand residential expansion with human behaviours, which are perhaps the most important contributors to this complex process. This is mainly due to the overwhelming of macro theoretical or physical studies in understanding land use change, while human activities are not taken as both theoretical and technical factors.

In fact, some researchers have taken their efforts in studying land use change and human behaviours in the past decade. Following some of their theories, I explore my study methodology in this chapter for my study of residential expansion. And the two methods I use—DPSIR reasoning and MAS/LUCC modelling are explained. With the DPSIR framework, I first can reason the process of residential expansion and find out the behaviours that contribute to residential expansion. This method is to answer the question of what are the behaviours of agents that have effects on residential expansion. Then by MAS/LUCC models, the detailed residential expansion with human behaviours may be modelled and represented in spatial and temporal dimensions. This model is to solve when, where and how residential expansion takes place as well as how the human behaviours in micro scale contribute to this process in macro scale.

2.2. Residential expansion

As the main part of urban expansion, residential expansion is conformed to the general rules of urban expansion. Therefore, we cannot neglect the concept of urban expansion when it comes to understanding of residential expansion. Furthermore, several concerned issues—such as complex and system theories — are also necessary in comprehending the basic concept of residential expansion.

2.2.1. Urban system

As argued by Barredo and Kasando (2002), cities are among the most complex structures created by people. Cities are highly complex social, economic, spatial syntheses, consisting of many, if not innumerable components. So in order to understand urban expansion, systematic method is employed.

➢ System

System thinking has been widely accepted by urban planners and other decision-makers engaged in urban management and construction. A system is an assemblage of objects, principles, or facts. United by some form of regular interaction or interdependence into an organized whole (Roe, G. N. Soulis et al. 1999). System consists of some elements, which work together to accomplish an objective. Their interrelationship is a very important component to systems' definition and formulation. To be exact, each system is composed of subsystems, and the interconnection and interactions between the subsystems are termed interfaces. Interfaces occur at the boundary (which separates systems from their surroundings) and take the forms of input and output.

Thus a system can be expressed as a limited part of reality with well-defined boundary and interrelated elements, and the elements inside system have strong functional relations with limited, weak or non-existent relations with elements outside the system. (Sharifi 2004)

If a system consists of limited sub-systems and their inter-relationships are simple, we categorize this kind of system as general system, e.g. computer system and plane system. While if a system consists of many hierarchical sub-systems and their inter-relationships are complex, we say this kind of system belongs to complex system, e.g. urban system, brain system and ecology system…(Qian, Yu et al. 1990) In the following, we will further discuss this kind of system for the prerequisite of understanding of urban system.

➢ Complex system

Zhou Chenghu and Sun Zhanli (1999) give the descriptive concept of complex system in complex sciences as "A complex system is a type of system that have medium-sized number of intelligent and self-adaptable agents that can respond to local information", in which the several core properties of complex system are put forward:

- Medium-sized[2] number of agents
- Intelligent and self-adaptable
- Local information without central control

Except for that, Pavard, B. and J. Dugdate (2002) argue the definition of complex system as "a system for which it is difficult, if not impossible, to restrict its description to a limited number of parameters of characterizing variables without losing its essential global functional properties." Formally, a system starts to have complex behaviours (non-predictability and emergence, etc.) at the moment it consists of parts interacting in a non-linear fashion. It is thus appropriate to differentiate between a complicated system and a complex system. The former are composed of many functionally distinct parts but are in fact predictable, while the latter is consist of self-organized agents that makes it non-predictable. (Pavard, B. and J. Dugdate 2002) Then another expression of general properties of complex system is below:

- Non-determinism and tractability

[2] Medium-sized means "not too many as complicated system or too few as simple system", which is originated from Weaver (1958).

- Limited functional decomposability
- Distributed nature of information and representation
- Emergence and self-organization

The first one means that we cannot predict the system behaviour; even we know every component of the system quite well. The second one implies that it is very difficult to decompose the complex system into functionally stable components. The third property means the system, as a whole is not equal to the sum of the functions of all the parts. The last but not of least importance is implies that the behaviour of the small part is different in isolation than we it is part of the larger system and the system organises itself from within and structures are not imposed from the outside.

In the further discussion of complex system properties for understanding urban system, Cheng (2003) stressed in particular three items: non-linear, emergence and self-organization.

Non-linear relationships and feedback among all components at the same and different scales often lead to instability and unpredictability in large complex systems. Emergence is often summarized as "a whole that is greater than the sum of tits parts or in simple terms, much comes from little". Thus the collective behaviour of a complex system is dependent on the behaviour of all of its parts. For example, Benenson, I. (1997), who have intensively studied the theoretical aspects of socio-cultural emergence during recent years, show the emergence of different forms of cultural and economic segregation as a consequence of the interactions between individuals and the city environment at the local and global levels. Self-organization is the spontaneous emergence of macroscopic non-equilibrium organised structure due to the collective interactions among a large assemblage of simple microscopic objects as they react and adapt to their environment. It suggests that insignificant local interaction behaviour can lead eventually to a qualitatively different global structure (Wu, 1998).

As Pavard, B. and J. Dugdate (2002) argued, a truly complex system would be completely irreducible which means it is impossible to derive a model to represent the real world without loosing some of the properties of the system. This means what we are attempting to model is only the simplifying representation of the real world. And from the definition of complex system, we know that complex emerges from the interrelationships between components. Therefore, it is too complex for us to comprehend a complex system entirely, while it is proper to understand it from a certain aspect. What we should do is to take into account the appropriate properties and choose the needed components or parameters that are necessary for our research. Actually, various urban models are good cases in point, and some of them will be discussed in the following.

- **Complex urban system**

Cities can be understood as complex systems considering their intrinsic characteristics of emergence, self-organising, self- similarity and non-linear behaviour of land use dynamics. (Cheng, 2003)

Then to interpret from the components of complex system: the dynamic process of urban growth involves various socio-economic and physical and ecological components at varied spatial and temporal scales, which result in such a complex system. For example, in urban economic field, large-scale economies of agglomeration and dis-agglomeration have long been understood to operate from local-scale interactive dynamics. From spatial aspect, peak-hour traffic congestion and large scale spatial clustering are induced by local-scale interaction behaviour of many individual objects (Nagel, Beckman et al, 1996). That means that many components act on each other within the city land use, transportation, culture, population, policies, economics and so on. No wonder Barros and Sobreira (2002) argued that spontaneous and simultaneous individual decision-making processes takes place both in spatial dimension and temporal dimension.

Due to the operation of complex urban system, there are some spatial processes: urban expansion, urban pattern change, land use conversion, urban population growth, social development, economic development, etc. Among all these items, some are presented as spatio-temporal changes. In the following section, focus will be put on one of the spatio-temporal process-residential expansion.

2.2.2. Defining residential expansion

Before we go further discussion of residential expansion, I think that defining the extension of residential expansion is a prerequisite for we are not clear about the connotation and the boundary of residential expansion although it seems that we are very familiar with it.

Urban expansion indicates a transformation of the vacant land or natural environment to construction of urban fabrics including residential, industrial and infrastructure development. It mostly happened in the fringe urban areas (Liu, 2002). It is brought about by urbanization and is consisting of continual urban expansion, leap-frog expansion[3] and low-density urban sprawl[4] (Zhang Xinsheng, 1996; Weng, 1996).

Similarly, residential expansion can be defined as: a transformation of the vacant land or natural environment to residential land, which mostly happened in the fringe urban areas. [5]Differentiating from residential sprawl, which is new residential development that occurs in a fragmented, non-contiguous pattern across the landscape, residential expansion means a natural and common land growth process.

With the entrance to industrial society, the interrelationship between residential expansion and urban expansion was becoming more and more obvious. For example, residential suburbanization in the western world has affected the development of urban centre a lot. As for China, because it is now undergoing rapid urbanization, it is necessary for urban planners to think about residential expansion actuality and its control for better urban development.

[3] Leap-frog expansion refers to discrete urban land expansion, which is newly developed area that is perhaps far from the urban built-up area. Such location choices are generally taken by the government directly for the purpose of alleviating the pressures of high population density on urban built-up area and setting guidance for direction of future urban development.

4 Urban sprawl is a term that is often used to describe certain inefficiencies of development, including disproportionate spatial growth of urban areas and excessive leap-frog development. These inefficiencies in land consumption are viewed by many as leading to a very costly form of development. (Carmen Carrión and Elena G. Irwin) In another opinion, urban sprawl refers to urban expanding phenomenon out of control (Zhang Tingwei, 1999). A. Dwons defines urban sprawl as a special form of suburbanization, and it means expanding towards urban fringe, taking undeveloped land. He also points out the difference between urban growth with suburbanization in that the latter refers to “population growth out of inner city”, in which process land use development is not concerned (Downs, 1994). R. Moe further defines urban sprawl as “developing in urban fringe in low density” with the properties of bad urban planning, great-consumption of land, car-dominant transport, etc (Moe, 1995). So urban sprawl can be seen as a fast and inefficient type of urban expansion.

[5] Notice: land use conversion from other types of land use such as industry and commercial in urban built-up areas is not included in residential expansion. In fact, it is the other type of residential growth.

2.2.3. The characteristics of residential expansion in China

Generally speaking, residential expansion as well as population mobility in China tends to be short-distanced spreading, which is not similar to long-distanced preferred growth that towards far-suburban areas with car-transport in developed countries. Sun Shijie, (2001) have verified this conclusion by studying Nanjing city in China.

Another obvious characteristic is the important role of the government decision in residential expansion. They make policies, land use planning, land management

Then we wonder: what are the driving forces that behind residential expansion phenomenon? How do the driving forces work and what are the responses of actors that take roles during the process?

2.2.4. Driving forces of residential expansion in China

Clearly, residential expansion is a complex spatial changing phenomenon in urban system that can hardly be separated from urban expansion. Different driving forces and influence factors will take actions. In the following sections, brief overview of driving forces of urban expansion will be taken, and then the main driving forces of residential expansion will be formulated.

Generally speaking, the driving forces of urban expansion can be divided into two parts: natural and social issues, among which the social side is more important. P. C. Stem further interprets social force from population change, economic conditions, technical change, economic growth, political structure ideas, etc.

Though urban growth is a global phenomenon, the driven forces may differ greatly in different countries and eras. Some researchers have made extensive investigation on urban growth process in U.S. They found urban growth has historically been strongly related to transport technology. In fact, in western urbanization process, accessibility and ground transportation system have played very important roles, especially in North America, and good transportation availability and convenience road network liberated western urban expansion process from traditionally centre-based models.

Then as for urban expansion driving forces in China, they are more complicated comparing with those of western countries. To different period, the corresponding driving forces will change greatly. The development of industry is the dominant driving force before the reforms and opening-up policy, while population growth and residential diffusion are main driving force after that. Here I will focus the period after the reforms and opening-up policy in1978 implementation in China, since its importance and realistic meaning for urban growth from then to even today. During this period, Chinese cities develop quickly, marked with old cities booming expansion and new cities sudden emergence. Several researchers have explored this special phase from different aspects.

Yang Rongnan (1997) explain the driving forces of urban growth as following:

Economic development is the decisive factor.
Natural geographical environment is the basic condition.
Transport construction is the directive factor.

Policy and planning are the controlling valves.
The need of houses by growing population has special influences.

There are still other researchers (Liu, 2002; Kevin Honglin, 2000) that discussed on driving forces of urban expansion by studying Chinese urban expansion process after reform and opening-up policy in 1978 and taking some data analysis. From the conclusions of studies above, we may see that economy is undoubtedly the all-agreed one that determines the whole development of city, policies are important in China in guiding residential expansion. Other driving forces such as population growth is always the vital driving force that can not be neglected, because with the population growth there is the corresponding needs for urban land.

Based on the analysis of the driving forces of urban expansion, the driving forces concerning to residential expansion can be classified into three parts: social, economic and political issues which means that residential expansion is a complex process that is concerned with many different issues. The driving forces and residential expansion are expressed as the following Figure 2-1 in the next page. First as for social issues, they consist of population growth, social development (the improvement of people's living qualities and civilization development of the whole society). Second are economic issues (development of market economy[6]). Third are political issues, which comprise urban master planning, and policy for real-estate market development.

Then we can tell that different driving forces determine different facets of residential expansion, for example, population growth and increase of residential area per capital mainly explain quantity increase of residential land. Policies enable and affect the location choosing behaviours of the stakeholders and sometimes determine the quantities and directions of residential expansion directly. Social-economic development change the needs of stakeholders and the properties of urban land as well, thus to cause effects on residential expansion. And, these driving forces are sometimes interrelated and are hard to be separated absolutely. For example, population growth accelerates environment deterioration, and requires for more transport construction, which needs economic development as well. Another is that inner-city reconstruction and new town construction are happening at the same time which brings about not only residential land increase in quantity but also residential mobility in space.

From the analysis of residential expansion by discussing about complex urban systems, urban expansion as well as residential expansion itself, we get the conclusion that as a process of complex urban systems, residential expansion is very complex and is driven by many driving forces. Therefore, to understand such a process, a method of reasoning cause-effects relationship is needed.

[6] Market economy is the counterpart to planned economy. China is under the system of planned economy before reform and opening up policy in 1978; and after that market economy takes a more and more important role during economic development. Under market economy, the economic behaviours by people are mostly controlled by the market, which means that the agents have more choices out of their own will, not that of the government. Another effect of market economy is more rapid urban economy development.

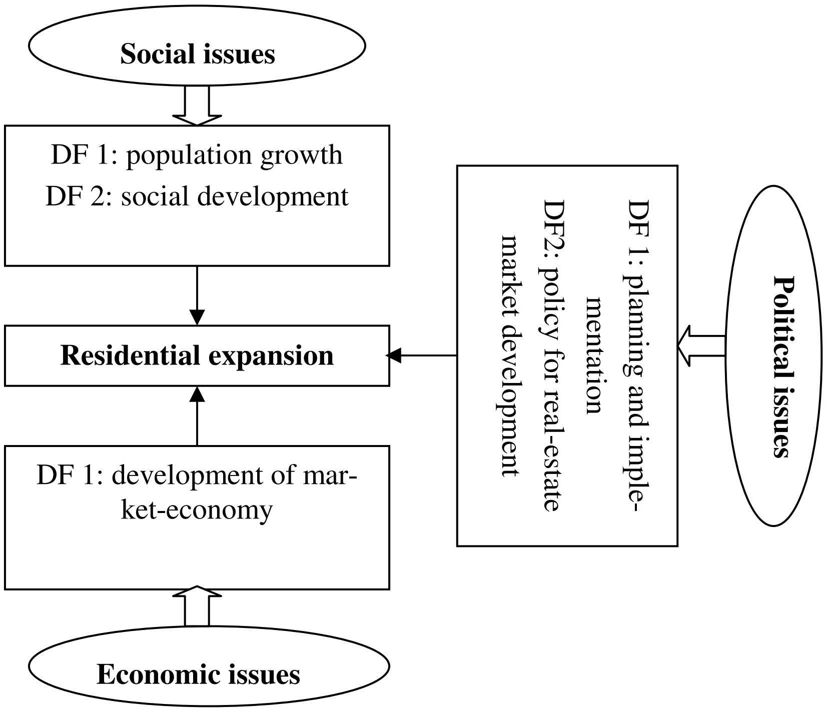


Figure 2-1 DS framework for residential expansion

2.3. DPSIR- on the reasoning of residential expansion

2.3.1. Introduction of DPSIR framework

According to DPSIR there is a chain of causality existing from driving forces over pressures to environmental state and impacts on human welfare, finally leading to political responses. So this framework is particularly useful for policy-makers in the original stage of its use.

- **The origin and concept of DPSIR**

Variations of DPSIR model include PSR, DSR and other such ones. OECD is perhaps among the early users that taking use of this framework. It uses a Pressure-State-Response (PSR) model for organizing environmental information (OECD, 1993). Human activities exert pressures on the environment that result in changes in quality and quantity of natural resources (state). Society responds to these changes through economic, environmental policies (response). In the preparation of a list of indicators for sustainable development including social, economic, environmental and institutional aspects of sustainable development, UNCSD uses a Driving Force-State-Response Framework (DSR). In the DSR framework, the term “pressure” has been replaced by that of “Driving Force” in order to accommodate more accurately the addition of social, economic and institutional indicators. The use of the term “Driving Force” allows that the impact on sustainable development may be both positive and negative as is often the case for social, economic and institutional indicators (UNCSD, 1999).

After further applications of DPSIR model as well as its variations into much other research, we can give a more general concept of this model:

----*"DPSIR is a general framework for organizing information about state of the environment. The idea of the framework was however originally derived from social studies and only then widely applied internationally, …"* (CEROI, last access: 01-09-2004)

- **The framework of DPSIR**

As far as the frameworks of DPSIR are concerned, there are several different expressions, while the concepts and essences of them are of the same. In the following, three of them are listed:

The first one is used by National Environmental Research Institute of Denmark. Figure 2-1 describes the framework. (NERI, last access: 01-09-2004)

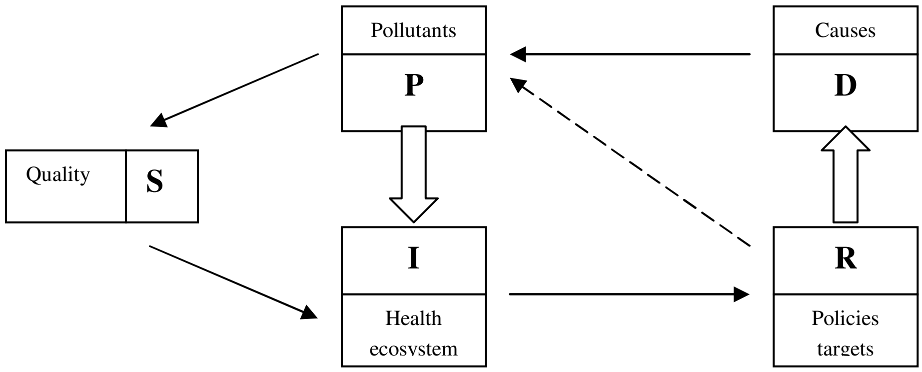


Figure 2-2 DPSIR framework by NERI

Drivers are the underlying causes that lead to environmental pressures. Examples are the human demands for agriculture, energy, industry, transport and housing.

These driving forces lead to pressures on the environment, for example the exploitation of resources (land, water, minerals, fuels, etc.) and the emission of pollution.

The pressures in turn affect the state of the environment. This refers to the quality of the various environmental media (air, soil, water, etc.) and their consequent ability to support the demands placed on them (for example, supporting human and non-human life, supplying resources, etc.).

Changes in the state may have an impact on human health, ecosystems, biodiversity, amenity value, financial value, etc. Impact may be expressed in terms of the level of environmental harm.
The task of managers or decision makers is to assess the driving forces, pressures, state and their ultimate impact. From the impact they must determine appropriate responses, in order to direct the final impact in the desired direction (a reduction in environmental harm). These responses will influence the drivers, pressures and states, thus completing a feedback loop.

The decision-maker is trying to produce a certain desired impact (typically, a reduction in environmental harm to a given level). She does this by applying responses that directly or indirectly influence the driving forces, pressures and state. The impact can only be changed indirectly, at the end of a chain of events.

The second one mentioned here are proposed and used by European Environment Agency (EEA), and it is illustrated in Figure 2-3. The main components of this framework have similar meanings of that in the framework above and the example is specially used for analysing the inter-related factors that impact on the environment. (EEA, last access: 01-09-2004)

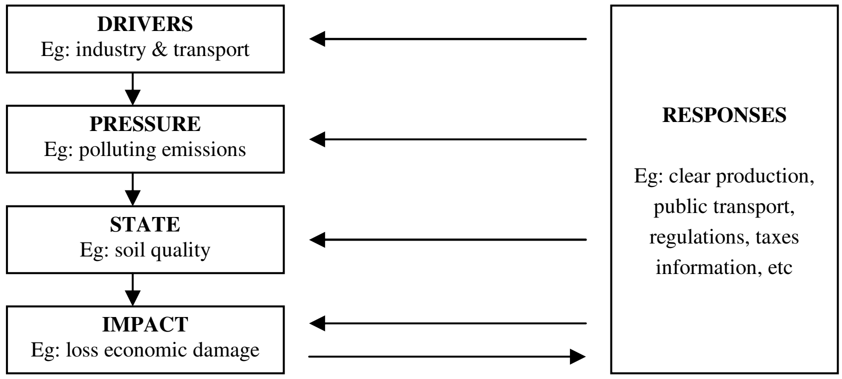


Figure 2-3 DPSIR framework by EEA

- The third framework differentiate to the second one only in that its responses aim at driving forces, pressures and states while impact is not included. See Figure 2-4 (Sharifi, 2004). Here driving forces stands for underlying causes and origins of pressure on the environment, pressure means the variables which directly cause environment problems, state represents the current conditions of the environment, impact means the ultimate effects of changes of state, damage caused and response stands for decisional option, which is the effort to solve the problem caused by the specific impact.

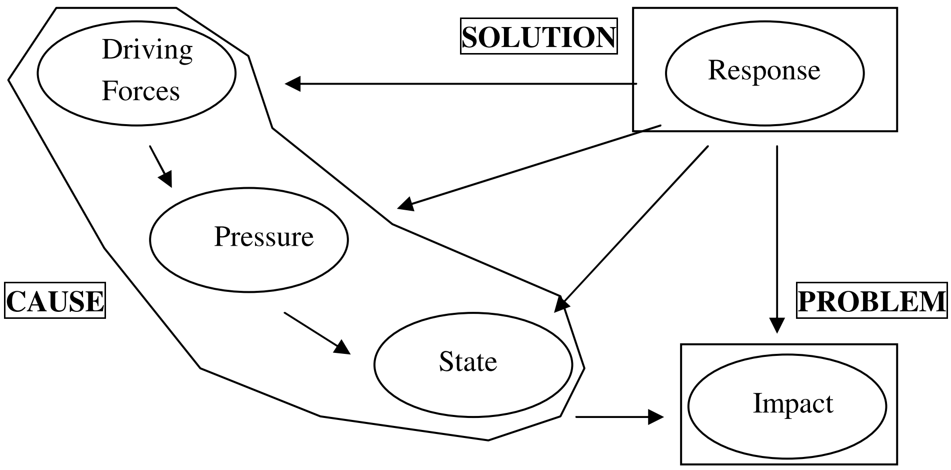


Figure 2-4 DPSIR framework for Decision-Making

Because of the shared cause-effect relationship of DPSIR model and its variations, it doesn't matter which one we select for reasoning a certain problem. And what is more, not all issues or themes need a full DPSIR presentation, in many cases some aggregation of DPSIR elements will only make them easier to work with and understand. The only standardization for choosing lies in that the chosen framework should be the most concise and clearest to reason and express the relationships.

2.3.2. Application of DPSIR framework

We have already know that DPSIR framework provides a rational and clear guideline for modelling of pressures derived from human activities on natural environment, and the way that they are changing state of the environment. The cause effect relationship can be established in a top-down fashion, starting from driving force, pressure, state and impacts, or bottom-up which goes the other way round. These models can be used to identify the related problem or opportunities. Here are some applications:

First, the aim of EEA to put forward the DPSIR model is described as following:

- To provide information on all of the different elements in the DPSIR chain
- To demonstrate their interconnectedness
- To estimate the effectiveness of responses

They also say that during the start-up stage of the agency, priority has largely been given to the areas of pressures, state and impacts, while more emphasis will be put on driving forces and responses in the future. Based on this idea, EEA has put DPSIR into the reasoning of environmental issues.

Another example of application is using DPSIR framework to evaluate sustainability in coastal areas. In this case, a DPSIR framework is developed in a practical context to integrate natural and socio-economic indicators. Sustainability reflects public policies towards the utilization of natural resources. Cost-benefit analysis included in DPSIR evaluates losses and benefits resulting from such policies.

The last but not the least important application of DPSIR framework I want to mention here is the process of planning & decision-making (Sharifi, 2004). This process can be divided into three phases: conceptual phase (problem identification, decisional analysis and problem decomposition), design phase (search of options, choice criteria implementation and outcomes' prediction) and choice phase (selection of one option and sensitivity analysis). The applied DPSIR frameworks are used as shown in Figure2-5 in the next page.

2.3.3. Reasoning residential expansion in China with DPSIR framework

- **DPSIR framework Building and explanation**

With the DPSIR framework, residential expansion can be explored in a logical way. As far as residential expansion in China is concerned, none of the above framework can be used for reasoning separately, for there are several driving forces. We may begin from several important driving forces, and then take articulate reasoning in a certain DPSIR framework. The DPSIR framework of residential expansion can be formed as the following figure with frameworks from the aspects of different agents.

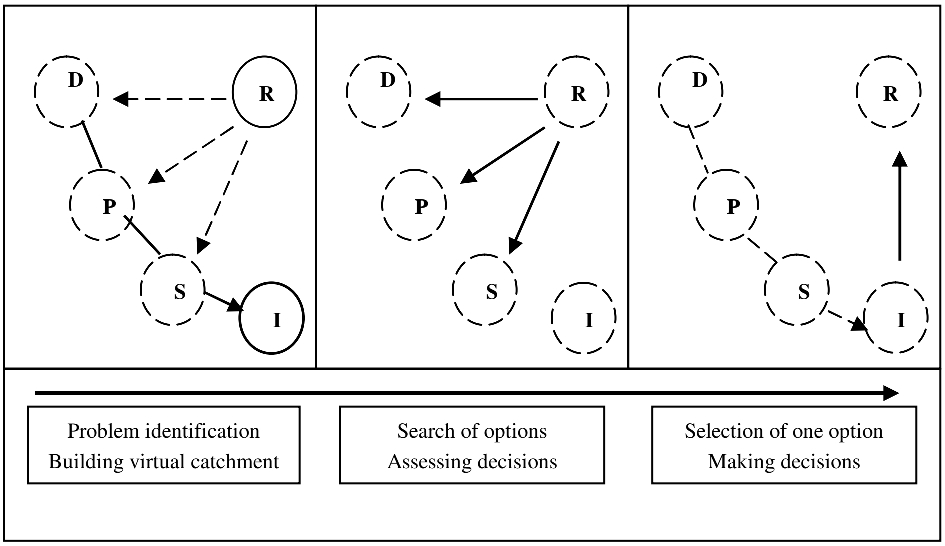


Figure 2-5 Process of planning & decision-making in DPSIR

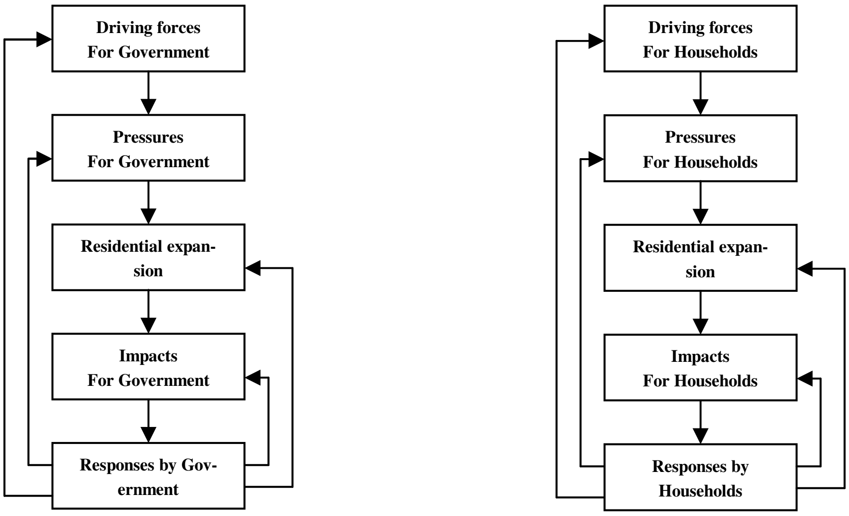


Figure 2-6 DPSIR framework from aspects of government and households

The complexity of cause-effect relationships increases with more types of agents. So as for other stakeholder such as land agent, they are regarded as the mediate-agents to implement the wills of the government and households, while other possible behaviours are neglected. In this sense, the reasoning work is restricted to the discussion of the government and households in my study. The two frameworks in Figure 2-6 shows the conceptual model in similar way: the main flow is the DPSIR cause-effects relationship, and the arrow directing to Driving forces, Pressures, States and Impacts (DPSI) that sent out from responses (by households or by the government) refer to the reactions (or behaviours) of the agents that will change DPSI of residential expansion process.

By such framework, together with the given possible driving forces analysed in the previous section and the set agents, it can be explained that what behaviours of certain agent will have what effects on residential expansion. Then as for the presentation of DPSIR are not the same in different time and areas, it is not proper to make general DPSIR frameworks for all the areas at any time. So the reasoning is implemented with a case in Wuhan city in China in chapter three.

- **Deficiency of this DPSIR reasoning**

The DPSIR reasoning above does give us an impression of its ability in cause-effect reasoning of residential expansion, whereas it cannot tell how the process of residential expansion is going on with human behaviors, not to mention what the choices of the government will direct to what kind of residential expansion. So there are still some questions to be answered: when and how does this process happen? How can we understand residential expansion by combining the analysis of the two frameworks? What are the location choices of different households? What they consider when they are choosing their houses? What are the relationships between the behaviors of the government and households? What will happen in space when many factors are interacted? And if the government wants to change current residential expansion, what it should do and to what extent can it change by certain responses? …This means, using DPSIR frameworks alone is not enough for understanding residential expansion process.

Therefore, because of the active role of households, which are a big group of people that almost include all the members of citizens, the behaviours factor becomes more important than any other types of urban land use change.

Further more, in one philosophical tradition, understanding means the construction of models and simulation of their cause-effect relationship in reality. So, a possible way to answer the questions that DPSIR cannot answer is to build up a quantificational model of residential expansion with human activities that can explain not only "what" but also "when", "where" and "how" issues of residential expansion process.

2.4. MAS/LUCC—on the modelling of residential expansion

In this section, multi-agent systems (MAS) are offered as the means to model and simulate residential expansion with human activities.

2.4.1. General approaches to modelling land use/cover change

With the common purpose of understanding the land use/cover change (LUCC) with human activities, some scholars have put forward many approaches already, and there are a number of ways of classifying models of urban growth. For example, in terms of system completeness, models can be system-level and specific-level with the former taking all components of urban system into account and the latter focusing only on a specific phenomenon or problem by using a limited number of components such as residential expansion (Cheng, 2003). In the following, we hereby attempt to classify and examine myriad LUCC modelling approaches that I think are perhaps worth considering about when it comes to understanding residential expansion as the consequence of human activities. They are equation-based models, statistical techniques, evolutionary models, cellular models, hybrid models, agent-based models, etc. this review is not exhaustive and only serves to highlight ways in which present techniques are complemented by MAS/LUCC modelling techniques.

➢ Equation-based models

Most models are mathematical to some extent, but some are especially so in that they rely on equations that seek a static or equilibrium solution. The most common mathematical models are sets of equations based on theories of population growth and diffusion that specify cumulative land use change over time. More complex models employ simultaneous joint equations that are often based on economic theory and linear programming. When linked to GIS technology, these models can be used for modelling land use change.

Although it has long traditions, equation-based models have obvious disadvantages:

- A numerical or analytical solution to the system of equations is formed, limiting the level of complexity in reality.
- Simulation models that combine mathematical equations need a large amount of raw data are difficult to obtain and validate which are the bases for the formation of equations.
- These models are not easily linked to GIS, which is vital in the spatial-correlative issue of land use change.

Therefore, equation-based models are maybe more suitable in the fields of social studies such as economic and ecological issues, while in the realm of spatial issues, models that of spatial connected in micro-layer are better.

➢ Statistical techniques

Statistical techniques are a common approach to modelling land use change, given their power, wide acceptance, and relative ease of use.

Traditional statistical models, such as Markov chain analysis, multiple regression analysis, principal component analysis, factor analysis and logistic regression, have been very successful in interpreting socio-economic activities. Cheng (2003) argued that these traditional statistical models have been widely used for modelling urban growth with varied strengths and weaknesses, and among the weaknesses is their inefficiency in modelling spatial and temporal data.

Then spatial statistics modelling is adopted. One is incorporating spatial sampling into traditional analysis (Atkinson, 1998). The other is developing new statistics based on spatial relationships. Successful examples of combining theory and statistics are provided by spatial econometrics. For my research of exploring the effects of human location choosing behaviors on residential expansion, a model of such method can be like this: the government take interviews or investigations to gather the data of location choosing behaviors of the stakeholders, and then represent them on a map. When they are making residential land use planning, they may make a more rational planning that take into account the choices of the stakeholders.

But this model shows disadvantages in the comprehension of the interactions between these stakeholders. In the local spatial aspect, there are conflicts between stakeholders such as a certain land parcel cannot be occupied by two stakeholders at the same time which the statistical technique is unable to solve. Another is in the temporal aspect, the reality of location choosing process is carried out randomly by the households, and if many households choose to live in a certain area, the land price there will rise, which in turn affects the choices of the following householders. Therefore, a model that specializes in spatial and temporal complexity is needed.

- **Evolutionary models**

Within the field of artificial intelligence, symbolic approaches such as expert systems are complemented by an evolutionary paradigm. Examples of this field such as artificial neural networks and evolutionary programming, are finding their ways into land use change models (Balling, et al, 1999).

Artificial neural networks (ANN) models are analogs of neural structure that are trained to associate outcomes with stimuli. ANNs are powerful tools that use a machine learning approach to quantify and model complex behavior and patterns. Thy are used for patterns recognition in a variety of disciplines, such as economics, medicine, landscape classification, image analysis, climate forecasting, mechanical engineering and remote sensing, etc. Evolutionary programming mimics the process of Darwinian evolution by breeding computational programs over many generations to create programs that become able to solve a particular problem.

In the field of urban growth, ANN models are often used to explore the connections between socio-economic and demographic variables and the phenomena of urban growth such as transportation and other spatial land use pattern change. For example, Pijanowskia, et al (2002) illustrates how combining geographic information systems (GIS) and ANNs can aid in the understanding the complex process of land use change by integrating ANN and GIS to forecast land use change, where GIS is used to develop the spatial predictor variables.

Although ANN is an ideal method of understanding non-linear spatial patterns by exploring the relationships between certain variables from the above, the major drawbacks of ANN that cannot be neglected is black-box and static nature, resulting in its inefficiency in interpreting the complex causes of a certain spatial change.

- **Cellular models**

Cellular models (CM) include cellular automata (CA) and Markov models. Each of these models operates over a lattice of congruent cells.

Cities, like most geographical phenomena, are complex nonlinear systems involving spatial and sectoral interactions, which cannot easily be modeled with the functionalities of current GIS software. CA-based approaches are useful in the study of urban spatial structure and evolution with distant roots in geography. For example, they have been used for assessing the role of density constraints in land development (Batty M, 1999), describing the evolution of urban forms (Clarke, 1997; Wu, 1998a), and simulating land-use transitions.

But none of these CA applications provide “support” for typical actor-based processes. They all focus on autonomous processes that can be entirely described through the interactions of spatial phenomena. The assumption of self-organization in spatial context means that CA can only be applied to explicit spatial systems that respond to rules, cells and neighborhoods that are stationary in space and time. CA themselves however do not provide methods to assign dynamic characteristics to the states, rules and neighborhoods, and are therefore limited in their use for modelling the human factor in a spatial decision-making process. Various researchers such as Deadman (1999) emphasize the importance of integrating human system modelling into spatial models. Therefore, CA models are not capable of such works by themselves alone.

- **Hybrid models**

Hybrid models combine any of the techniques mentioned above, each of which a fairly discrete approach unto itself. Examples of hybrid models such as GEOMOD2 (Hall et al. 1995) that combine statistical techniques with cellular models and system models, the CLUE family (Veldkamp, 1996) that include larger-scale models.

A distinct variant of hybrid models is dynamic spatial simulation (DSS), which portrays the landscape as a two-dimensional grid where rules represent the actions of land managers based on factors such as agricultural suitability (Gilruth, 1995). Dynamic spatial simulation typically does not represent heterogeneous actors, institutional effects on decision making, or multiple production activities. However, due to their ability to represent individual decision making and temporal and spatial dynamics, they represent an important advance over previous models (Lambin 1994). The orientation toward individual decision-making in DSS is shared by agent-based models. Thus, these models are logical precursors to MAS/LUCC. Then, multi-agent models and MAS/LUCC models will be articulated in the following sections.

2.4.2. Multi-agent models

An increasing number of scholars are exploring the potential of multi-agent systems (MAS) tools for modelling human behaviors and their corresponding effects on certain spatio-temporal phenomena. Agent-based (or entity-based) models are usually implemented as multi-agent systems, a concept originated in the computer sciences that allows for a very efficient design of large and interconnected computer programs. But its applications nowadays are far more than its original meaning. For example, during residential expansion, the stakeholders such as the government, households and land agents can all be regarded as agents. Then in the following, the basic theory and methodology about MAS will be articulated.

- **Background**

Although agent researchers come from a variety of backgrounds, the Distributed Artificial Intelligence (DAI) and the Distributed Computing (DC) communities stand out as traditional agent research areas.

During the mid-1970s, researchers from DAI began to formulate some of the basic theories, architectures, and experiments that showed (computationally speaking) how interaction and division of labour could be effectively applied to problem solving (Gasser, 1998). Experiments showed that intelligent, rational behaviour is not an attribute of isolated components, but rather an outcome that emerges from the interaction of entities with simpler behaviours.

More recently, DC became an active discipline in agent research. DC is challenged to integrate heterogeneous, largely autonomous computer components that span several generations as part of collaborative environments. From this perspective, agents are applied as interaction entities to mediate differences among components, while providing a syntactically uniform and semantically consistent intermediary role (Huhns, 1998).

In virtue of their innovative concepts and theories, MAS has been applied to other realms during the past decade. Then we will first interpret some general definitions of terms concerned with MAS and understand some basic theories of them.

- **Agent**

What is an agent or autonomous agent? It has been a very controversial topic these days. As given by Maes (1994): "An agent is a system that tries to fulfill a set of goals in a complex, dynamic environment. An agent is situated in the environment: it can sense the environment through its sensors and act upon the environment using its actuators". Based on a comprehensive survey of the existing definitions, Franklin and Graesser (1997) have provided a formal description of the autonomous agent. That is "a system situated within and a part of an environment that senses that environment and acts on it, over time, in pursuit of its own agenda and so as to effect what it senses in the future".

Except for the definitions, agents are often described as entities with attributes considered useful in a particular domain. This is the case with intelligent agents, where agents are seen as entities that emulate mental processes or simulate rational behaviour; personal assistant agents, where agents are entities that help users perform a task; mobile agents, where entities that are able to roam networking environments to fulfil their goals; information agents, where agents filter and coherently organize unrelated and scattered data; and autonomous agents, where agents are able to accomplish unsupervised actions. And autonomous agents could be humans, animals, autonomous mobile robots, artificial life creatures, and software agents. Based on the understanding above, agents can be regarded as a new kind of modelling paradigm that allows a closer resemblance to the reality to be modeled (Arend Ligtenberg, et al, 2001). In the world of urban system, urban land use change can be seen as the consequence human agents activities.

A few distinctive characteristics are of major importance for an agent, and they are listed in the following Table 2-1.

Table 2-1 Properties of agents (After Franklin and Graesser, 1997)

Property	**Meaning**
Reactive	Responds in a timely fashion to changes in the environment
Autonomous	Exercises control over its own actions
Goal-oriented/ pro-active/ purpose-ful	Does not simply act in response to the environment
Temporally Continuous	Is a continuously running process
Communicative/ socially able	Communicates with other agents, perhaps including people
Learning/ adaptive	Changes its behavior based on its previous experience
Mobile	Able to transport itself from one machine to another
Flexible	Actions are not scripted
Character	Believable "personality" and emotional state

Although the definitions of an agent are still not the same for many researchers in this field, the importance of studying, modelling, developing, or analyzing the possible interactions between more or less autonomous entities acting in a more or less common environment is very widely recognized. Today, there are many computing systems that cover networks of computers and interact with each other and human beings and, in order to either understand their doing or to develop them to do certain tasks, the concepts from the field— multi-agent systems are needed.

➢ Multi-agent systems

Various definitions from different disciplines have been proposed for the term multi-agent system (MAS). As seen from DAI, a multi-agent system is a loosely coupled network of problem-solver entities that work together to find answers to problems that are beyond the individual capabilities or knowledge of each entity (Durfee, 1989).

So, in a broad sense, including the fields outside computer sciences, many researchers share the definition of multi-agent systems, among whom is Ferrand (1996). He said that multi-agent system can be defined as a set of agents interacting in a common environment, able to modify themselves and their environment.

The first MAS applications appeared in the mid-1980s and increasingly cover a variety of domains, ranging from manufacturing to process control, air traffic control, and information management (K. A. Raju, 1998). Application examples can also be found in domains of technical and medical diagnostics, production planning and supervision, electronic businesses, entertainment systems, etc (Editorial, 1999).

Exploring the studies of a number of researchers, the motivations for the increasing interest in MAS research include the ability of MAS to do the following:

- To enable more than one agent to complete a very large problem
- To allow for the interconnection and interoperation of multiple existing systems or agents
- To provide solutions to problems that can naturally be regarded as a society of autonomous interacting components-agents
- To provide to exchange and share information resources that are spatially distributed
- To enhance performance such as efficiency and reliability

The abilities of MAS mentioned above are for general MAS use and with more emphasis on the settlement of a problem or development for a certain task, while in the field of epistemology (to understand how things work) such as the understanding of land use change, which is a spatial process, we can give further advantages of them:

First, in such complex land use change situations, understanding dynamics in land use should be based on activities of the agents, not just considering about physical conditions. And that is just what MAS enable us to do.

Second, as a part of complex urban system, the multi-agent activities for urban land use change are very complex for just only one or two equations to explain. In this sense, MAS provide strong tools for understanding complex systems with their agents and protocols.

➢ Multi-agent models and multi-agent simulation

Multi-agent models mean systems with multiple agents. But we seldom say multi-agent models, for when MAS is concerned, we often want to not only model a complex system, but also simulate the complex system of reality. Instead we use the term multi-agent simulation. Generally speaking, there are no obvious differences between multi-agent systems and multi-agent simulation and they are always substituted mutually. By utilizing multi-agent simulation rather than multi-agent systems, it is intended to stress the reality-like agent systems, which combine the capacities of visualization and modelling together. Moreover multi-agent simulation usually may be customized to allow researchers the possibility of setting a range of parameters for exploratory purposes.

While cellular models are focused on landscapes and transitions, multi-agent simulation focuses on human actions. And such simulation can be summarized in the following set of elements: agents, objects, behaviours, environments, and communications. They are described with the five items:

< *agents, objects, behaviours, environments, communications* >

Where agents are the set of all the simulated individuals; objects are the set of all represented passive entities that do not react to stimuli (e.g. land, buildings in urban environments); behaviors refer to the activities taken by the agents within the system, and such behaviors maybe toward other agents or objects; environments are the topological space where agents and objects are located, move and act; and communications are the set of all communication categories, such as voice, information interchange. Behaviors are generated through agent interaction or communication with other objects and their environment(s), and can therefore be seen as properties of objects and/or environments.

Given the comprehension of agent, object and environment concepts, the terms “behaviors” and “communication” here are not very clear yet, without which the activities and the relationships between the activities of different agent cannot be explained explicitly. So I will articulate on that issue.

Agents can behave as a self-organization, yet their behaviors affect the behaviors of other agents and are restricted by behaviors of other agents at the same time. To affect each other, the agents can either change the environment through acting on objects within the environment by their actions or restrict certain behaviors of other agents directly. This in turn brings about communications between agents.

Communication is a vital element of MAS, which differentiate MAS from other systems. In general, communication refers to all the interactions between agents (actors), while it has various representations in different systems uses. For example, in a synergic multi-agent system, the communications are mainly exhibited as cooperation. The agents do their best to share information and supply conveniences to other agents. Then in a resource management system, the will of different profit-groups may be conflict sometime and may also be consistent at other occasions. Thus the communications between the agents are manifested in the form of negotiations and compromise.

In terms of communications between agents for understanding multi-agent activities and the consequent functions in residential expansion, what we concern about most is the negotiations between them. When we look residential expansion as a complex system, we should explore the interrelationships between the agents as well as the individual activities, for they contribute to the residential expansion reality as a whole.

2.4.3. MAS/LUCC for modelling residential expansion

Interest in the application of multi-agent models to the study of land change has been growing rapidly in recent years, as more researchers seek to apply increasingly sophisticated models to understand and project the land use dynamics. While when we are taking MAS as a means for understanding land use change, we have already defined MAS to a specific boundary, within which we combine MAS and CA essentially. So we can narrow this model to a more specific one, which aims at understanding or monitoring land use change from the aspect of multi-agent activities. Then in this section, I will have an overview of this kind of models—MAS/LUCC models (Multi-Agent System Models of Land Use and Cover Change) and explain why and how I want to take use of MAS/LUCC for my research of understanding the functions of agents' activities to residential expansion.

- **Introduction of MAS/LUCC models**

As a special class of LUCC models, MAS/LUCC (or called ABM/LUCC) combine two key components into an integrated system. The first component is cellular model that represents the landscape over which actors make decisions. The second component is an agent-based model that describes the decision-making architecture of the key actors in the system under study. These two components are integrated through specification of interdependencies and feedbacks between agents and their environment (Dawn C. Parker, et al, 2002).

For an ABM/LUCC, a shared landscape defined through the cellular model provides a key environment through which agents interact. Land markets, social networks, and resource management institutions may provide other important interaction environments. While agent interactions may lead to recognizably structured outcomes in MAS/LUCC, a set of global equilibrium conditions is not employed in these models, in contrast to modelling techniques such as conventional mathematical programming or econometrics. Thus, multi-agent models offer a high degree of flexibility that allows researchers to account for heterogeneity and interdependencies among agents and their environment. Further, when coupled with a cellular model representing the landscape on which agents act, these models are well suited for explicit representation of spatial processes, spatial interaction, and multi-scale phenomena.

- **Current applications of MAS/LUCC models in urban simulation**

In this section, we briefly discuss recent studies that apply multi-agent systems to study land use/cover change for practical cases. A number of published studies which demonstrate the broad range of applications especially for natural resource management, agricultural economics, archaeology, and urban simulations are demonstrated (Dawn C. Parker, et al, 2002). While here I only want to discuss about the topic of urban simulation.

Torrens (2002) discusses drawbacks of traditional spatial interaction and discrete choice models of urban landscapes, and argues that these drawbacks provide motivation for scholars of urban studies to undertake multi-agent simulations. Drawbacks of traditional models include poor representation of dynamics in urban simulations and poor handling of details in spatial and socioeconomic representations. He also argues that the top-down approach in traditional urban models conflicts with the bottom-up perspective of complex systems.

Torrens argues that a new wave of urban models provides a detailed, decentralized, and dynamic view of urban systems. While most are based on cellular automata, a few MAS and CA-MAS oriented models are being developed. Torrens (2002) himself combines CA and MAS models in an exploratory study. In this study, the geosimulation approach (which reflects the theory of MAS/LUCC) offers a unique perspective that traditional simulation has commonly lacked: a view of urban phenomena and the spatial processes that shape them as a result of the collective dynamics of multiple urban animate and inanimate objects. He also points out that this new kind of models enables spatial interactions and treatment of time.

The second example of application, Arend Ligtenberg and his colleagues propose a land use simulation model that allocates only one type of land use (urbanization) based upon a priori defined spatial claims. The allocation is based upon individual preferences of various actors (reconnaissance actor and planning actor in the current model). These preferences of the individual actors are translated into a new land use configuration through a process of voting and decision-making on possible allocations.

Besides the examples above, there are still others, such as multi-agent simulations of residential dynamics in the city by Benenson, I. (1998); exploratory modelling of land use change scenarios by Pohill et al; exploring the impact of rural household decisions on observed patterns of land use change by Parker et al; testing ideas and hypotheses relating to the processes driving urban growth, its geography, and its sustainability by Torrens. (detailed models of the latter three are available in LUCC Report Series No.6, 2002)

- **Why using MAS/LUCC models**

As discussed above, many well-developed techniques for modelling land-use/cover dynamics exist. However, each of these techniques has some limitations. Equation-based models may require simplifying assumptions to achieve analytical or computational tractability, and they are often based on empirically implausible assumptions regarding static market equilibriums. Moreover, during ecological research and management, many ecologists were realizing the important effects of complex natural phenomena and the limitations of conventional differential equation-based models for dealing with complexities. While cellular modelling techniques offer greater flexibility for representing spatial and temporal dynamics, these dynamics also are based on stationary transition probabilities. Therefore, such models have limited ability to reflect feedbacks in the system under study, as global changes in the system do not influence transitions at the cellular level. Perhaps most significant, none of the above modelling techniques can represent the impacts of autonomous, heterogeneous, and decentralized human decision making on the landscape.

Modelling residential expansion as a consequence of human activities has raised three key points. First, of the host of methods used to model land-use/cover change, dynamic spatial simulation offers a promising degree of flexibility. Second, as noted above, cellular models successfully replicate aspects of ecological and biogeophysical phenomena, but they may not always be suited to modelling decision-making. Third, as explored more fully below, agent-based modelling is a promising means of representing disaggregated decision-making. When all three points are taken together, they suggest the use of a dynamic, spatial simulation-like MAS/LUCC model that consists of two components. The first is a cellular model that represents biogeophysical and ecological aspects of a modeled system. The second is an agent-based model to represent human decision-making. The cellular model is part of the agents' environment, and the agents in turn act on the simulated environment. In this manner, the complex interactions both within agents and between agents and their environment can be simulated.

Therefore, MAS/LUCC models are particularly well suited for representing complex spatial interactions under heterogeneous conditions and for modelling decentralized, autonomous decision-making, Socioeconomic and biophysical complexity. While at the same time, it has limitations in that whether we can meet the challenge of complexity: process-based explanations, spatially explicit models of agent behaviour, representation of socioeconomic-environment lindages, representation of impacts of heterogeneous local conditions on human decisions, etc. they all restrict the resemblance between the model and reality. Therefore, the precision of most MAS/LUCC models implementation is not very high in the time being, although they are theoretically reliable.

- **How to model residential expansion with human activities**

According to the theories of MAS as well as LUCC, modelling residential expansion with human activities by using MAS/LUCC models should include the human behaviours, their interrelationships as well as the relationships between the behaviours and residential expansion, which can be illustrated in Figure 2-7 in the next page.

With the reasoning results of DPSIR framework, we can carry out the cause-effect reasoning work on residential expansion from driving forces to responses (human behaviors of the agents): what factors can contribute to what responses of the agents that will in turn affect residential expansion. This reasoning is the prerequisite of agent behaviour analysis. In the following chapter, I will implement that in study area.

The relationship between DPSIR framework and MAS/LUCC model is illustrated in Figure 2-8 in the next page, which can be regarded as a combined DPSIR-MAS/LUCC model framework.

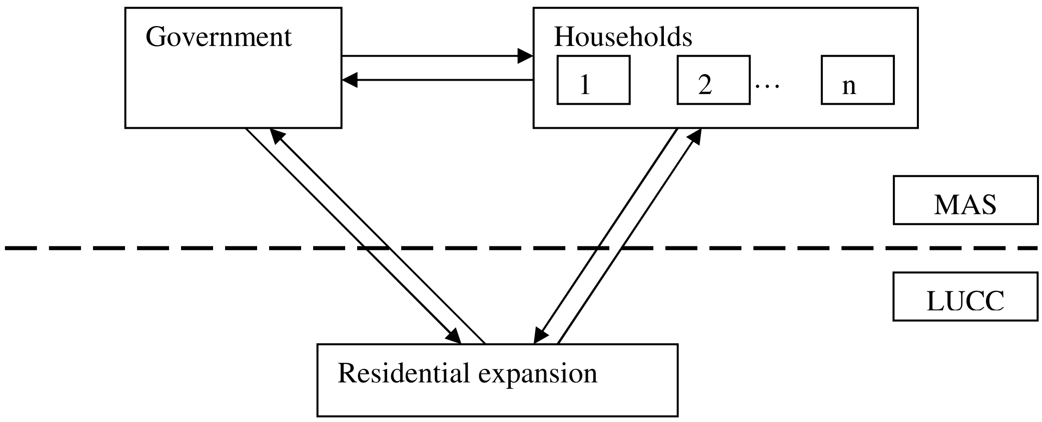


Figure 2-7 Conceptual MAS/LUCC model framework of residential expansion

First are DPSIR frameworks from the aspects of households as well as the government. They comprehend residential expansion with different driving forces (or there are possible shared driving forces), pressures and various resulting impacts and of both spatial-related and non-spatial-related, while they share the same state of residential land use distribution. From this framework, we can get what responses by what agent will take effects on residential land use distribution.

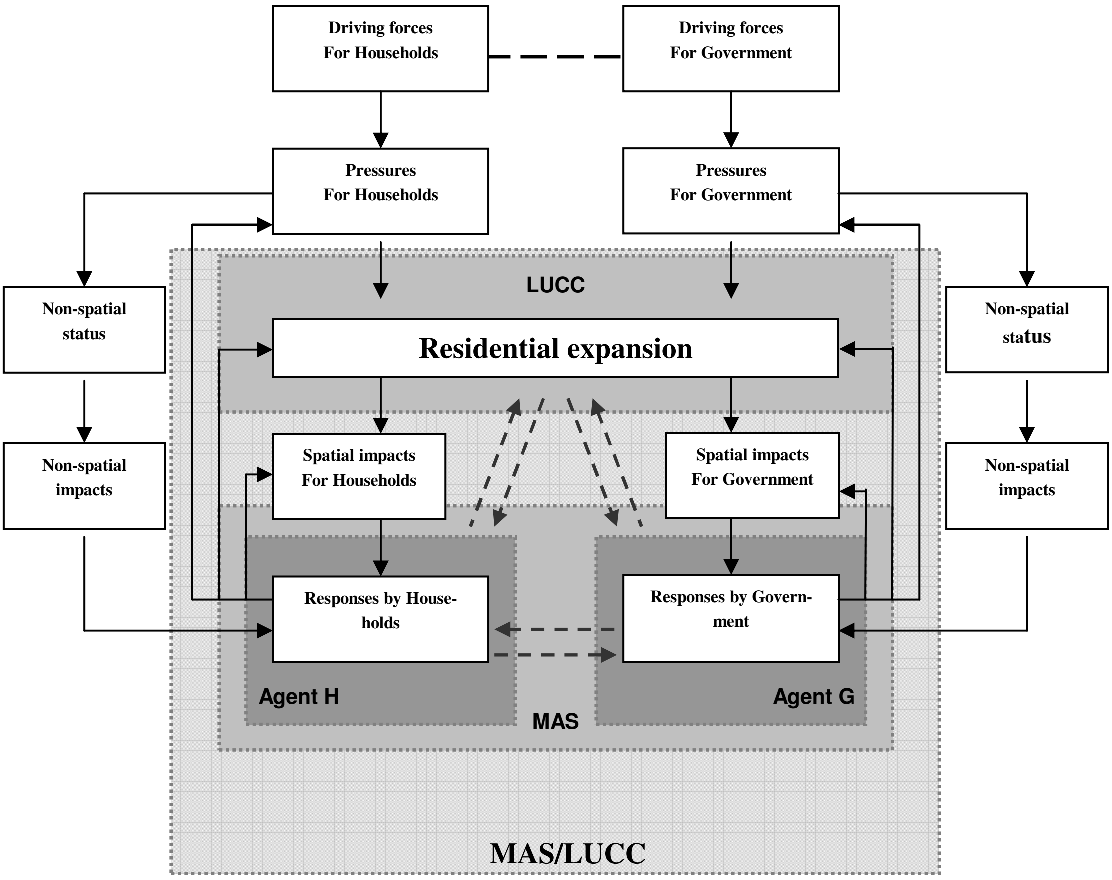


Figure 2-8 Combined DPSIR-MAS/LUCC model framework of residential expansion

Then comes to the interpretation of behaviors and their interrelationship. For in the complex real world, the activities of different agent are affected mutually. That is just the core ideology of MAS. After that, the relationships between human behaviours and residential land use change will be explored, thus to fulfil MAS/LUCC modelling of residential expansion with human behaviours. This modelling will be discussed in the chapter four for study area as a case.

2.5. Summary and conclusion

This chapter deals with research background of my study, which gives theoretical support for understanding residential expansion with human behaviours.

In first part, it is pointed out that residential expansion is a complex spatio-temporal process as a part of complex urban system with various driving forces. Then several main driving forces for residential expansion are put forward. This is the prerequisite for further reasoning.

In second part, DPSIR framework is introduced for analysing residential expansion with human behaviours. As a powerful tool for cause-effects reasoning, DPSIR framework is supposed to be used for analysing residential expansion process from its driving forces, pressures, states, impacts to human reactions that affect the process finally. While as for the complexity of residential growth process and time limit, only two main types of agents are selected for DPSIR reasoning-households and the government. Therefore, with the driving forces got in the first part, the agents set here and the given conditions of study area, this DPSIR reasoning of residential expansion with human behaviours will be implemented in chapter three.

Although DPSIR framework can tell what behaviours will bring what effects to a process, it exhibits deficiencies in that it cannot answer how the residential expansion process is going on in space. Therefore, some other methods should be taken to make up for these disadvantages for further understanding of residential expansion. Then in third part, MAS/LUCC model is advanced for analysing human behaviours with residential expansion. Owning to its strong ability in dealing relationships between multi-agent as well as human behaviours and land use change, it can be a good choice for explaining not only "what" but also "when", "where" and "how" issues of residential expansion process.

This chapter finally arrives at the conclusion finally in this chapter that it is theoretically reasonable to understand the process of residential expansion with the effects of human behaviours by combining DPSIR framework analysis and MAS/LUCC modelling.

3. Analysing residential expansion in study area

3.1. Introduction

Although DPSIR framework and MAS/LUCC method for understanding residential expansion with human behaviors have been put forward in chapter two, how to use these methods in practice still needs to be discussed. In this section, the research practice will begin from analysing the residential expansion in study area during the time period of 1996 ~2002. First, the background of the study area will be introduced with more emphasis on the issues concerning to driving forces of residential expansion process. Then, the DPSIR framework of the study area will be formulated and the activities of the stakeholders that have effects on residential expansion will be find out.

3.2. General overview of the study area

Hongshan District of the Wuhan municipality is chosen as the study area. The Wuhan municipality is the biggest city in central China and the capital of Hubei province with about 4 million urban inhabitants and a total municipal population of 7 million people. The municipality has around 1600 square kilometers built-up areas and another 6400 square kilometers of non built-up areas. As the Beijing-Guangzhou railway and the Yangtze-river (the third largest river in the world) cross here, Wuhan has become one the key transportation nodes in China. The geographical location and importance is similar with that of Chicago in US, so Wuhan got a nickname: Eastern Chicago. Meanwhile Wuhan is characterized with abundant water resource. Since not only two big rivers (Yangtze river and Han river) intersect here but also many different sized lakes locate in the city. So Wuhan also has another nickname “water city” as shown in Figure 3-1.

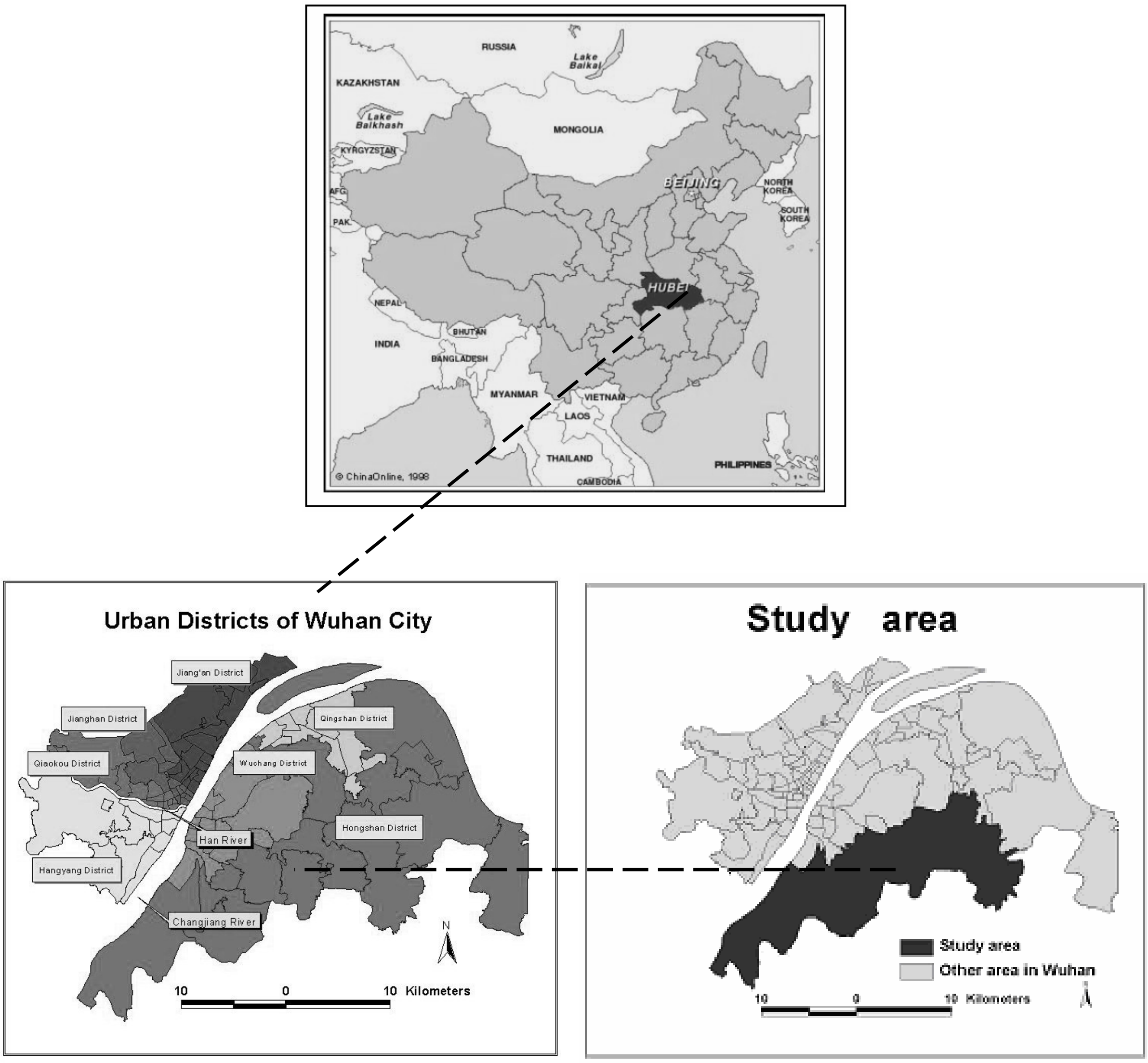
Within the area of the city zone, Wuhan is divided into three parts (Wuchang, Hankou and Hanyang) by two rivers (Yangtze river and Han river), and is subdivided into seven districts (Wuchang District, Qingshan District, Hongshan District in Wuchang, Qiaokou District, Jianghan District and Jiang’an District in Hankou, and Hangyang District in Hangyang).

Hongshan District is the second largest domestic scientific, educational and intellectual concentrated area. It has 23 universities and colleges, 56 state-level scientific research units, 10 important state laboratories and 4 state technology centres. It is thus eulogized as “silicon valley in central China” and “The second ZhongguanCun” by home and abroad. Optical valley is situated here. It has also been recognized as one of the first “Comfortably off Districts/Counties” in out province.

Hongshan District consists of 6 streets[7] and 8 townships and it is a typical administrative district where there are both urban and rural areas. In this study, I set may study area within the area of Hong-

[7] Street is the smallest administrative region in china that is just under the level of district.

shan District, but not the same as the boundary of it. To be exact, my study area is made up of 5 streets (Zhang Jiawan street, Hongqi street, Shi Zishan street, Luonan street, Guanshan street) and 3 townships (Jiufeng township, Hongshan township, Qingling township) with the area of 236 square kilometres.



Map 3-1 Study area

3.2.1. Study area scope set

Lying in eastern part of Wuhan city, Hongshan hems in the two districts of Wuchang and Qing shan from east to west. In geographical form, the three districts seem to have close relationships. But why I choose Hongshan as the study area while excluding the other two in that China is undergoing a rapid residential expansion that happens in urban fringes such as Hongshan at the stage of accelerating urbanization. As for Wuchang District, which is an inner district of Wuhan, the accommodation of growing population is through the increase of residential density. And as for Qingshan District, which is an industrial district of Wuhan, the residential expansion follows urban planning well, and the households have not much room for residential choices.

Another issue cannot be neglected is whether I should take the whole area of Hongshan or just a portion of it as the study area. As a typical administrative district where there are both urban and rural areas, Hongshan covers an area of 509 square kilometres which takes up 58% of the areas in the whole city zone, and much area of Hongshan is made up of cropland which is so far away from urban built-up areas for developing into residential land within my study period of time, because residential expansion as well as population mobility in China tends to be short-distanced spreading (see chapter 2.2.3), and another support is the land use actuality map of 2002. So I choose five streets and three townships[8] of them that have large areas of urban built-up areas or have possibility for developing into built-up areas.

3.2.2. Residential expansion in study area

The time period I choose to study the residential expansion is from 1996 and 2002, so the residential expansion reality of those two times should be reviewed before analyzing the causes-effects relations of that change. Map 3-2 and Table 3-1 gives the spatial distribution and the quantity of residential expansion in the study area between 1996 and 2002.

Table 3-1 Residential land use change in study area (1996~2002)

Year	Residential Areas (Ha)	Increase from 96 to 02 (Ha)	Residential converts to other land use types (Ha)	Residential expansion (areas of other land uses convert to residential)
1996	710	169	416	585
2002	879			
96&02	294			

From the data in the table and residential land use distribution in 1996 and 2002, we know that residential land in 1996 in study area is 710 hectares, in 2002 is 879, and those residential land of 1996 have not be converted to other land uses till 2002[9] is 294 hectares. And several conclusions can be drawn:

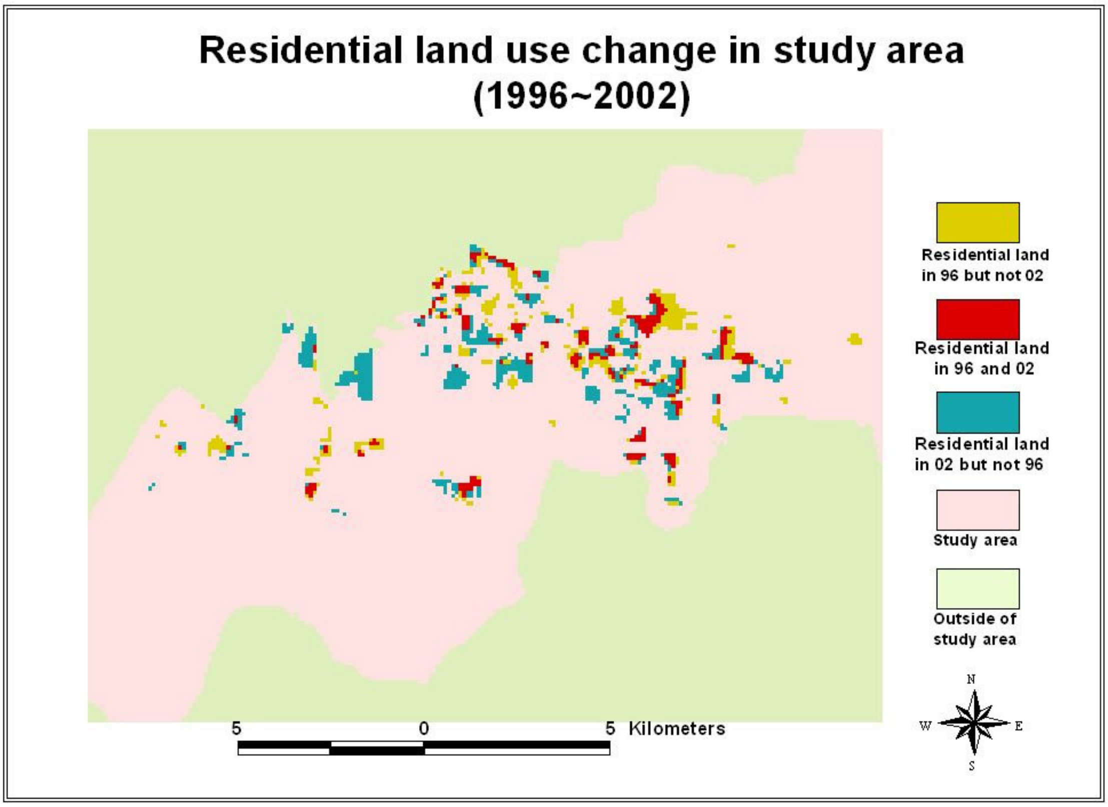
- Residential land use has changed much, although the growth in quantity is not obvious.
- As far as residential expansion is concerned, what we concern about is the newly increased residential land (residential land in 2002 but in 1996, it is not for residential use) as shown in blue color in the map, which cover total area of 585 hectares.

3.2.3. Prerequisite understanding study area for DPSIR analysing

According to the understanding of DPSIR framework as well as driving forces of residential expansion, analysing possible driving forces of residential expansion in study area is the prerequisite for DPSIR analysing about residential expansion in study area. Then the driving forces are discussed.

[8] Why I choose administrative area as the study area lies in two aspects: first is to conform to statistical units, which determines data collection; second is that some behaviours of the government are taken within the boundary of its administrative area, such as decisions of location choices.

[9] In China nowadays, due to the fast urban development, a lot of residential land in inner city has been converted for commercial uses or green spaces for better urban environment.



Map 3-2 Residential land use change in study area

➢ Social issues on study area

In social aspect, first is population growth. The population growth is illustrated in Figure 3-1:

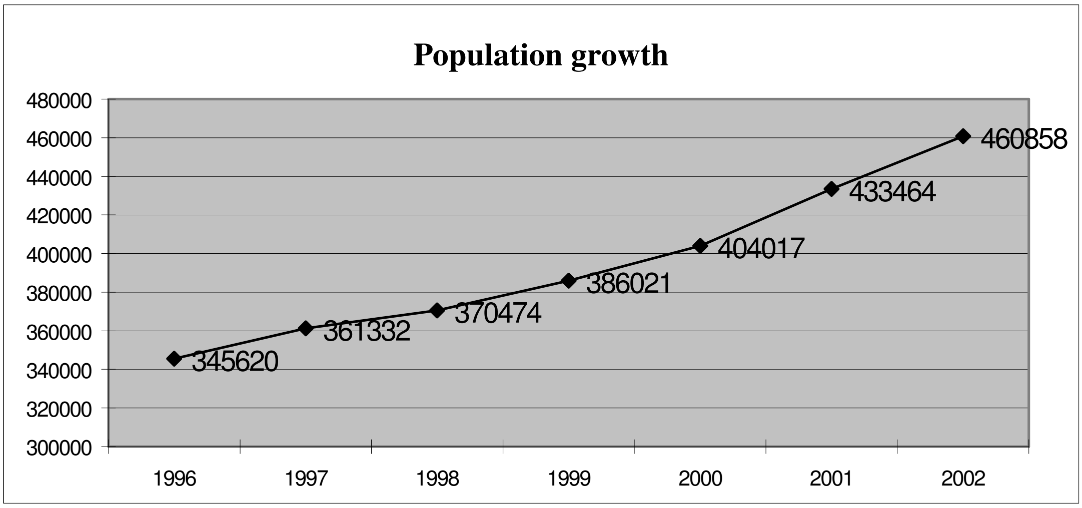


Figure 3-1 Population growth

From the population growth data, we see that the population growth rapidly after year 1997.

Then as for social development composed of the improvement of people's living qualities and the civilization development of the whole society. As for living quality, the qualities of environment and houses of residential district are becoming better and better. Besides, with the civilization development of the whole society, when people buy houses, they put more emphasis on natural and cultural environment except the qualities of houses themselves nowadays than in 1990s.

- **Economic issues on study area**

In the aspect of economic issues, first is the development of market economy. It has brought about two effects on the study area: first is the more rapid economic development than that in planned economy times; second is the more active and vivid market that allows multi-investment and multi-ways of urban construction which is the supply side of residences.

Second are economic issues including higher households incomes and economical segregation as shown in Figure 3-2 and Figure 3-3[10].

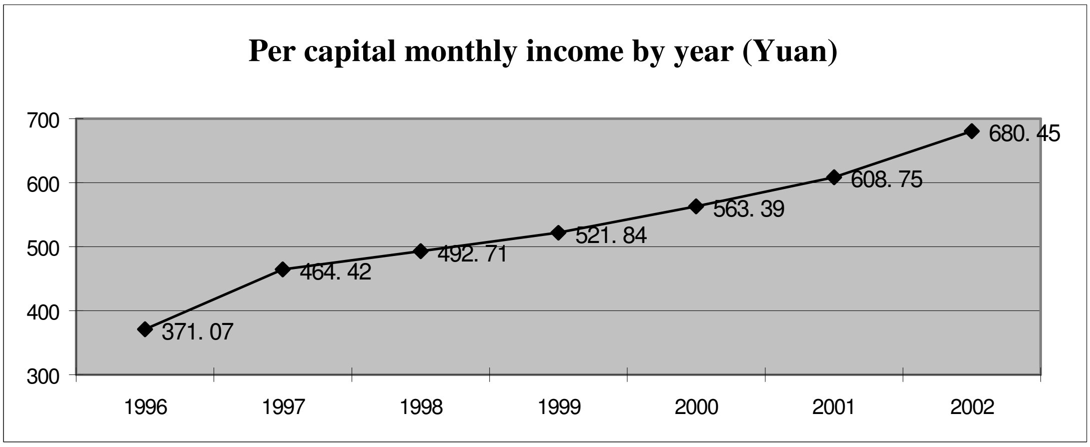


Figure 3-2 Per capital monthly income by year (source: Wuhan statistics bureau)

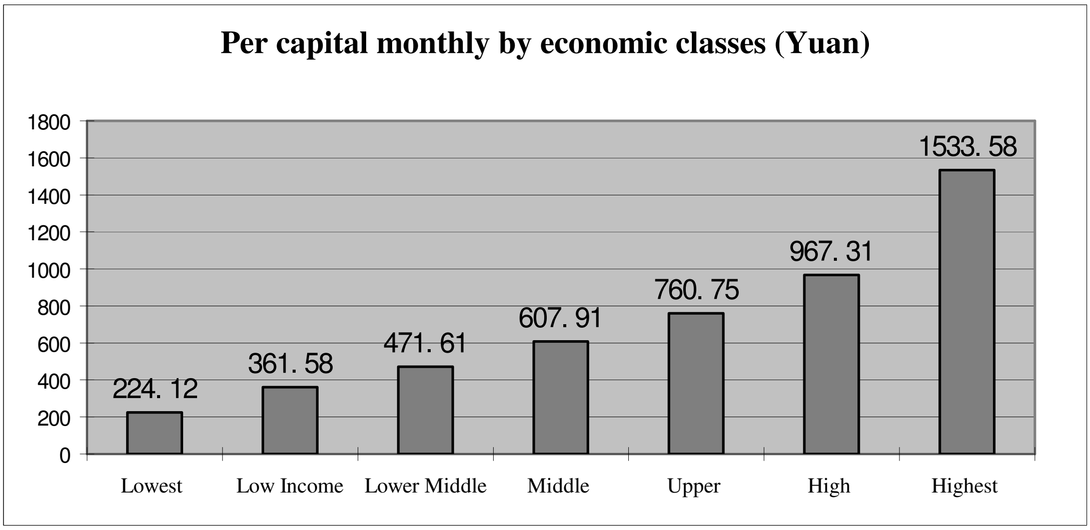


Figure 3-3 Per capital monthly by economic classes (source: Wuhan statistics bureau)

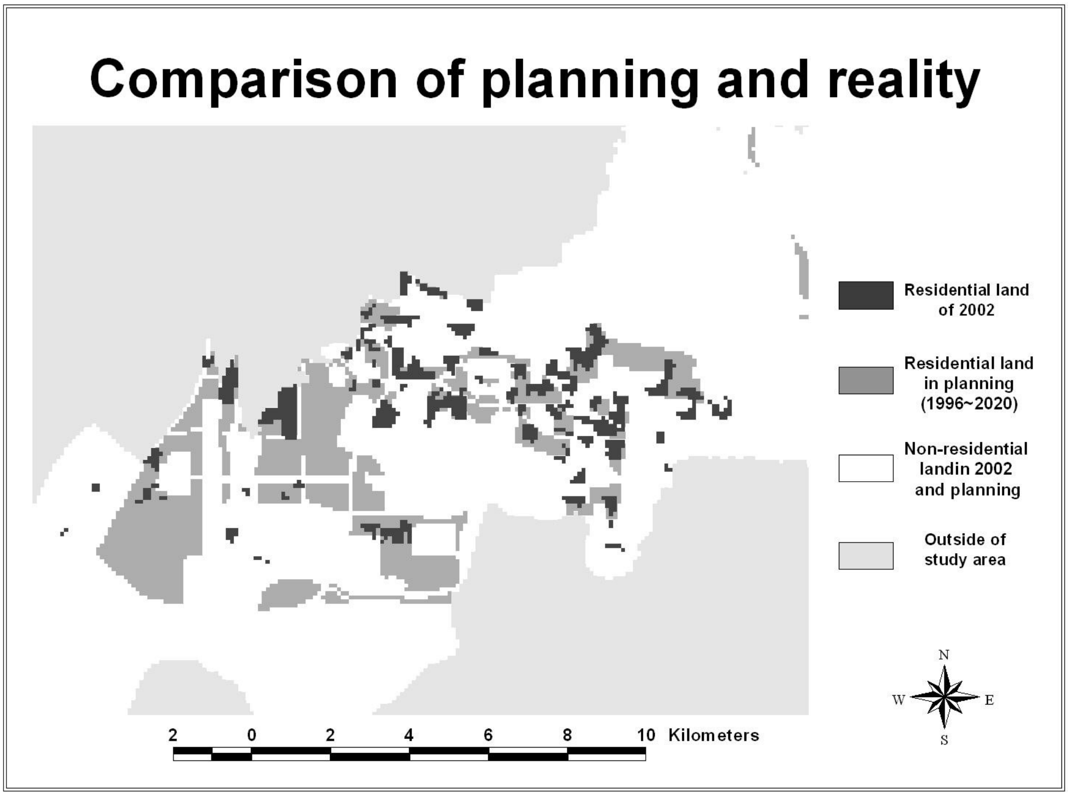
[10] For the data limit, the data is the statistical results of Wuhan as a whole, not specifically in study area.

From the income growth and segregation in the study area, we can see there is obvious household income increase from 1996 to 2002, which enables most households to take part in real-eastate market to choose their houses. Then the differentiations of their income conditions cause different choices of residential location. And with the development of market economy, it becomes possible for the households to realize their location choices.

- **Political issues on study area**

As far as political issues are concerned, first is urban master planning and implementation. Wuhan master planning (1996~2020) works as the guidance for residential expansion. In general, all the land development should conform to the planning. While as for the long time of implementation, there are conditions that the planning does not supply the needs of urban development reality. Therefore, urban master planning changes a little during the implementing years. As for residential expansion, according to the comparison of master planning (1996~2020) and its development reality (Map 3-4), some areas have developed into residential land while in planning it has been planned as other land uses. So, the government still gives certain probabilities for accepting residential construction in place it has planned as other land uses.

Then as for policies for real-estate market development, it in fact is not only a policy taken in study area, but all over China. These policies comprise land usufruct transfer, housing system reforms. These policies take effects in 1990s cancelled welfare housing policy[11] and at the same time entitle households with choices of their own residential locations.



Map 3-3 Comparison of planning and reality

[11] Before housing system reform, urban dwellers in China mostly live in houses distributed by their units or organization. And they have no choices of residential locations.

3.3. Analysing residential expansion with DPSIR framework in study area

As is known in previous chapter, DPSIR framework exhibits strong abilities in logically analysis. In the following, the framework is taken for analyzing residential expansion in study area. Then according to driving forces of residential land in China discussed in chapter two, residential expansion process is analyzed in this chapter from the aspects of households and the government. And the purpose of this analyzing is to get an idea of what behaviors of the two agents will contribute to residential expansion. Then as for the detailed behaviors as well as their interactions, they will be discussed in the next chapter.

3.3.1. DPSIR analysis from the aspect of government

The following figure shows DPSIR framework for analysing residential expansion from the aspect of government. (Figure 3-4 in the next page). In this study, the government is simplified as one agent with "one voice". That is to say, although in reality, the government is made up of a hierarchical structure, and different branches always have different opinion towards the same thing. And they discuss, negotiate until finally arrive at the result of "one voice". Therefore, in this research, we only consider about their final opinion.

From the aspect of the government, three driving forces are put forward: population growth, social development and development of market economy. On one hand, with the population growth, it becomes difficult for the actual residential land to accommodate all the people, which results in residential expansion. Then residential expansion has some impacts: urban sprawl, urban sprawl, environment economy, people are putting more emphasis on life quality and have more freedom to choose residential location by themselves. These all take pressures on urban master planning, which in turn cause differentiations between planning and reality. This has the impact of urban development out of control. To alleviate these impacts, the government have some responses:

- Urban master planning (marked with ***A*** in the Figure 3-4)
- Examine and approval of residential land development proposal (marked with ***B, F*** in Figure 3-4)
- Residential environment and traffic conditions improvement (marked with ***C*** in Figure 3-4)
- Policies and decisions of new areas development and city centre reconstruction (marked with ***D*** in Figure 3-4)
- Economic policies on land price as well as the incomes of households (marked with ***E*** in Figure 3-4)

3.3.2. DPSIR analysing from the aspect of households

The following figure shows DPSIR framework for analysing residential expansion from the aspect of households. (Figure 3-5)

From the aspect of households, the driving forces comprise of four items: development of market economy, policy for real-estate market development, urban master planning and population growth.

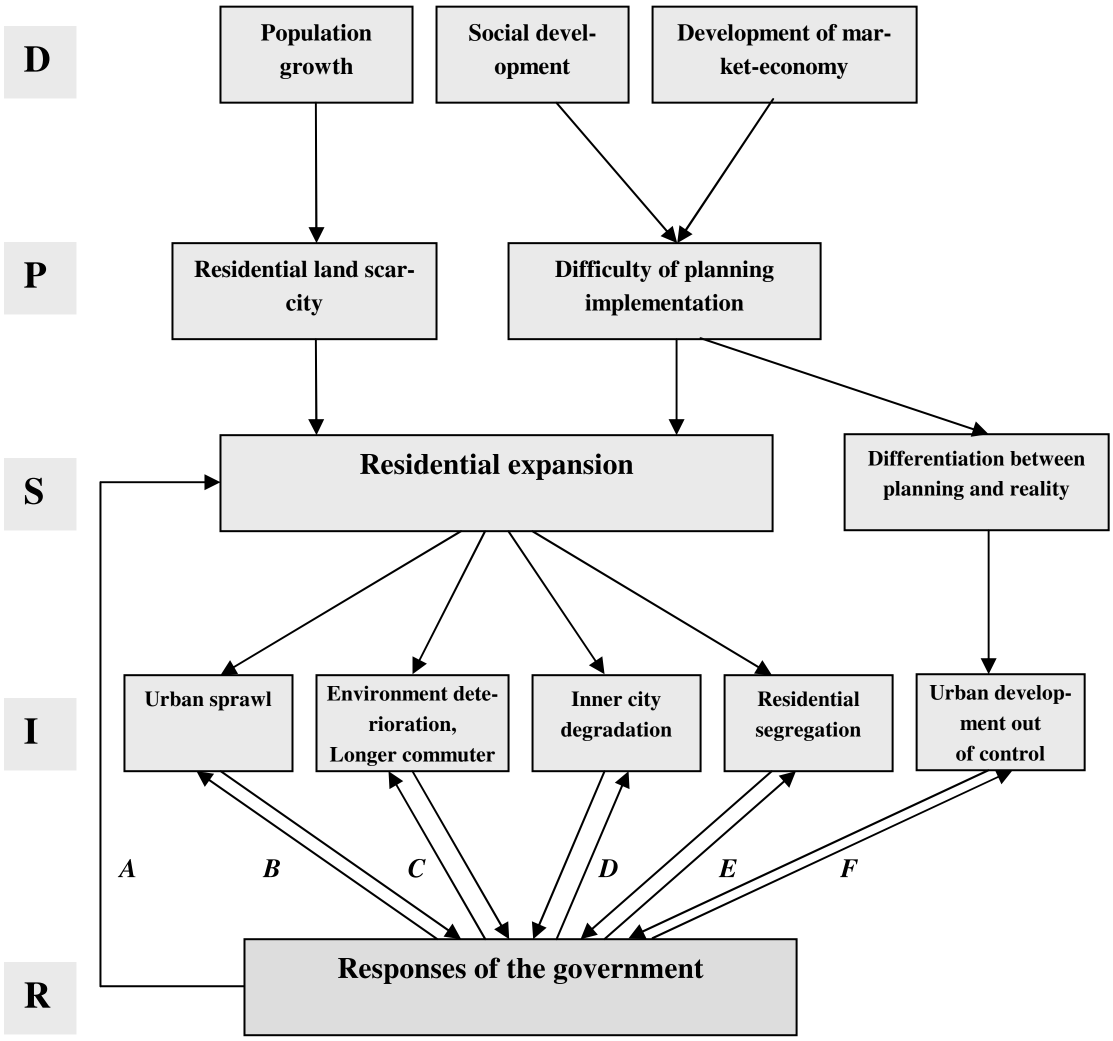


Figure 3-4 DPSIR analysis from the aspect of government

The development of market economy brings about income change to most people; while at the same time induces economic segregation. That means, different households will have different residential location choices according to their different economic properties (marked with ***A*** in Figure 3-5).

Second is policy for real-estate market development, although China is under the development of market economy after the reforms and opening-up policy in 1979, the beginning of housing becoming a commodity is from the first half of 1990s, before which urban dwellers are mostly live in welfare houses distributed by their institutions and establishment. Owning to the policy, the houses and land usufruct are traded as commodities and people thus have the right and chance to purchase the houses they like in the real-estate market. This results in the effects of location choices of households on residential expansion. (marked with ***B*** in Figure 3-5)

Third is urban master planning. Once the master planning of a city is established and ratified by higher-up government, it has the effectiveness of policy. While during the planning implementation, several changes can be made by the government to adapt to the development of the society, while as for individuals and households, they can give location choice proposals, but the proposals should conform to the decisions of the government. (marked with ***C*** in Figure 3-5)

Fourth is population growth, although its resulting pressures, states are the same as that for government, while the impacts are different. From the aspect of households, what they see are environment deterioration and longer commuter. Then they might take moving decisions as responses. (marked with ***D, E*** in Figure 3-5)

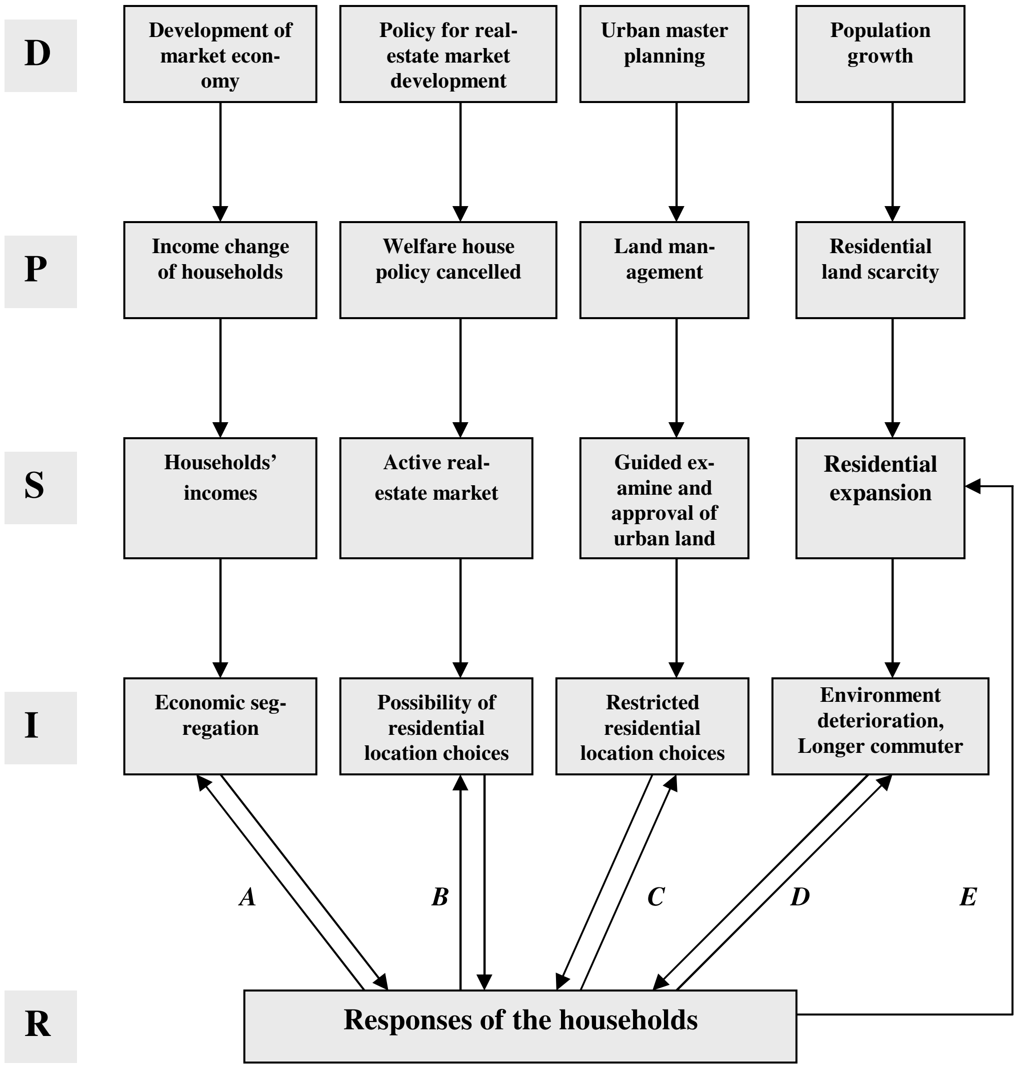


Figure 3-5 DPSIR analysing from the aspect of households

3.4. Discussions and conclusion

This chapter has overviewed the study area. It then analyses residential expansion from the aspects of both the government and households with DPSIR framework. From the analysing process, we find out that:

Above all, the two agents think differently about the same process. That is to say, the government and households comprehend residential expansion by different driving forces; and even the state of residential expansion is the same, their feeling of its impacts is different. Besides, they see various states and impacts during residential expansion, which have effects on responses and in turn the responses of the agents will affect residential expansion. And these are the verifications and applications of conceptual DPSIR framework in chapter 2.3.3.

Then, although analysing with limited agents and driving forces, we see complex relationships between residential expansion and human behaviours. When we consider the responses of the two agents together, we meet with even more difficulties: there are interactions between their responses, and sometimes the response of one agent is the driving force for the other. For example, urban master planning and implementation is the response of the government towards urban development control; while it is at the same time the driving force of residential expansion in the understanding of households, and it will thus affect the final location choices of households. Therefore, although analysing the effects on residential expansion of certain behaviour is possible, it is unwise for us to attempt studying residential expansion further by combining these two DPSIR frameworks. Because what we get is only a mess of interlaced relationships, from which we cannot attain logical understanding.

Furthermore, even DPSIR framework does well in theoretical analysis, it is not easy linked to spatio-temporal complexity as what the residential expansion process needs. That is to say, it cannot tell when, where and how does a action take place. Taking residential location choice of households as the instance: we have known it contribute to residential expansion process, but what do the households think when they choose a residential location? How they choose? And when? Such questions cannot be answered by DPSIR model.

Finally, we arrive at the conclusion in the end of this chapter: from DPSIR framework, we have known what activities the government and households take that can affect residential expansion; while as for the interrelationships between their behaviours as well as between behaviours and land use change, it needs interpreting by other effective methods. That is what chapter four will deal with.

4. Conceptual MAS/LUCC modelling of residential expansion in study area

4.1. Introduction

Based on the analysis the combined theoretical model of MAS/LUCC and DPSIR formed in the end of chapter two and the outcome of DPSIR analysing of residential expansion in study area in chapter three, this chapter aims at constructing the MAS/LUCC modelling of residential expansion in the study area. The modelling follows such procedures as marked in the following figure (Figure 4-1):

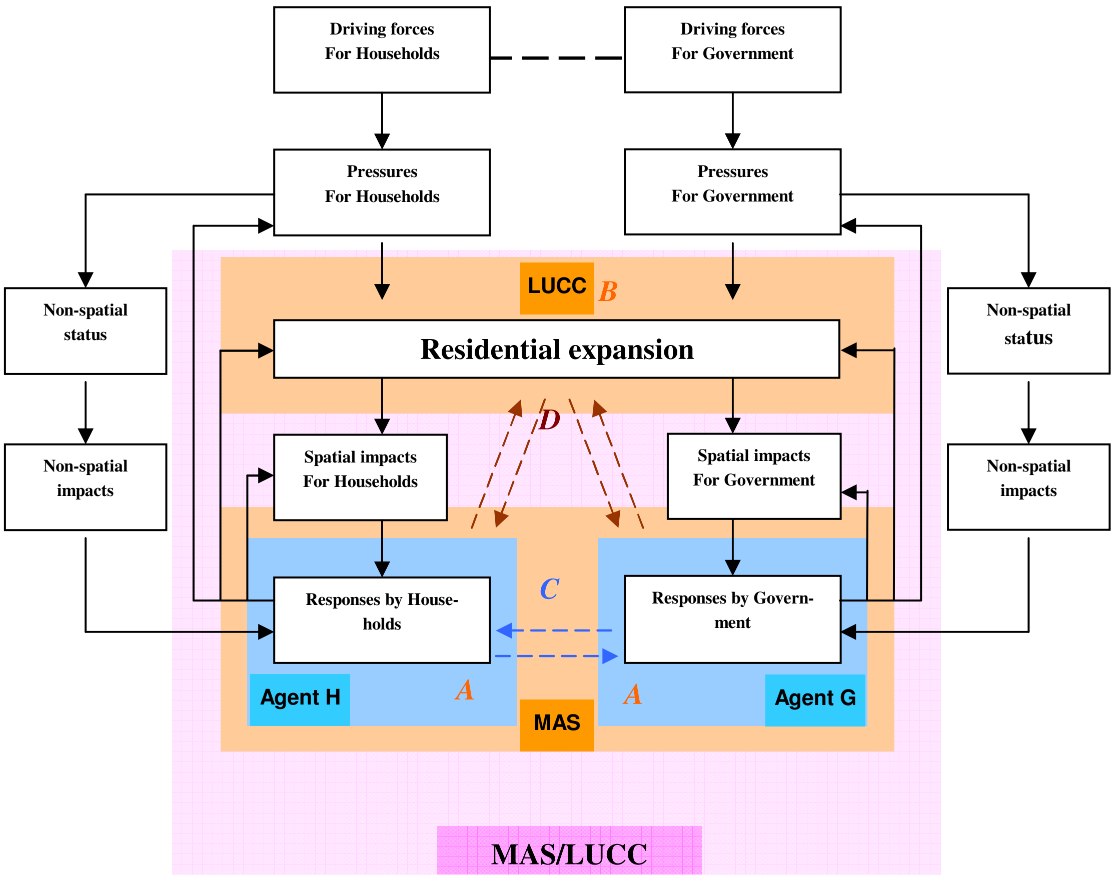


Figure 4-1 MAS/LUCC modelling structure

Where number ***ABCD*** illustrates the modelling sequence:

First is in chapter 4.2 (marked with ***A*** in the above figure), the two types of agents concerning to residential expansion will be modelled with their properties. Second is in chapter 4.3 (marked with ***B*** in the above figure), residential expansion (the LUCC part of MAS/LUCC model) will be discussed for modelling, including land properties, spatial presentation of residential expansion and temporal representation of residential expansion. Third is in 4.4 (marked with ***C*** in the above figure), the behaviours of the agents (the MAS part of MAS/LUCC model) will be modelled as well as the interactions between households and the government, and interrelationships within households. Fourth is in 4.5(marked with ***D*** in the above figure), the interactions between multi-agents behaviours and residential expansion are modelled and thus to integrate MAS/LUCC model of residential expansion.

4.2. Agents

According to DPSIR analysing in chapter three, two main kinds of agents during residential expansion are considered: households and the government.

4.2.1. Households

This type of agents is made up of a large number of discrete agents with different properties. While as for residential expansion which means the increased residential lands towards urban fringes, the households here refer to the candidate households that interested in those newly development residential lands.

Therefore, the households can be expressed as:

$$H = \{H_1, H_2, H_3, \ldots, H_m\} \qquad (4.1)$$

Here ***H*** means the set of all the candidate households, and it is the set of ***m*** discrete households with different economic, social and psychological properties illustrated in the Table 4-1.

Table 4-1 The properties of the households

Economic properties	Household income (I)	
Social properties	Household structure	*Number per household (Nh)*
		Number of children (Nc)
	Job	*Number of people who have income (Ni)*
		Occupations (cultural properties) (O)
		Working place (W)
	Traffic means (T)	
Psychological properties	Household preferences to land properties (P)	

Then a given household H_i is presented as:

$$H_i\,(I_i, Nh_i, Nc_i, Ni_i, O_i, W_i, T_i, P_i) \qquad \forall i \in \{1,2,\ldots,m\} \qquad (4.2)$$

Every property above can be further divided into several classes. For example, as for household income, it comprises the classes of high-income, mid-income and low-income.

4.2.2. Government

As a simple agent with “one voice” not like households agents, the properties of the government (***G***) are not so complex as those of households.

Although only one agent, it can take complex behaviours to react to residential expansion, which have the decisive effects on residential expansion.

4.3. Residential expansion: MAS part of MAS/LUCC model

As for LUCC part of MAS/LUCC, it refers to residential expansion in this study. The modelling work is carried out in two aspects: land itself and spatio-temporal representation of residential expansion.

4.3.1. Land

A piece of land differentiates with others by its position, state and properties. In this sense, a given piece of land L_i can be expressed as:

$$L_i\,(Po_i,\ S_i,\ P_i\ (p_1,\ p_2,\ \ldots,\ p_n)) \qquad (4.3)$$

Where Po_i stands for position of land i. S_i stands for state of land; as for residential expansion, it refers to residential or non-residential state. $P_i\ (p_1,\ p_2,\ \ldots,\ p_n)$ stands for those properties of land i that the agents take into consideration when act on residential expansion process.

4.3.2. Spatial and temporal representation

Although land pieces have been modelled, there are other two main issues on LUCC modelling: spatial representation and temporal representation of residential expansion. The former deals with the representation of residential land in space: how can we define discrete land pieces from continuous land? The latter deals with the representation of residential land use change (refers to residential expansion in this study) process: how can we tell the happening of residential expansion in discrete time sequences?

- **Residential land: spatial representation**

Many different spatial elements exist which are relevant to residential expansion process. They are:

- ***Land parcels***

Land is owned on a parcel by parcel basis, but parcel also are not immutable, and even in today's world of reasonably well developed GIS database, working with parcel-level data can be an extraordinarily frustrating and difficult task due to incomplete/inconsistent information, etc.

- ***Zones***

Zones provide a stable, consistent spatial representation, and much of the data we use in constructing even disaggregated models inevitably comes in zone-based formats from sources such as the census. But, the arbitrary spatial aggregations of zones introduce aggregation bias (the aggregation based on different or arbitrary standards by various purposes such as traffic census) into models which use them as their unit of analysis.

- ***Grid cells***

Grid cells provide a stable representation of space, are generally computationally more efficient to work with than zone. And, if defined on a sufficiently fine scale, will largely avoid aggregation bias problem. On the other hand, they are a very artificial construct and their use can lead to and overly abstracted representation of space and spatial processes. And as the grid size goes to small, the spatial representation becomes more continuous.

Therefore, in this model, space is represented by grid cells. One of the principal benefits of this approach is uniformity in treatment that requires very little information about the land system data while still working at very detailed level. It is thereby possible in a practical sense to establish a representation that is very close to continuous that allows appropriate aggregate behaviour to emerge.

- **Residential expansion: temporal representation**

Agent-based approach is taken for temporal representation of residential expansion. In this approach, all decisions for each agent are processed before moving to the next agent. The processing order in which the agents of a given type (e.g. different households) are processed could be random or sequential. An illustration of this approach is as follows: when a household is selected, the properties of the household are generated, followed by the residential location choice of this household, then the government evaluates the choice proposal and decides whether to accept or not, if yes, the residential land properties are updated. Once the process has finished, the simulation moves to the next household.

4.4. Agent decision process: MAS part of MAS/LUCC model

The most important and complex issue of MAS/LUCC model is the MAS part which refers to the behaviors of the agents concerned and their relationships. According to DPSIR reasoning in chapter three, the behaviors of the agents consist of the following actions:

- ***Households:***
  - Residential location choices
  - Moving choices

- ***Government:***
- Urban master planning
- Examine and approval of residential land development proposal
- Policies and decisions of new areas development and city centre reconstruction
- Economic policies on land price as well as the incomes of households
- Residential environment and traffic conditions improvement
- Then in the following, behaviours of households and the government will be articulated and modelled as well as their interactions.

4.4.1. Behaviours of households

- **Residential location choices of households**

From the analysis above, households, as a kind of agents, take residential location choices in residential expansion. This behaviour can be explained by taking discrete choice analysis.

Discrete choice analysis provides the theory and methods to model individual choice from a set of mutually exclusive and collectively exhaustive alternatives and to investigate aggregate demand from disaggregate data. Discrete choice analysis employs the principle of utility maximization, i.e., a decision maker is modelled as selecting the alternative with the highest utility among those available at the time a choice is made. And the analysis is commonly taken by discrete choice model (Xu, 1999). He points out that every alternative is associated with the following utility index:

$$U_{ik} = U\,(Z_{ik}, S_k) \qquad \forall i \in \{1,2, \ldots, n\} \qquad (4.4)$$

Where U_{ik} is the utility of a decision-maker i making choice k (all the unoccupied land cells make up the choice set); Z_{ik} is a vector of the attribute values for alternative k as viewed by decision maker i such as transport time, and cost, and S_k is a vector of socioeconomic characteristics of the decision maker i such as age, income, and education.

When discrete choice models function in a fashion that resembles spatial interaction models, they are actually concerned with spatial choice. The most widely used manifestation of the discrete choice model in urban simulation is the random utility model. (Torrens, 2000)

Random utility models proceed on a number of assumptions. The first assumption specifies that each decision-maker (refers to those will take residential location choosing decisions) is faced with a decision set of choice alternatives—a choice is either made or not made. The second assumes that an individual (or a group of individuals) will settle upon one decision from a larger set of available options in such a way that the most utility, or satisfaction, is yielded. Conceptualising this in an urban sense, we might think that a household makes a location decision amongst a set of given locations that a city offers, so that a combination of utilities is maximized. Finally in random utility models is that choices are made in a probabilistic fashion—decision-makers have a likelihood of making certain choices.

Mathematically, we can build up a formula for the random utility model based on these assumptions. The notion of utility maximization can be expressed as:

$$U_{ik} > U_{ij} \qquad \forall k \neq j, j = 1,\ldots,n \qquad (4.5)$$

Where U_{ik} is the utility of a decision-maker i making choice k; U_{ij} is the utility of a decision-maker i making choice j; and $\forall k \neq j, j = 1,\ldots,n$ asserts that j stands for all choices other than k. Simply then, the above formula establishes a framework for a decision to be chosen from a set of alternatives. (Torrens, 2000a)

Introducing the idea of probabilistic decision-making develops the random utility formula further:

$$P_{ik} = P_r \lfloor U_{ik} > U_{ij} \rfloor \qquad \forall k \neq j, j = 1,\ldots,n \qquad (4.6)$$

Where P_{ik} is the probability of a decision-maker i choosing alternative k; and P_r is a probabilistic expression. This assigns likelihood to various choices from a set of alternatives.

In some applications of discrete choice models (Cheng, 2003; Torrens, 2000), they conclude that the most common derivative of the random utility model is the multinomial logit model. And this logit model can be expressed in a linear way as:

$$U_{ik} = b_{1i}x_{1k} + b_{2i}x_{2k} + \ldots + b_{mi}x_{mk} \qquad (4.7)$$

$$U_{ij} = b_{1i}x_{1j} + b_{2i}x_{2j} + \ldots + b_{mi}x_{mj} \qquad \forall k \neq j, j = 1,\ldots,n \qquad (4.8)$$

Where $x_1, x_2,..., x_m$ are those variable that contribute to decision-making; $x_{1k}, x_{2k},..., x_{mk}$ are values of those variable that contribute to choosing k; $x_{1j}, x_{2j},..., x_{mj}$ refer to values of those variable that contribute to choosing j. The parameters $b_{1i}, b_{2i},..., b_{mi}$ are the regression coefficients to be estimated.

To apply this utility model, $x_k, x_2,..., x_m$ should be set first. As for residential location decision-making, Torrens (2000) used three theories to explain the rationales underlying urban residential locations: bid-rent theory, travel cost minimization theory, and travel cost and housing cost trade-off theory.

First and the most fundamental theory is *bid-rent theory*. Residential demand for accessibility tends to be very complicated, depending on the utility of certain locations and even of particular sites expressed in terms of:

- Travel time and costs related to distance from work, shops, schools, entertainment, cultural activities and recreational facilities; and
- non-monetary considerations such as space, fresh air, peace and quiet, locational prestige, neighbours and family ties.

Since both these aspects of residential utility come within our definition of accessibility—the advantages of particular locations in terms of movement and convenience—we can use the bid-rent-curve technique to analyse the main factors which determine residential location. Once again we start from the basic simplifying assumption that accessibility to work, shops, and so on involves distance to the CBD. But the non-monetary considerations mentions mentioned above have an additional influence on households as they seek to maximise utility in deciding where to live. Though accessibility to the CBD is important, there is a pull the suburbs, not only on account of the lower rent, but because accessibility to more house-space and better natural environment.

Expressing the household location decisions of two households in a monocentric city in a bid-rent framework generates bid-rent curves such as those displayed in Figure 4-2.

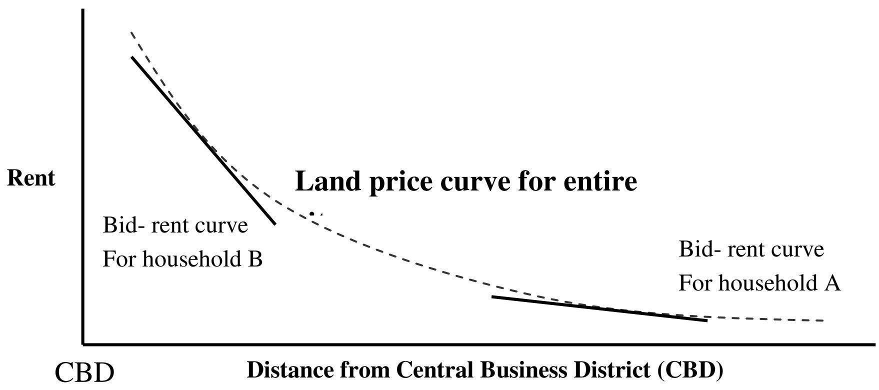


Figure 4-2 Diagram illustrating a residential bid-rent curve for a monocentric city

As shown in the figure, when seeking out a location, each household pursues a location on the bid-rent-curve where the land price curve touches the bid-rent-curve nearest the origin. The shape of a household's bid-rent curve is dependent upon their particular situation (tastes, income, etc.) for example, a young family, a rich family (household A) will generally require space and good environment. Its bid-rent-curve is likely to be relatively flat as a result (implying that a household is more likely to locate in the suburbs). On the other hand, single people, the elderly, and the wage-earned family (household B), are likely to have steeper bid-rent-curves, and may favour locations closer to the CBD.

Travel cost minimization theory assumes that the only consideration in the residential location decision is that households select locations that reduce their need to travel. If we consider a city with jobs located in a central core, this implies that the most sought after locations would be close to the CBD, while the less popular areas would be concentrated on the urban fringe. Socio-economically, this would suggest concentrations of wealthy households in the central city, with poorer households towards the urban periphery. In reality, the cost of travel is not the only residential location factor affecting the decisions of households. Nevertheless, travel cost minimization theory does have some relevance to household location (particularly through the notion of accessibility).

Travel cost and housing cost trade-off theory assume that households trade off the competing influence of housing cost and travel cost in making their residential location decision. This implies, in geographic terms, that land values will be higher close to a central business district and lower towards the periphery. While this is largely true in practice, there are many complicating factors, both economic and non-economic. High-income households may not have to trade off housing cost against travel cost, because they may be able to afford both. People who can afford to live close to the CBD may elect not to because they wish to enjoy the amenities on offer in the suburbs. Because of the dearth of available space in central cities, outer areas generally offer a wider range of opportunities of the construction of new houses. Also, transportation innovations may make outer location more accessible to a CBD rather than inner suburban areas.

Then in the following, some studies of practises are reviewed to explore specific variables of choosing criteria: $\boldsymbol{x_1, x_2, \ldots, x_m}$.

In the study of Du Debin's (1997), he concluded that the conditions of traffic, commerce, culture, medical treatment, environment quality, public security and the social structures of the households all contribute to the evaluation when households choose their residential locations. Wu Yongxiang and Wu Fang (2001) described properties of residential location from three layers of human needs: the first is for human basic need, which includes traffic, sanitation and basic services; the second is for comfortable living, which mainly includes environment conditions; and the third is for human development, which consists of cultural, educational and physical infrastructure conditions. In practice side, K. A. Raju, et al. (1998) have taken properties of accessibility including travel time by private modes and public transport availability for simulation of residential location choices.

An investigation was carried out by Li Tieli (1997) for analyzing housing locational decision behaviour in Beijing, which reflected the general conditions in Chinese big cities. He learned that residential location was a very important factor only second to housing area that people consider about when choosing their houses, and 40 percent of the interviewed households think residential location is vital.

To sum up the theoretical and practical analysis above, we can arrive at the conclusion that land price, traffic accessibility and residential environment (both natural environment and social environment) are all main contributors to residential location choice-making. Then the variable of $x_1, x_2, ..., x_m$ defined as land price, traffic conditions and residential environment conditions.

After setting the variables of $x_1, x_2, ..., x_m$, logit regression is needed for setting values of $b_{1i}, b_{2i}, ..., b_{mi}$. But in this study, these values will be given directly by behaviours analysis and experiences instead of logistic regression method, because in the nature of MAS/LUCC model, households are regarded as discrete agents that take the location choosing decisions separately, and differentiations exist in different choices by different types of households. What we want to know is not the aggregate demand of households from disaggregate choices, but the outcome of aggregate multi-agent behaviours on residential expansion. And during that process, the separate choices of households in micro scale might have different effects on other agents' behaviours. Therefore, a further exploration of different discrete choices is needed.

In fact, with formula ***4.4*** and ***4.7***, we get:

$$U(Z_{ik}, S_k) = b_{1i}x_{1k} + b_{2i}x_{2k} + \dots + b_{mi}x_{mk} \qquad \forall i \in \{1,2, \dots, n\} \qquad (4.9)$$

From the implecation of random utility model shown as formula 4.6, we have already know that $x_k, x_2, ..., x_m$ stand for choice properties that decision-makers take into consideration when making decisions, $b_{1i}, b_{2i}, ..., b_{mi}$ demonstrate the preferences to different factors ($x_1, x_2, ..., x_m$) by agent i. Therefore, $b_{1i}, b_{2i}, ..., b_{mi}$ are determined by the properties of households. And this relationship can be expressed by a theoretical formula:

$$(b_{1i}, b_{2i}, ..., b_{mi}) = f\,(\textit{Properties of households, Properties of residential location}) \qquad (4.10)$$

In fact, some researchers have already explored the relationship by practical studies. Li Tieli (1997) studied the different preferences by different households classes: he divided the households by their different properties of occupation, income, household structure and personal preference. Because the properties of households are complex, the numbers of the classes can be of large amount, he concluded the classes into several typical ones: salaried nuclear households, the aged households, young-coupled households. Then he came to the conclusion that although different households had different choices, the households of same classes tend to share similar choices.

Du Debin (1997) is another researcher who has taken research to analyse the residential location tendency of different household classes based on the distribution of residents. In his study, he first divided the study area of CMAs (Montreal census metropolitan area in Canada) into five zones: central business district, the inner city, mature suburbs, new suburbs, and exurbia. Then, with a combined method of quantitative analysis and qualitative analysis, the relationship had been examined between location behaviour of households and the spatial distribution of housing and the factors of location. The properties of the households he took into account include household' structure, income and education. The results showed that households of middle income and middle achieved education level and with children ended to reside in urban outer areas; the young single, the childless couple and the aged with both lower and higher income and education level tended to choose urban central areas to live in, the movers within urban areas predominantly move to the outer areas. Therefore, he further pointed out that the differentiations of their tendencies accounts for the different choices by different people.

Joseph S. Desalvo, et al. (1996) had put emphasis on the interrelationship between income and residential location. K. A. Raju, et al. (1998) and some other researchers also share the opinion that relationships exit between the properties of households and those of the land.

From the above, we know that there are direct relationships between properties of households and land locations. As for the location choosing decisions, same classes of households tend to choose similar location for living. This conclusion enables us to analyse choices of households by properties. Because there are several households properties that concerned with the choices, which are too complicated to be articulated here. Therefore in the following modelling, only the economic properties of households will be taken into consideration. The general rule is like this: given the same cultural properties, high-income households tend to live in place of better environment, without much consideration about the traffic and price properties; middle-income households put more emphasis on traffic and price properties; and low-income ones concern about price most.

Together with the discussions of residential location properties that households consider when choosing locations, formula ***4.11*** can be further expressed as:

$$(b_{1i}, b_{2i}, \ldots, b_{mi}) = f\,(\textit{Economic properties of households, land price, traffic conditions and residential environment conditions}) \qquad (4.11)$$

Traffic conditions refer to traffic accessibilities that are evaluated by distance to main roads, distance to city centre, and so on. Environment conditions include both natural and cultural environment, which refer to distance to green spaces, lakes and facilities, and so on.To decide U_{ik} in formula ***4.7*** for household ***i***, a simplified formula based on the analysis above is made as:

$$U_{ik} = P_{iprice} * V_{ikprice} + P_{itraffic} * V_{iktraffic} + P_{ienvironment} * V_{ikenvironment} \qquad (4.12)$$

Where P_{iprice} is the value of b_{1i}, which stands for the preference to land price by household ***i***, $V_{ikprice}$ is the value of x_{1k}; $P_{itraffic}$ is the value of b_{2i}, which stands for the preference to land price by household ***i***, $V_{iktraffic}$ is the value of x_{2k}; and P_{iprice} is the value of b_{3i}, which stands for the preference to land price by household ***i***, $V_{ikenvironment}$ is the value of x_{3k}.

As for $V_{ikprice}$, $V_{iktraffic}$ and $V_{ikenvironment}$, they present actual conditions of land choice ***k***, while as for P_{iprice}, $P_{itraffic}$ and $P_{ienvironment}$, households of the same economic class share the same preference values in this formula, which can be demonstrated by the following table:

Household class	P_{price}	$P_{traffic}$	$P_{environment}$
High-income households			
Mid-income households			
Low-income households			

Table 4-2 Preferences of households

In general, a household will choose the land with the biggest utility value, which means the choice ***k*** by household ***i*** should conforms to:

$$P_{iprice} * V_{ikprice} + P_{itraffic} * V_{iktraffic} + P_{ienvironment} * V_{ikenvironment} >= P_{iprice} * V_{ijprice} + P_{itraffic} * V_{ijtraffic} + P_{ienvironment} * V_{ijenvironment} \quad \forall k \neq j, j = 1,\ldots,n \quad (4.13)$$

➢ **Moving choices of households**

Except for location choices, moving is another vital behaviour taken by households. Kamhon Kan (1999) got the results from his study that household heterogeneity is significant for residential mobility. Then with examination empirically using data from the Panel Study of Income Dynamics, Kamhon Kan (2002) investigated the relationship between job changes and residential mobility. He argued that a job change might be prompted by reasons unrelated to factors associated with housing consumption. However, a job change might lead to an adjustment to housing consumption, i.e., residential relocation. Jos van Ommeren, et al. (1999) and Santiago M. Pinto (2002) also have got similar conclusions.

The studies above are the description of mobility phenomenon and its characteristics. While as for its nature, Benenson has studied on that. After the location choosing decision of a certain household, or after he has occupied a certain land, another problem would arise—the location of a household will affect the properties of the chosen land and land around it to some extent. He further explained this opinion by studying the changing of economic and cultural properties of land locations, including the cultural environment properties such as the extent of heterogeneity. This will affect the value of U_i of the current residented land by a household ***i***, because it changes the properties of the land which is the consideration factors that contribute to the value of U_{ik}. While as for job changes, it changes traffic preference values of the household, thus to affect value of U_{ik}.

Furthermore, the households can evolve which means the properties of household can change as well. When the gap between U_{ik} and any other available land (U_{ij}) exceeds a certain threshold, the household may have an allocation decision—moving to another land with bigger U_i. On this issue, Benenson (1998) use *trade-off between migration alnd changes in an individual's economic status* to explain the moving behaviour[12].

So the moving decision can be expressed as:

$$Moving = f(U_{ik}, U_{ij}) \quad \forall k \neq j, j \in \{1,2, \ldots, n\} \quad (4.14)$$

And it happens under the condition that U_{ik} is too low to endure (For example, when it is lower than a certain threshold), and the household has lived in this land for at least a certain time periond. This can be expressed as following:

[12] Beneson argued that if, in spite of high economic tension, an agent remains at its current location, the tension continues to increase. However, this tension can be occasionally resolved by the agent leaving the current residential land.

$$(U_{ij} - U_{ik}) > Th_g \ \& \ T_{ik} > Th_t \qquad \forall k \neq j, j \in \{1,2, \ldots, n\} \quad (4.15)$$

Th_g means the threshold of minimum utility gap to endure; T_{ik} means the time period that household I has lived in land k, and Th_t represents the minimum time threshold of living in a place.

Th_g and Th_t are the given parameter by a certain household. In fact, different households will give different values of Th_g and Th_t, because they differ in their notions of endurances between ideal and current status.

The above are the two behaviours (residential location choices and moving) that got from DPSIR model. In the following, behaviours of the government will be discussed.

4.4.2. Behaviours of the government

Although a single agent with no complex properties, the government manifests complex behaviours in terms with residential expansion. And they will be articulated as follows.

- **Urban master planning**

Urban master planning making is the most fundamental and powerful action that the government takes when intervening residential expansion process. Parts of the contents of urban master planning are *"land use layout for urban construction, functional division and overall arrangement of various constructions, …, and a short term construction program"* (The city planning act of the P.R. China, chapter one). That means, this planning sets the distribution of different types of land use as a whole for the future several decades (20 years in general). The plan has force adeffect indeed and everybody should not act inconsistently with the will of this planning randomly. In this way, urban master planning can be regarded as the guidance of land growth, including residential expansion.

But because the time period is too long to direct rationally the detailed land development under the condition of rapid economic development and more and more self-determinacy of residential location choices by households and land agents, the urban master planning is amended to adapt to urban development. Therefore, the planning implementation management becomes very important.

In general, the implementation management of the government takes effects by two means: active implementation management and passive implementation management. The former refers to policies and decisions of new areas development and city centre reconstruction that the government invests directly or by raising funds, while sharing the common points of deciding the residential location directly, this is discussed in section4.4.2.2. The latter refers to examination an approval of residential location choice proposals by the households, which is examine and approval of residential land development discussed in section4.4.2.3.

- **Policies and decisions of new areas development and city centre reconstruction**

These two policies and decisions are taken for urban development purposes and for accommodating the residential needs of households as well.

As for new area development, it happens often by direct investment of the government at first. There are two forms of this new developed areas: first is only for residential land use, which is aiming at alleviating the high population density of inner city, and second is for industry development. As for the latter, although the purpose of the government is not for residential expansion, the increased job chances attract people to those areas not only for work but also for living. Then as for city centre reconstruction, the government take this action for urban centre renaissance. The occasion the government choose for city centre reconstruction is concerned with the urban economic conditions and the degradation extent of the city centre.

- **Examine and approval of residential land**

In this model, the government behaves like this: after a certain household (or a households group) has made its choice of residential location, the government will decide to accept or not by referring to urban master plan and considering about the actual urban development as well. In this model, the decision is made according to the acceptance probability P_a. And the value of is set basically by comparing to the land use planning map (a outcome of urban master planning) and considering about strategies and regulations of land development. Therefore, the acceptance probability can be modelled as:

$$P_{aik} = f\,(P_{planning\,j},\ SR_{\{1,\,s2,\,\ldots,\ m\}}) \qquad \forall i \in \{1,2,\ \ldots,\ n\} \qquad (4.16)$$

P_{aik} here refers to acceptance probability of residential location choosing proposal of land k by household i, $P_{planning\,j}$ refers to the general acceptance probabilities of a certain land use type j by referring to land use planning map. For example, the government generally gives higher probabilities to accept a residential proposal in locations of residential land use as planned than locations that they have planned for green space. $SR_{\{1,\,s2,\,\ldots,\ m\}}$ refers to land development strategies and regulations including items such as urban development direction controlling, basic cropland and waters protection, and urban expansion form and scope controlling. For the former two items, the chinese local government will have lower $P_{planning}$ for specific land parcels that are in the opposite direction of urban development direction as planned in urban master planning or those parcels are protected for agricultural use and waters use. While as for urban expansion form and scope controlling, the government always restrict that by prescribing the minimum distance from candidate residential land to built-up areas, especially residential land or the minimum residential land areas within the neighbourhood area of the candidate land parcel. And it can be expressed in a formula:

$$N_{r(m)} >= (m * 2 + 1)^2 * Th_r \qquad (4.17)$$

Where $N_{r(m)}$stands for the number of residential land within distance m of the candidate land parcel, and Th_r means the given minimum threashold value.

- **Economic policies on land price as well as the incomes of households**

Economic policies on land price refer to policies of pricing residential land by the government. These policies are aiming at decreasing land speculation and controlling land development, and what the government regulate is to control the highest and lowest land prices in different areas.

As for other economic policies on the incomes of households, they comprise welfare policies for increasing incomes of low-income households and narrowing down the incomes gap between the rich and the poor, this might in turn change the preferences towards land price when choosing residential locations.

- **Residential environment and traffic conditions improvement**

The aim of residential environment and traffic conditions improvement action taken by the government is for better urban development as a whole. While as for the process of residential expansion, it is for pushing residential development in specific places. For instance, if a certain area is planned for residential land use while after several years, not many people are willing to live there for poor residential environment and traffic conditions, the government will probably to improve those conditions for attracting more people. Such actions can be shown as:

$$I_e = I_{(e1,\ e2,\ \ldots,\ en)} \qquad (4.18)$$

$$I_t = I_{(t1,\ t2,\ \ldots,\ tmn)} \qquad (4.19)$$

Where I_e and I_t stand for the environment and traffic improvements actions by the government, which are the results of improvements of different environment and traffic vectors ***e1, e2 ,.., en; t1, t2, …, tm***.

4.4.3. Multi-agent interactions between the government and households

After separated analysis of agents behaviours, then the interactions between these agents should be explored while taking multi-agent decisions as a whole. The interactions can be interpreted from the following aspects shown in Table 4-3.

- **Interactions between urban master planning and residential location choices**

As for the planning decision, it is taken by the government directly, while it is really a restriction for households choices. In general, the households in China have few possibilities to change the planning decisions. But during the planning implementation years, there are still some changes of planning.

	Behaviour of Government	Behaviour of Households
Interactions	Urban master planning	Residential location choices
	Examine and approval of residential land development proposal	Residential location choices
	Policies and decisions of new areas development and city centre reconstruction	Residential location choices and moving choices
	Residential environment and traffic conditions improvement	Residential location choices and moving choices
	Economic policies on land price as well as the incomes of households	Residential location choices and moving choices

Table 4-3 Multi-agent interactions between the government and households

- **Interactions between examine and approval of residential land development proposal and residential location choices**

The interactions between the two types of agents here are very important, which is a kind of negotiations[13].

First, the government gives a certain acceptance probabilities to different types of land other than residential land that planned in urban master planning, while not just setting those probabilities as zero. These existing probabilities are the results of long-time negotiations between the two types of agents. If a probability value of green spaces is 2%, that means, among 100 times of residential land location proposal in the places that have been planned for green spaces use, the government will accept two of them.

Second, after examining a residential land development proposal, if the government accepts it to be residential land, the acceptance probability of next evaluation in places around this land will increase, because it is more likely for the government to accept residential land to be developed around newly-developed residential land. The outcome of this interaction is expressed as:

$$P_{planning\,jk}' = P_{planning\,jk} + \Delta P \qquad k = 1, 2, \ldots, [(m * 2 + 1)^2 - 1] \qquad (4.20)$$

Where $P_{planning\,jk}'$ means the acceptance probability by the government after it has accepted a proposal in place k that was planned to be land use j in urban master planning after referring to urban master planning, and $P_{planning\,jk}$ is the probability of that before acceptance; ΔP is the variable that reflects this increase; and m is the affecting distance within which the preference will change.

And if the government refuses the proposal by a certain household, the household has to make another proposal that with the second highest value of attractiveness; this process goes on until the government accept a location choice proposal and the household is assigned to a certain land cell.

- **Interactions between urban renewal policies and households behaviours**

Although it has been addressed in 4.4.2.2 that the actions of new areas development and city centre reconstruction (the two as a whole are called urban renewal) are complex, what is more, when it comes to their interactions with residential location choices and moving choices, the condition becomes more difficult to interpret. In fact, the two actions take place synchronously together with residential mobility as well, because the three have relationships. With the city centre reconstruction, the original residential land in city centre is less likely for residential use in the future for the economic reasons, and the residential land use change of the study area has shown this character. Then the households there moved out for new area for living. Except for the common chances of residential location choices as other house-hunters, the government often take new residential areas development actions to accommodate the housing needs of these emigrants. Also we can start from new areas development, whether it is residential areas or others, it will surely has a certain degree of attractions for households moving into that area, which in turn accelerates the reconstruction of city centre and development of new areas.

[13] Negotiation is seen as a method for coordination and conflict resolution. Negotiation has also been used as a metaphor for communication of plan changes, task allocation, or centralized resolution of constraint violations (Katia P. Sycara, 1998).

Such policies and decisions of new areas development and city centre reconstruction affect residential expansion and land use conversions as well, and they are too complicated to be expressed by simple mathematical formulas, and sometimes they happen just randomly and abruptly. Only after further analysis of this behaviour, can this modelling be accomplished successfully.

- **Interactions between residential environment and traffic conditions improvement and residential location choices and moving choices**

In 4.4.2.5, the actions of impoving environment and traffic conditions (I_e and I_t) have been discussed. Because these improvements throw added values (ΔU_k) to utilities residential land k (U_k) for those households that care much for traffic and environment conditions, thus to affect the residential location choices of households.

This is the condition for new developed areas. While as for built-up residential areas, the improvements of environment there will affect the moving choices of households. One of the conditions of moving mentioned previously is that: $(U_{ij} - U_{ik}) > Th_g$. Taking U_{ij} as static one, and then the increased utility ($U_{ik} + \Delta U_{ik}$) for household i will make the moving possibility smaller.

- **Interactions between economic policies on land price as well as the incomes of households and residential location choices as well as moving choices**

As for land price policies, they affect residential location choices of households in much the similar way as that of environment and traffic condition changes. While the difference is that land price change is two-way change, which means it can be increased and decreased (controlled by government policy), the new utility ($U_{ik} \pm \Delta U_{ik}$) will affect the moving choices of household i by changing the moving probabilities to higher or lower. At the same time, the location choices of households affect pricing policies. For example, if a certain land areas are mainly for commercial development in urban master planning, while many households argue for residential development in their choosing proposal. then the government might set high land use price to restrict the choices of households.

As for other economic policies for increasing incomes of low-income households and narrowing down the incomes gap between the rich and the poor, it affects the properties of households (P_{iprice}, $P_{itraffic}$ and $P_{ienvironment}$) first, thus to bring changes to utility value of choosing location k (U_k), in turn to affect location choices and moving choices of households.

4.4.4. Multi-agent interactions within households

Because households can be regarded as discrete agents within themselves, interactions are not only take place between different types of agents (the government and households) but also within households.

As for agent-based approach in time representation, the households' location choices are taken one by one randomly. And the choice of former household will causes restriction for the choices of latter households in that each location cannot be occupied twice.

The second interaction is that after the former chooses a certain location, this will change the properties of this location and its neighbours, which in turn affects the choices of the households following it.

The third interaction is the peer pressure. When a household chooses a certain location, the others will make consider about its choice and their own as well. What they choose will have interactions mutually, and the moving choices as well.

4.5. Agents and space: integrating MAS and LUCC

What have discussed above are MAS and LUCC parts of MAS/LUCC model separately. This part is for the exploration of relationship between human behaviors and land use change.

As shown in DPSIR analysing and from the analysis of multi-agent behaviours above, we know that not all the behaviours of contribute to residential expansion directly, because some behaviors are taking use as the affecting factors for behaviours of other agents, which in turn can change residential land use.
And this is shown in Table 4-4 with respect to the behaviours of the government and households:

Table 4-4 Behaviours that contribute to residential expansion

	Households	***Government***
Direct-effect Behaviors	• Residential location choices • Moving choices	• Examine and approval of residential land development proposal • Policies and decisions of new areas development and city centre reconstruction
Indirect-effect Behaviors		• Urban master planning • Economic policies on land price as well as the incomes of households • Residential environment and traffic conditions improvement

4.5.1. Direct effects of human behaviours on residential expansion

Then the interactions between MAS and LUCC (human behaviours and residential expansion) are articulated in the following. The direct effect comprises:

- Policies and decisions of new areas development and city centre reconstruction by the government changes residential land use expansion directly undoubtedly.

- The interactions of residential location choices of the households and examine and approval of residential land development proposal by the government contribute to residential expansion directly as discussed in 4.4.3.2 in that they decide on new residential land location.

Besides, the behaviours have another effects on residential land after the household has occupied that chosen land parcel if accepted: bring about changes to neighbourhood environment, which in turn might affect residential location choices of other households. Bonaiuto (2003) has explored the relationship between households and their neighbourhood of residence in the urban environment. This is a typical research of environment psychology (EP) (Lawrence, 2002) that has focused on the relationship between people and their residential environment on different levels (home, neighbourhood and city). In his study, he took many indicators of people feeling and arrived at the conclusion that some are positive-sense items indicating presence of environmental quality and negative-sense items indicating absence of environmental quality. Among the positive-sense items in neighbourhood scale are public facilities accessibility, outdoor sports and relaxation, people communications and corporations, etc. And for negative ones, they are concerned with feelings of lack of privacy, annoyance by gossip, being controlled by others and overcrowding.

Generally speaking, better facilities and infrastructure conditions lie in places with bigger scale of residential land. Thus with more households living around, those positive items are easier to attain. While as for the negative ones, this model only consider about the condition that residential density is not high as in the urban peripherals, so these items are not very important. Therefore, in this model, after a household has occupied a land parcel, $V_{environment}$ of other location choices within a certain neighbourhood will increase.

With the improvement of environment conditions, there is change in land price within the neighbourhood. In fact, amenities and other neighborhood factors have been utilized to explain the changes of urban land price in a number of studies. In the study of Asabere (1985), he uses scaled dummy variables to capture the land price change brought about by of varying degrees of neighborhood quality. The improvement of environment and change in land price can be expressed as the following:

$$V_{environment\,jk}' = V_{environment\,jk} + \Delta V_{environment} \qquad k = 1, 2, \ldots, [(m * 2 + 1)^2 - 1] \qquad (4.21)$$

$$V_{price\,jk}' = V_{price\,jk} + \Delta V_{price} \qquad k = 1, 2, \ldots, [(m * 2 + 1)^2 - 1] \qquad (4.22)$$

Where $V_{environment\,jk}'$ means the value of environment conditions of place k within distance m of the newly occupied residential land parcel after occupation, and $V_{environment\,jk}$ is the value before occupation; $\Delta V_{environment}$ is the variable that reflects environment improvement; and m is the affecting distance within which the preference will change. As for land price, the condition is similar.

- Moving choices bring change to current residential land use distribution (residential land converted to other land uses. While as for residential expansion, moving choices take effect together with residential location choices.

4.5.2. Indirect effects of human behaviours on residential expansion

The interactions mentioned above are direct. While as for indirect interactions, they consist of the following items:

- Urban master planning takes effects as a decisive factor for examining and approval of residential land development proposal.

- Economic policies on land price affect the preferences of the households, the change of households incomes affect the preferences of location choices by households. Residential environment and traffic conditions improvement affect location choices of households by changing values of land environment and traffic properties.

4.5.3. Integrated MAS/LUCC model for residential expansion

Sum up the analysis and modelling of human behaviours and residential expansion in this chapter, an integrated MAS/LUCC model for residential expansion is formed and expressed by the Figure 4-3 in the next page:

This figure shows the elements and relationships within MAS/LUCC models of residential expansion, and it is also the integrated presentation of what have been discussed above. As for LUCC side above the dashed line, there is residential expansion with land properties (land price, environment and traffic conditions) and land use state (residential or non-residential). While as for MAS side below the dashed line, there are two types of agents considered: households and the government. The listed items are their behaviours summarized in DPSIR framework in previous chapter. The arrows between the two agents refer to their interactions, and the arrows between LUCC and MAS elements refer to the interrelationships between agents and residential expansion. One-way arrow means one element has effects on the other, while two-way arrow means they have interactions mutually.

4.6. Conclusion and discussions

This chapter mainly discusses the components of MAS/LUCC model of residential expansion in study area for further understanding of behaviours on residential expansion. It first discusses on the LUCC part, which refers to residential expansion. And then explains the MAS part, including the behaviours of households and the government and their interrelationships. At last, the interrelationships between the agents and residential expansion are explored.

As the achievement of this chapter, an integrated MAS/LUCC model is formed for modelling residential expansion with the effects of human behaviours in a structured way. Therefore, it comes to the conclusion that it is not only methodological sound but also applicably proper to understand residential expansion by MAS/LUCC modelling with the prerequisite analysis by DPSIR framework.

However, this MAS/LUCC model still has some problems:

- When considering the properties of the model elements (households, government and land cells), not all the properties but only the main properties are considered. While in fact, every property will contribute to the behaviours effects. In this way, the model is the simplification of reality.

- As for a model for representing complex human behaviours, there are sometimes uncertain factors. For example, during master planning process, the government sometimes accept residential location choosing proposal in place that they have planned for other land use before. But what is the probability? There are only two ways in my study to solve such dilemma, first is to get an idea from experience and reality, and second is to calibrate the model by comparison to residential expansion reality. Another example is the behaviours of residential location choices and moving choices. These behaviours are indeed very complex, because the decision-makings sometimes take place not out of rational thinking. To analyse such behaviours, literature review and investigation data are looked into for formulating the general rules, while neglecting the random ones.

- The model does not take into consideration of other physical effects, such as its neighbourhood lands, which CA models do well in.

There are maybe other problems, and all these problems stem from less complex model structures in terms with complex world. These problems in theory affect its resemblance to reality. And in practice, they might decrease the precision of simulation.

While in fact, we can protect the model with two reasons. First is that models always understand and reflect the real world from certain aspects. And if we put emphasis on certain aspects, the model can explain better. Second is that models always demonstrate the main rules of a thing, while neglecting several minor ones.

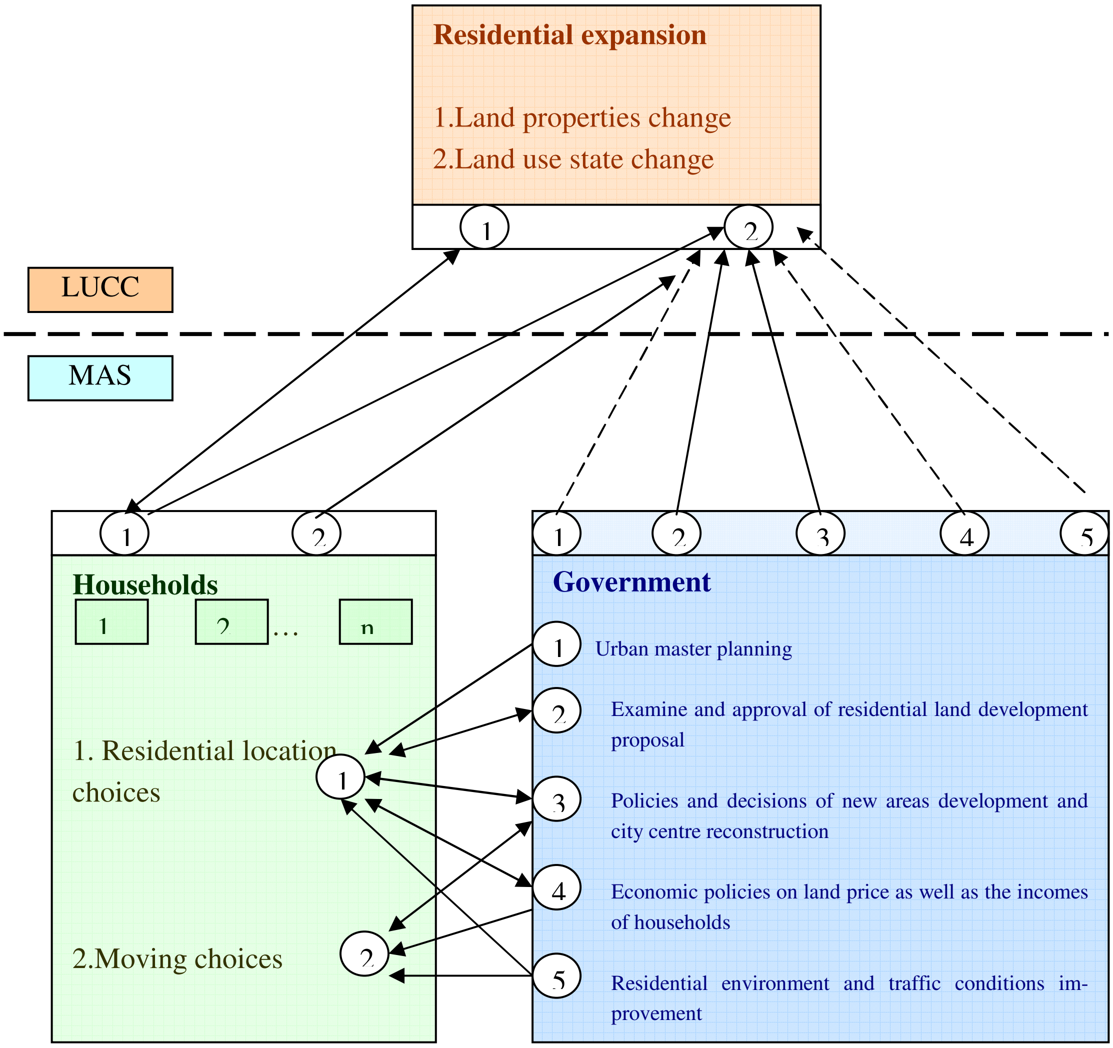


Figure 4-3 Integrated MAS/LUCC model for residential expansion

5. Model implementation and analysis

5.1. Introduction

During the conceptual modelling stage, implementation details and system requirements were not considered. In this chapter, the simulation work is to visually present how the behaviours of the agents will contribute to residential expansion by taking use of the rules in the built-up MAS/LUCC model. While for the time limit and data limit, the simulation is carried out based on simplified model with the absence of some rules. Then after calibration and evaluation of the model, it is taken for understanding residential expansion from aspects of time, space and complex behaviours.

Starting from implementation platform, this chapter covers all the operational part of this research till evaluation and application of this MAS/LUCC model.

5.2. Implementation platform

5.2.1. Guideline for choosing the implementation platform

As discussed in chapter two, we know that the model of MAS/LUCC is essentially a CM-MA model that combines the biogeophysical land use change and decision-making of the agents concerned. This enables us two means of technical realization of simulating residential expansion as a consequence of human activities. The first comes from the perspective of agents of the land use dynamics process and is supplied by advanced development of software and programming languages—object (agent)-oriented languages. In such a way, several software are enabled and have been used by some researchers already. They are SWARM, PePast, Ascape and CORMAS, which are developed in 1990s and are based on object-oriented languages such as Object C, JAVA and Smalltalk with support to GIS connection. They manifest strong powers in simulating human activities and their relations, while not very good at cell transformation dynamics side.

Another means start from the theory of cellular models (CM), which is another important component of MAS/LUCC. Such method is in nature a combined method of CA and MAS technology (hybrid MAS/CA model). In this field, several well-developed software are enabled such as ARC/INFO (Grid sub-model) and UrbanSIM, They are strong at cell transformation dynamics, though they are not developed specially for the purpose of human activities simulation. But if we can transfer the human activities into transition rules of land cells, it is also a proper way to implement the model of MAS/LUCC. Such software should represent agent architecture, agent communication, human-biological interactions, and the spatial and temporal scales at which the model operations, and many properties of agents mentioned in chapter 2.4.2.2.

Therefore, an appreciated platform for my study should have the following characteristics:

- Efficient for cell-based modelling
- Presenting agents' negotiations
- Agents' behaviours involved as land use conversion rules

Comparing the two technical means of agent-based and cellular-based, they both can implement our models, while the former is more promising for dealing with complex relationships within human behaviours and the latter more adept in cell-based analysis. Here in my simulation work, I choose the latter because I just want to test a certain number of behaviours, and I implement it in software ARC/INFO.

5.2.2. Implementation techniques

The implementation of simplified MAS/LUCC model is carried out by using module of GRID and TABLES in Arc/Info. GRID[14] deals with residential land use change according to change rules made out in previous chapter that present human behaviours, and TABLES[15] generates households with properties and stores the records of their residential location.

5.3. Model simplification

The implementation work is carried out with simplified model in that not all the behaviours of the agents modelled in chapter four are simulated here. What we do is to test the effects of a certain number of behaviours, while neglecting the others (shown in the following Figure 5-1). The items and interactions in bond black refer to those that will be simulated, and the items in grey colour refer to those that are neglected.

Besides human behaviours, there are still other factors simplified:

- Residential land is regard to be of homogeneous population density.
- Set the quantity of residential expansion as known quantity, only to simulate its expansion in spatial distribution, temporal sequence, and behavioural sensitivity.

5.4. Model implementation flow in Arc/Info

According to the simplified model above, the implement flow in Arc/Info is illustrated in the following figure (Figure 5-2).

[14] GRID is a raster- or cell-based geoprocessing toolbox that is integrated with ARC/INFO. GRID provides tools for both simple and complex grid-cell analyses. It represents space from a locational perspective (dividing space into discrete units called cells) and can accurately portray continuous surfaces. The commands and functions of GRID have been designed to optimize these representations, which allows for greater analytical capabilities. In GRID, the inherent power of the grid-modelling structure is coupled with the capabilities of a relational database that manages all attributes associated with the cell values. (Arc/Info help files, version 8.1)

[15] TABLES is a relational database manager for the tabular data associated with geographic features in ARC/INFO. It helps you to create, manipulate, list, and manage attribute tables and other tabular data. The TABLES relational database model represents data as a set of 'flat' logical tables where columns represent attribute fields, and rows contain all of the attribute values for each record. (Arc/Info help files, version 8.1)

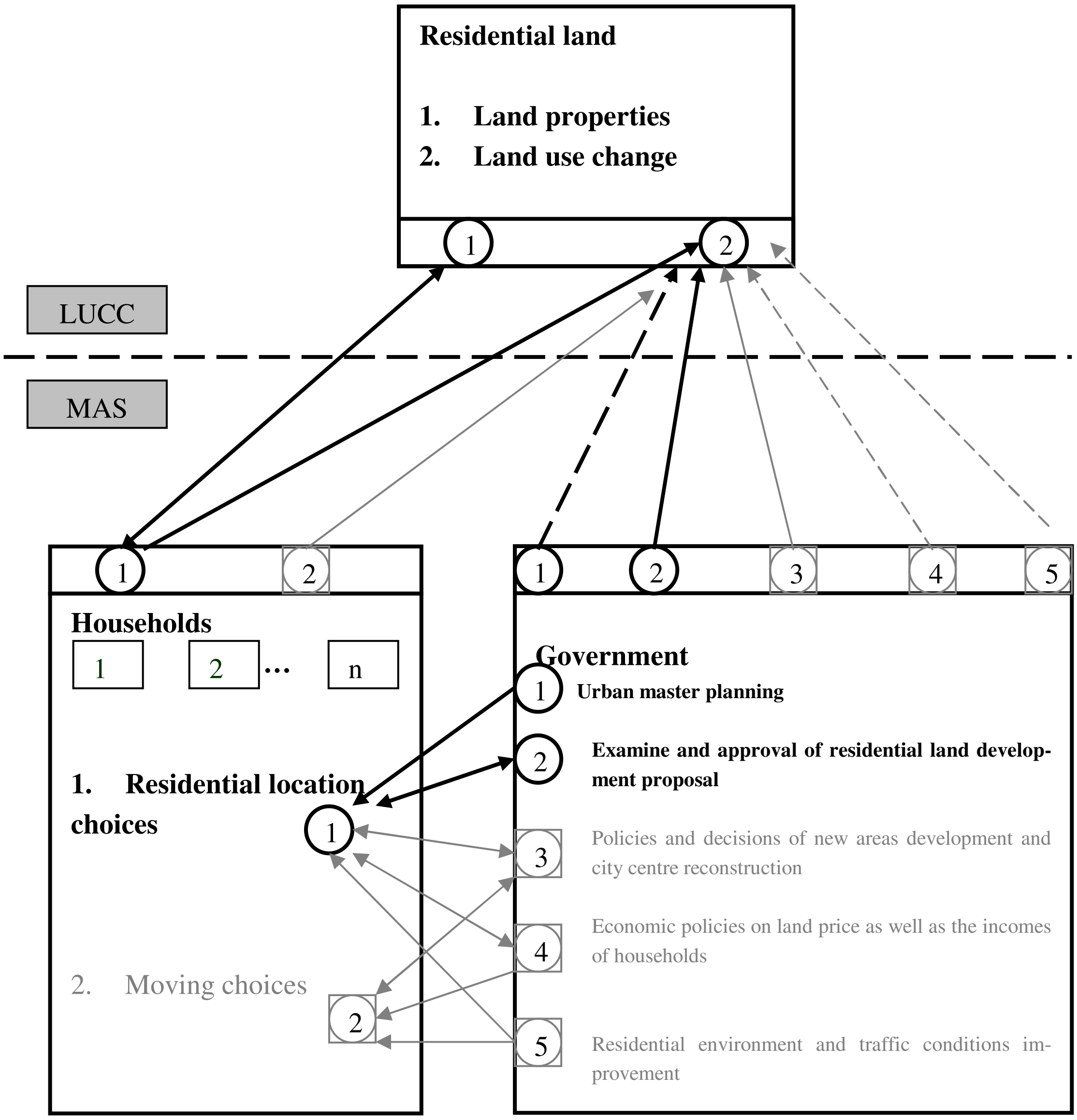


Figure 5-1 Model simplification

The inner box demonstrates the simulation flow of the agents' behaviors on residential expansion. ***A*** means a household group compare candidate land choices with their income properties and preferences recorded in a table *Family.ori*, and then make their residential location-choosing proposal. ***B*** means mean that the government determine whether to accept or not by referring to urban land use master planning map and ***C*** means that the government evaluate also by urban growth controlling policy. if the proposal is accepted, it changes residential land pattern by assigning this household group to the chosen cell and results in residential expansion as in procedure ***D***. Otherwise, the household group should give another proposal for evaluation. That is the way the behaviours of the government affect that of the households (shown in ***I***). The added residential land cell in turn brings changes to land price properties, environment properties in procedure ***E*** and acceptance probabilities of its neighbour cells in procedure ***J***. This is the condition for one household, while there are a large number of such agent, this process is cycled. Of course, this flow will be validated and calibrated by the actual residential expansion from 1996 to 2002.

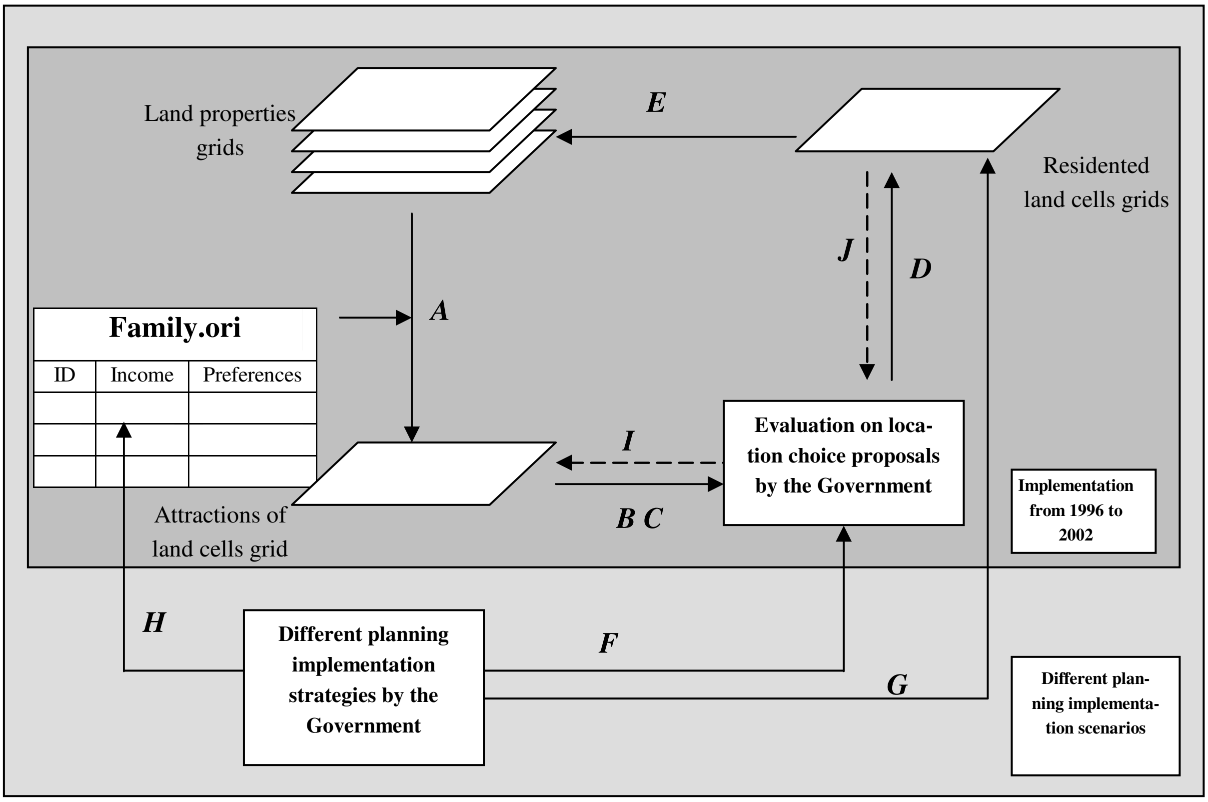


Figure 5-2 Model implementation flow in Arc/Info

After this model implementation, further analysis will be carried out on how well the model does for presenting residential expansion in time sequence, spatial segregation and complex human behaviours. As for time sequence presentation, the residential expansion process will be presented by the time sequences of different households groups.

Then as for spatial segregation presentation, the residential expansion modelling implementation will be looked into by segregation of different households of different income classes.

Last as for human behaviours presentation, several master planning implementation scenarios can be implemented as shown in outer box in the figure above for presenting effects of different behaviours on residential expansion. The scenarios such as the following items can be considered:

- As for planning implementation intensity, scenarios with planning control and without planning control can be taken in ***F***.
- As for pricing policy, more higher or lower land price in city centre can be taken in ***G***.
- As for welfare policy, the change of incomes of households will bring changes to the properties of households in ***H***.

While in this study, only the scenarios of different planning implementation intensities will be implemented for an instance.

5.5. AML and programming

ARC Macro Language (AML) is part of the Arc/Info geographic information system (GIS) software. It is an interpreted language. An AML program can automate frequently performed actions, provide a quick and consistent way to set up environments. The simulation flow is shown in Figure 5-3, and part of the source code is listed in Appendix 1.

In this simulation, AML programs are used for realizing residential expansion simulation. The source code of residential expansion simulation from 1996 to 2002 is listed in Appendix.

5.6. Parameters settings and data processing

In accordance with the flowchart, the parameters and data processing necessary in this implementation can be articulated into three parts: land grid, agents, and residential land expansion simulation rules.

5.6.1. Land grids

The study area is divided into cells as location choosing candidates, and some issues concerning to land grids should be considered: cell size, grids generation, and grids change visualization.

- **Cell size**

The size of the grid cell chosen for the study depends upon the data resolution required for the most detailed analysis. Larger grid cells may include more than one data value which must be aggregated or prioritised and given a single value, thereby decreasing data resolution.

The optimum grid-cell size to capture the appropriate detail varies from study to study. The smaller the grid cells the greater the resolution and accuracy; but coding, database storage, and processing speed for analysis is more costly. Determining the cell resolution is one of the most important decisions to be made when using a cell-based GIS. Before specifying the cell size, the following factors should be considered:

- The resolution of the input data
- The size of the resultant database and disk capacity
- The desired response time
- The application and analysis that is to be performed

As for the study area, it covers an area of 236 square kilometres with the residential area of 710 hectares in 1996, 879 hectares in 2002 and 2974 hectares according to planning in 2020.

Generally speaking, the smallest continuous residential land plot in Wuhan is more than one hectare and the residences are mostly storied buildings of about 5~13 stories. That means, a certain residential location choice is taken by a households group out of their common will, and the area of land chosen is more than one hectare. Thus, it is of no meaning to simulate only one household to choose a location for living at one time step. And according to location choosing model of chapter four, what we implement here is to simulate residential location choices by discrete households groups with all the households in one group share the common points of income conditions and choosing preferences. Then the choices of all the households within a group can be simplified as one “group choice”.

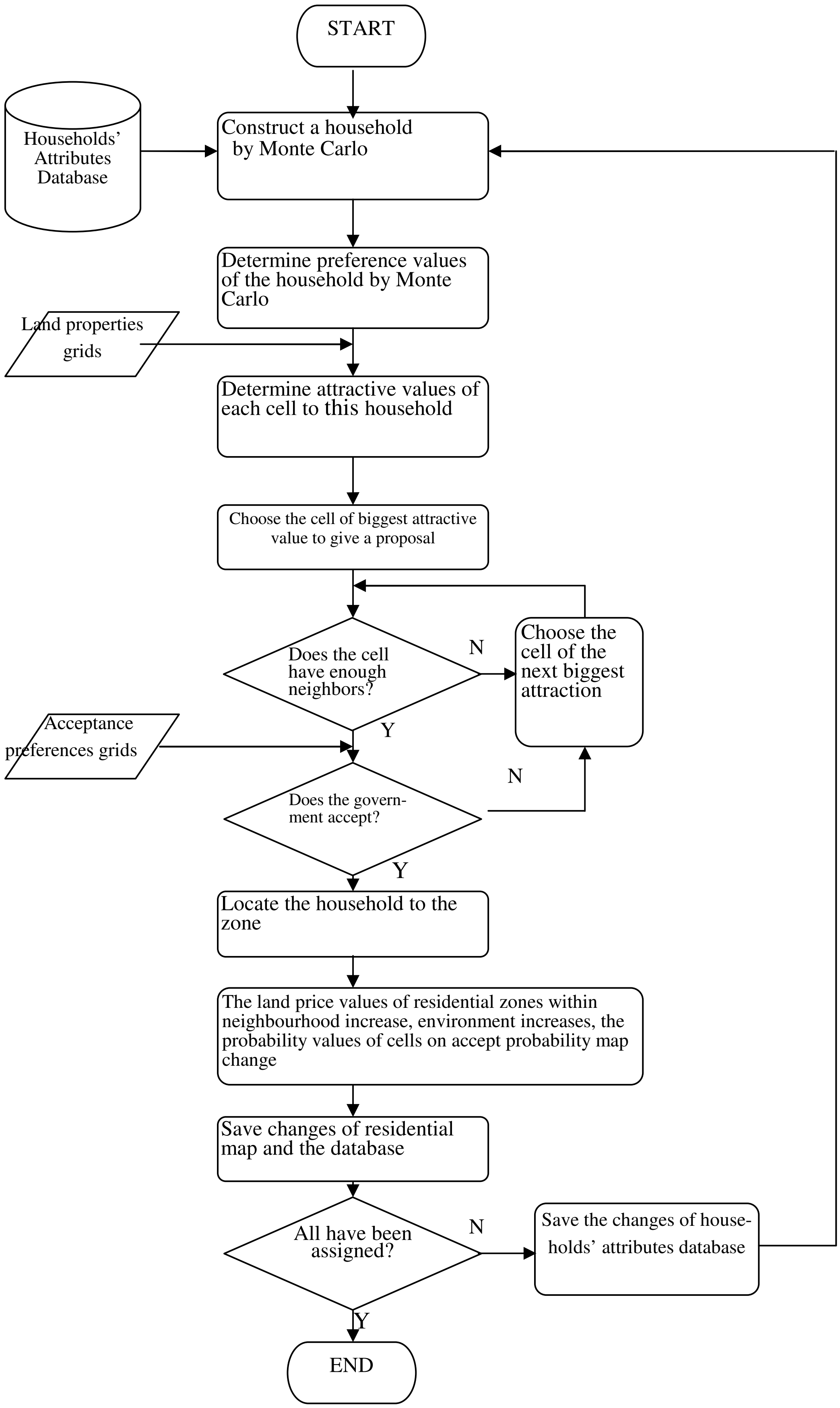


Figure 5-3 Simulation flow

Therefore, it is not necessary to analyse cells smaller than one hectare (100 metres * 100 metres cell). But above that, the cell size increases at the cost of less groups of households which affect the accuracy of simulation (it is assumed that housing buildings have no differentiations in height), which might affect the precision a lot. So considering about both the analysis requirement and computer calculation speed, the cell size is set to one hectare (100 metres * 100 metres).

➢ Grids generation

Multiple raster maps (called "grids" in Arc/Info-GRID) are produced because different themes of land cells of the study area should to be depicted. As a result, five grids are generated, and they are:

- **Residented**—shows residential land and non-residential land of the study area in 1996.
- **Maskgrid—**shows the candidate cells for choosing as residential land.
- **Landprice**—shows land price distribution of the study area.
- **Landtraffic**—shows traffic condition distribution of the study area.
- **Landenvi**—shows residential environment conditions distribution of the study area during 1996~2002.

First is **residented** grid. This grid is to give initial residential map for simulating residential expansion from 1996 to 2002. But I do not take residential land in 1996 (area ***(A + C)*** in the following figure) as the simulation start, because I have not considered about households' moving in this simulation. So those residential areas (in 1996) that are converted to other land uses in 2002 (area ***C***) which is the presentation of households mobility will not be included in simulation initial residential map. Therefore, the initial state for residential expansion simulation is residential land exists both in 1996 and 2002 (area ***A***). (see Figure 5-3).

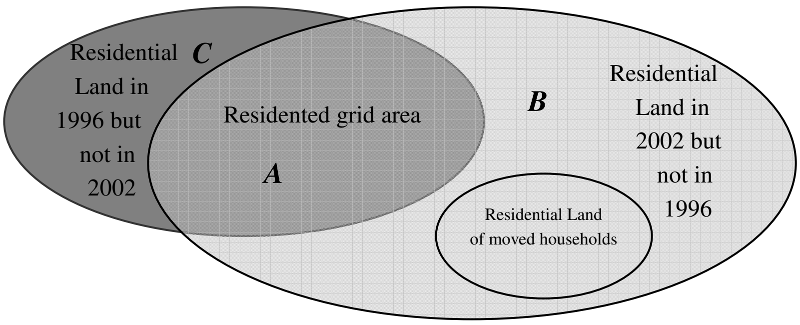


Figure 5-4 Initial residential grid of simulation

Second is **maskgrid** grid. It takes use of a function of GRID module in Arc/Info, it set the scope of choice cells, that means, the cells with "NODATA" value in this grid are not for location choosing. The masked item include the existing roads, protected waters and farmland, and residential land both in 1996 and are 2002.

Third is **landprice** grid. It describes land price property of each land cell by ranking land price into several classes (values for different classes are 1, 2, 3, 4 and 5) with higher value for higher land price.

The data of land price ranks distribution are got from land price rank distribution map for residences that is publicized by Wuhan Urban Planning Bureau (2000).[16]

Similarly, as for land traffic and land residential environment conditions, they are also ranked by classes. But the data of the distribution maps are not got directly, they are made by literature review, land use map and statistical data of the study area as explained in the following.

When making land traffic rank map, three factors are taken into account: the distance to first-class road, the distance to second-class road and the distance to the city centre area. According to the experiences values of the research results by J. Xu (2002),[17] While as for residential land location choices, the agents concern about not only the road conditions but also the commuter time. So the distance to the city centre area is also taken into consideration. Based on traffic research above, the traffic evaluation values given in my study is as the Table 5-1.

Table 5-1 Land traffic evaluation

Distance to first-class roads (Metres)	Distance to Second-class roads (Metres)	Distance to city centre area	Traffic value
< 500	Any distance	Inner ring	5
500~1000	<500	Inner ring	5
500~1000	>500	Inner ring	4
>1000	Any distance	Inner ring	4
500~1000	>500	Middle ring	3
>1000	<500	Middle ring	3
>1000	>500	Middle ring	2
500~1000	>500	Outer areas	1
>1000	<500	Outer areas	1
>1000	>500	Outer areas	0

When making land environment rank map, The factors that contribute to residential environment include the following items as discussed by Poll (1997): noise, malodour, pollution, litter, safety risks, crowding, lack of facilities. Here in my study, because of the restriction data accessibility and time limit, only the physical environment is taken into considerations, while neglecting cultural environment. The factors include: noise and pollution (presented by the distances to waters, green spaces and railways), facilities accessibility (presented by the distance to public facilities and utilities land use areas). And the map grid generation is in a similar way to traffic map, with the data of buffer distances in the study of Kyushik (2002) [18], the environment value is given as the Table 5-2:

[16] In the land price rank distribution map for residences that is publicized by Wuhan government, the land price is evaluated by seven classes. While within the areas of study area, there are only five classes exist.

[17] Their evaluation of land traffic accessibility is done by making buffer three ring areas for first-class roads and two rings for second-class roads, and one for third-class roads and give comprehensive traffic value.

[18] With regression method, this study concludes: as for the effects of facility, within a distance of 350 meters, it shows strong benefits in contribution to residential environment, and then from distance between 350 and 500, it have an effects to a certain degree, more than 500 meters, its effects can be neglected. While as for the effects of green spaces and waters, the two distance data are 500 meters and 1000 meters.

Table 5-2 Land environment evaluation

Distance to public facilities (Metres)	Distance to green spaces or waters (Metres)	Environment value
< 350	<500	5
< 350	>500	4
350~500	<500	4
350~500	>500	3
>500	<500	2
>500	500~1000	1
>500	>1000	0

Based on the analysis above and the given data, the five grids are generated with ArcView3.3. The output grids and the corresponding data source are illustrated in Table 5-3 and the grids layouts are shown in the next page (Map 5-1).

Table 5-3 Data source and output map

Data source	Output grid name
Wuhan land use map of 1996, Wuhan land use map of 2002	Residented
Wuhan Master Planning-Land use master planning map (1996-2020) (Wuhan Urban Planning Bureau)	Maskgrid
Land price rank distribution map for residences (Wuhan Urban Planning Bureau)	Landprice
Wuhan land use map of 1996	Landtraffic
Wuhan land use map of 1996	Landenvi

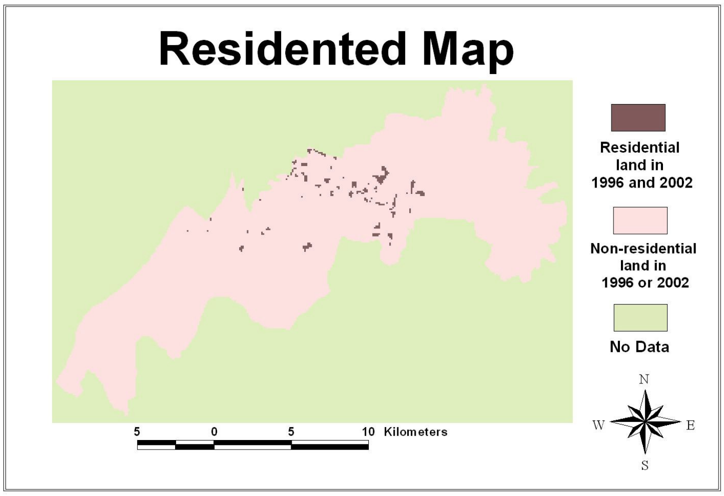
- **Grids change visualization**

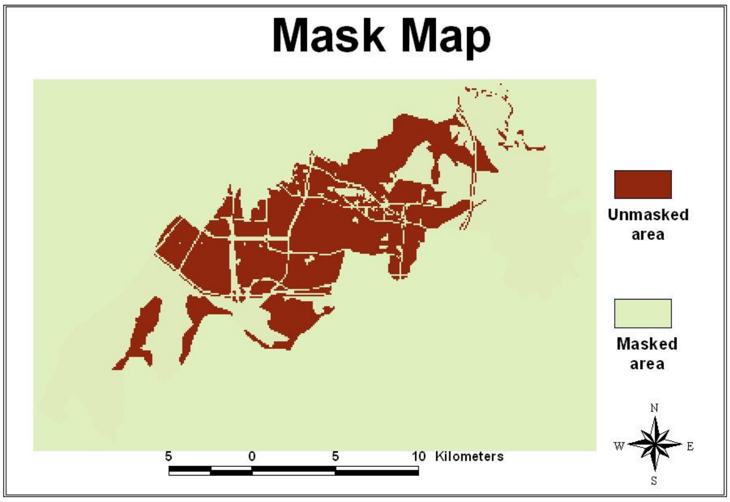
After the above process, the residential land pattern of the initial state is visualized in **residented** grid and the other properties of different land cells are visualized in separate grids. Because the value data of the grids are recorded in VAT, so the management of changing data in VAT will bring corresponding changes in grids visualization. As for visualization of residential expansion, it is to set data changing rules for changing values in VAT records of **residented** grid.

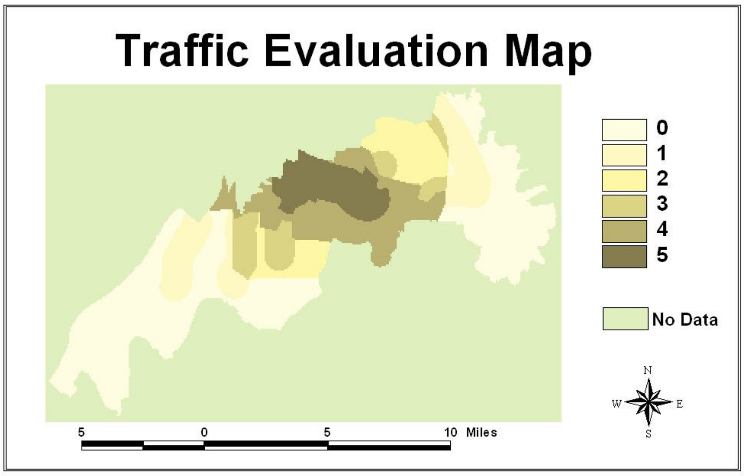
5.6.2. Agents

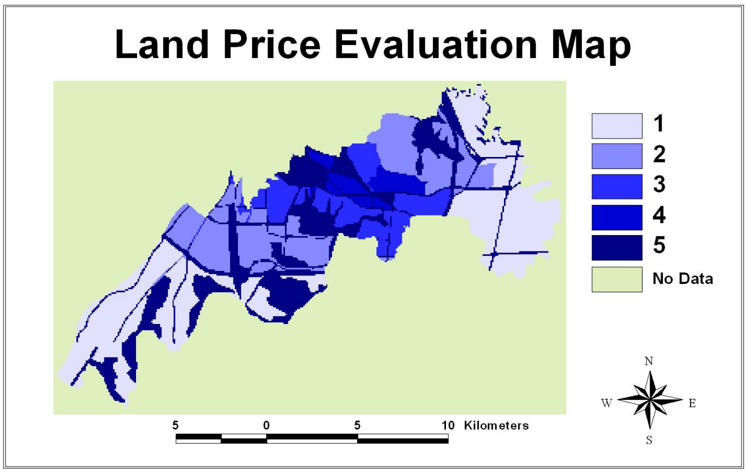
The agents consist of households and the government. As for the government, its location choosing decisions are taken by planning and land management. While as for households, because there are many separate ones, and different households have different choices, different households should be generated for location choosing process.

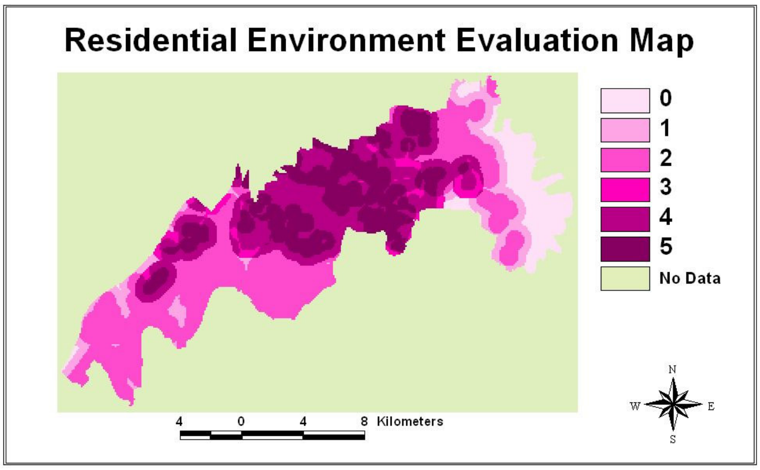
From the analysis in chapter 5.6.1.1, what we simulate is to make every households group chooses residential location at a step, and different households groups choose one by one. With TABLES database in Arc/Info, households database can be built up.


Residented Map
Residential land in 1996 and 2002
Non-residential land in 1996 or 2002
No Data
N
W
E
S
5
0
5
10 Kilometers


Mask Map
Unmasked area
Masked area
N
W
E
S
5
0
5
10 Kilometers


Traffic Evaluation Map
0
1
2
3
4
5
No Data
N
W
E
S
5
0
5
10 Miles





Map 5-1 Generated grids maps

In fact, there is not data about the income and preference properties of every household in the study area. We only have sample data from investigations taken by Wuhan Statistics Bureau, and the data show that the proportion of three income classes[19] of households are 10% (low-income), 80% (mid-income) and10% (high-income). Then as for their preference parameters, according to the analysis in chapter four, the initial values are given as the Table 5-4.[20]

[19] Another classification is to divide households into seven income classes as data shown in chapter three. The adopted classification in fact is to merge the middle five classes of the seven-classes classification as middle-class and the other two as high-income and low-income households.

[20] Although all the members of each households group share similar preferences for different properties of residential location as discussed in chapter 4.4.1.1, they can have random differentiations for personal preferences. Here the preference parameters setting further divide each household class into three sub-classes.

Table 5-4 Households preferences settings

Household class	P_{price}	$P_{traffic}$	$P_{environment}$
High-income household (10%)	1	2	7
	2	2	6
	1	3	6
Mid-income household (80%)	3	3	4
	2	4	4
	2	3	5
Low-income household (10%)	5	4	1
	6	2	2
	6	3	1

Then with the method of Monte Carlo, the household groups can be generated[21]. The result is listed in Appendix 2.

5.6.3. Residential land expansion simulation parameters

➢ Examine and approval of residential land development proposal

According to model analysis in 4.4.2.3, the parameters setting of government examine and approval consist of two aspects:

First for $\boldsymbol{P_{planning}}$, it is set by analysing the relationship between residential expansion actuality (1996~2002) and urban master planning (1996~2020), and the data are shown in the following Table 5-5:

Table 5-5 Acceptance actuality

Land use type in planning (1996~2020)	**Total area (Ha)**	**Area that accepted to residential from 1996 to 2002(Ha)**
Residential	2986	380
Public facilities and utilities	1679	107
Industry	992	44
Green space	2145	38
Waters	3368	15
Agricultural and vacant	8730	1
Traffic	2179	0
Study area outside of planning area	1557	0
Total	23636	585

If the $\boldsymbol{P_{planning}}$ of acceptance coefficient of residential land in planning is initially set as 90, the $\boldsymbol{P_{planning}}$ of other land uses are set by proportion as illustrated in the Table 5-6:

[21] Monte Carlo is a mathematical method combined with computer technology that is to generate entities according to certain rules automatically and randomly. The quantity growth of residential land for simulation is 585 hectares (presented by 585 cells which are regarded as discrete choices for discrete household groups), so the number of household groups is 585 according to analysis in chapter 5.6.1.1.

Table 5-6 Acceptance probabilities initial settings

Land use type in planning (1996~2020)	$P_{planning}$
Residential	90
Public facilities and utilities	25
Industry	10
Green space	9
Waters	3
Agricultural and vacant	0
Traffic	0

Second for $\Delta \boldsymbol{P}$ and $\boldsymbol{m}$**:** the initial $\boldsymbol{m}$ is set as 1, and $\Delta \boldsymbol{P}$ is 1.

- **Land properties change and government acceptance preferences change**

As for parameters of land properties change (shown in formula ***4.22*** and ***4.23***), $\Delta V_{environment}$ is initially set as 0.1, ΔV_{price} is 0.1, and $\boldsymbol{m}$ is 3.

Then as for government acceptance preferences change, $\Delta \boldsymbol{P}$ is set as 1, and $\boldsymbol{m}$ is 1.

5.7. Calibration and evaluation

Calibration is used to estimate a model's parameters that provide the best fit to an observed set of data—the 'goodness of fit' test. In this sense, the calibration is the process of exploring for the set of parameters for getting the best-fit results. Evaluation indicates the measurement of how good a fit is.

In virtue of the complexity of multi-agent behaviours and their interrelationships in MAS/LUCC model, there are rare general automatic calibration techniques available for implementing such models in a MAS-CA hybrid way for the time being. Manually calibration judged by visual interpretation and analysis is used in this implementation. Evaluation is one constituent of the calibration process. The evaluation of the goodness of fit has to be carried out after the change has been made to the parameters settings and the evaluation result sequentially serves as the input information according to which the new parameters settings are set for the next calibration.

In this section, the MAS/LUCC model of residential expansion has to be calibrated according to the analysis and empirical data. The result of the model will be evaluated by comparing them with the real development and this information in turn feed back to the calibration procedure. Finally, when the best-fit result has been generated, it is evaluated in terms of accuracy of matching to the real residential expansion.

5.7.1. Calibration approach

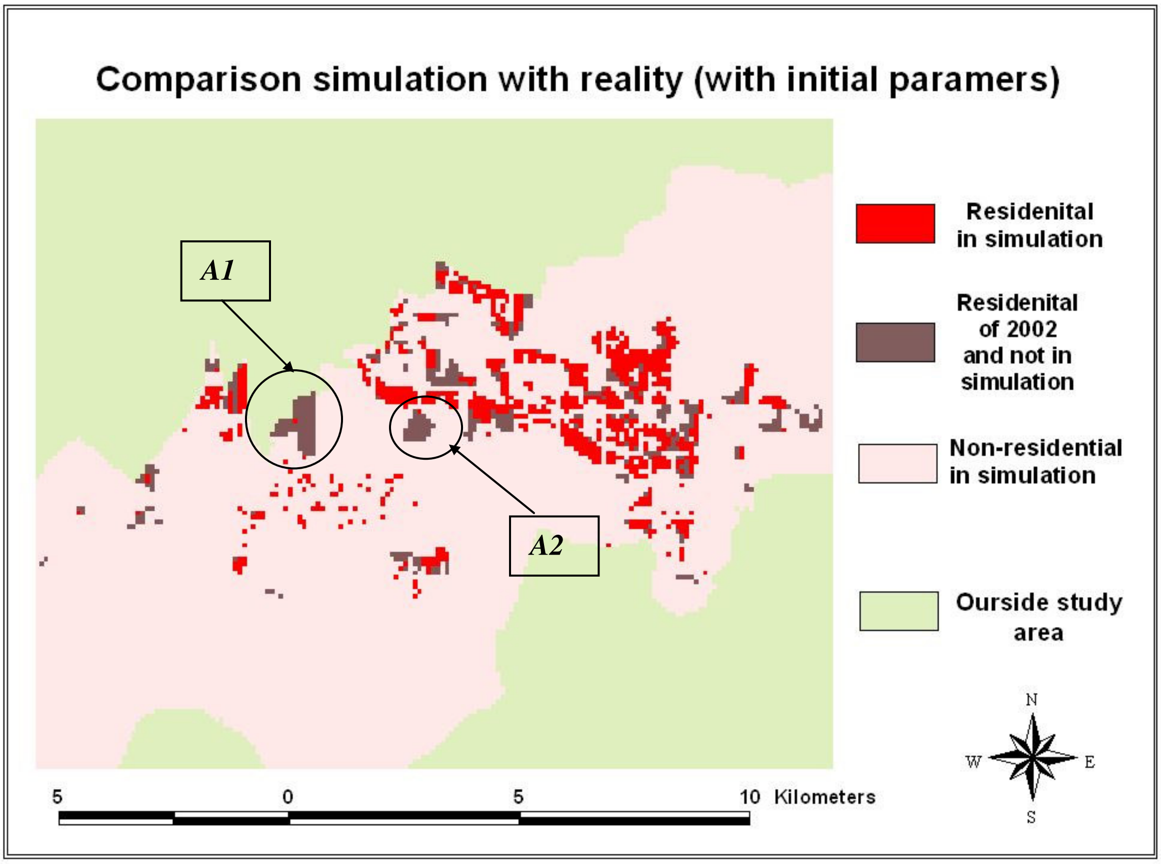
A try and error approach was used to calibrate this MAS/LUCC model. Visual interpretation is used to make the judgement on how good the model result is and again by visual interpretation, those behaviour rules that are thought to be too weak will get more weight and those too strong will get less.

The calibration approach is taken as the following procedures:

- Simulate residential expansion in study area from 1996 to 2002 with parameters of the initial parameters setting;
- Visual interpretation and manual calibration for better-fit implementation;
- After several attempts based on calibrations, best-fit attempt is formulated;
- Evaluate accuracy of the best-fit attempt.

5.7.2. Model implementation with initial parameters settings

With the parameters setting and processed data in the previous section, the model is implemented as the initial simulation. And the comparison between simulation result and actuality is shown in Map 5-2 and Map 5-3.



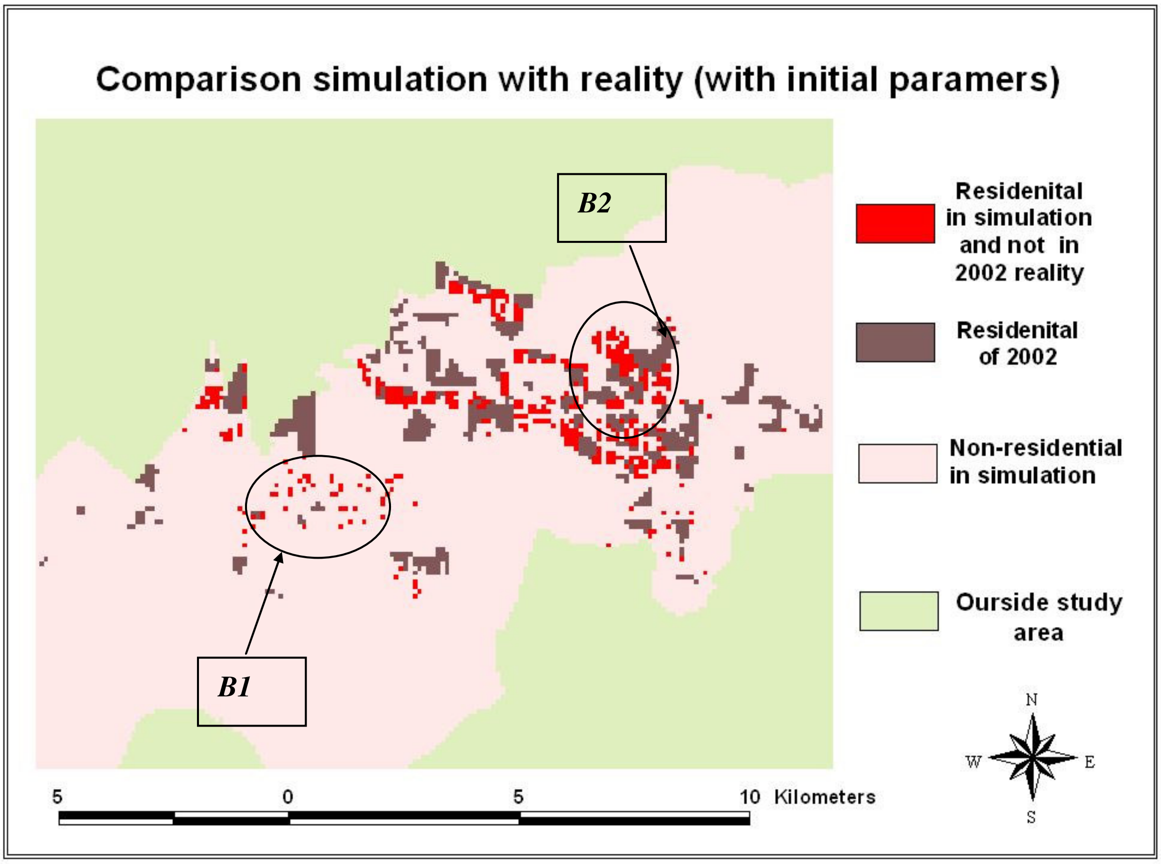
Map 5-2 Comparison A: actual development beyond simulation

5.7.3. Visual interpretation and manual calibration

From the former two maps, we can see that the implementation represents the overall actual residential pattern. While they differs in the following items:

- The residential pattern in simulation is more discrete than that in actuality (an obvious area is ***B1*** in Map 5-3).

- The residential development in simulation is more centralized in original residential land areas near city centre, or otherwise it expands to farther areas as discrete locations. While in reality, the residential land focuses on areas around original residential areas near city centre; instead, it expands to new areas that are of short-distance from original residential areas.



Map 5-3 Comparison B: simulation development beyond actuality

As for the former differentiation, it comes from the properties of MAS/LUCC model and programming as well. To be in more detail, the built-up MAS/LUCC model regards residential expansion as the result of discrete location choosing (or decision) behavious by agents, while not considering about the land use change interrelationships between land parcels directly. And this is another important factor to land use change-the physical effects not the behavioural effects, which have been well considered in CA models. In reality, owing to the effects of neighbourhood, land parcels that are in the same neighbourhood tend to be homogeneous and not likely to be of many different land use types.

Then there are two strategies for decreasing such differentiation: parameters that reflecting environment changes and price changes brought out by neighbouring land parcels are adjustment to higher values and another is developing a hybrid model combined with multi-agent rules and neighbourhood rules.

As for the latter differentiation, it can be further discussed by examples of areas ***A1, A2, B2*** in Map 5-2 and Map 5-3. First is ***A1*** area, which is developed during 1996 and 2002, while the simulation gives little clue of that. By referring to the detailed information of this residential land, it is "South-lake Garden Residence" which has developed very quickly from 1998, with the land price being 3 million per hectare in 1998 and 10 million per hectare in 2002 (Soufun, 2004). But as for the data limits, only land price data of 2001 is available. Generally speaking, land price changes not much within 1996 and 2001, but this area is an exception, which changes too much, so the parameter of land price parameter value of this area is not properly set for 1996 presentation. Then in the further simulation, the parameter is revised lower. Another factor that might contribute to this differentiation is decisions of direct areas development by the government. This area used to be "South Airport" before it is for residential use, then after the airport was moved out, the government planned it to be residential use. So when the land agents want to invest to this area, it is more likely to be accepted. Then when more and more land agents and households argue for this area, land price will increase quickly while it is still a favourable choice. Because this rule is not included in the modelling implementation, so this may be realized by including the rules in further model implementation work.

Second is A2 area. Although this area is near to South Lake, which provides good natural conditions, but its surrounding areas are used to be villages that have inconvenient access to public facilities, which causes a poor cultural residential environment condition, so the environment value is not as high as that of its neighbouring land parcels. But from 1996, due to the environment improvement by the government (planning of park construction and the moving of Hongshan District People's Government to that area), the environment there increased quickly. So the environment parameter in that area is revised higher in that area for the next simulation.

Third is B2 area, this shows the quantity of residential land expected to be built around original residential land areas in simulation exceeds that in reality. Such areas are mostly for public facilities, green spaces in urban master planning[22], so the acceptance probability parameters of residential development in public facilities and green spaces land use in planning are set to lower.

5.7.4. Best-fit attempt and accuracy evaluation

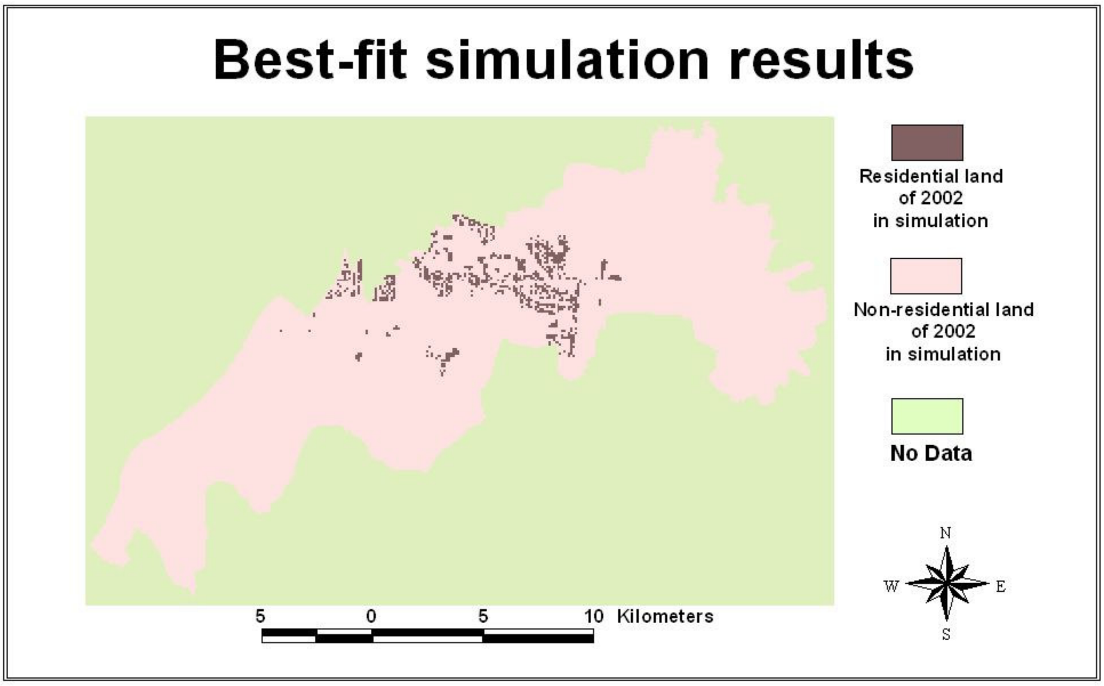
After visual interpretation and manual calibration of the initial attempt, the result of best-fit attempt with calibrated parameters is shown in the following Map 5-4 and the running map in Arc/Info is shown in Appendix 3.

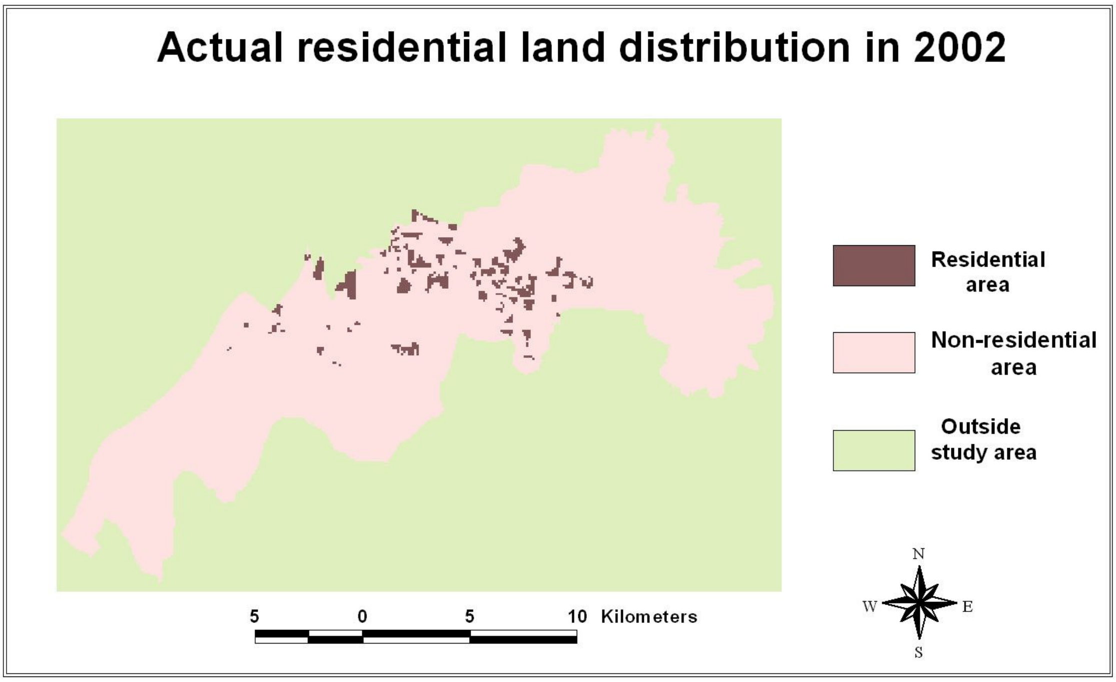
From visual interpretation, the best-fit simulation results conform to basic residential expansion pattern, especially in expansion extend, direction and sites selection of newly development areas, while it differs from reality in local residential land density. In this sense, this model is acceptable for presenting residential expansion with human behaviours by taking study area as a whole, while as for residential land use change in local scales, it shows to be more dispersed than reality.

Then with an evaluation method-error matrix, the error matrix of best-fit simulation results is shown in Table 5-7.

[22] Except land use planning map in Wuhan master planning, the text of master planning also mentions two items concerning to land use change:

- To promote development of the service sector especially in central city.
- To improve ecological environment and toward sustainable development.





Map 5-4 Best fit simulation and actual residential land distribution in 2002

Table 5-7 Accuracy of best fit simulation

Real / Model	Residential	Non-residential	Total	Error of commission (%)	User accuracy (%)
Residential	454	425	879	48	52
Non-residential	425	22332	22757	1.8	98.2
Total	879	22757	23636		
Error of omission (%)	48	1.8			
Product accuracy (%)	52	98.2			

The total residential cells in 2002 is 879 and the number of residential cells in simulation is set the same as that in reality in advance. Then as for the simulation results of residential expansion, among 879 residential cells in simulation, there are 454 matches with the reality. There are 425 non-residential cells in reality have been developed into residential cells in simulation. Therefore, the user accuracy is 454/879 = 52% and the commission error of residential cells is 425/879 = 48%. Among 879 residential cells developed by MAS/LUCC model, 454 of them match with reality, 425 of them do not become residential cells in reality. Thus, the product accuracy is 454/879 = 52% and the omission error of residential cells is 425/879 = 48%.

The overall accuracy is 97%. It is calculated as (454 + 22332)/23626 = 97%, the sum of the matched residential cells and non-residential cells divided by the total cells number in the study area. Since the model has set the quantity of residential expansion in advance, the calculation can only give a rough idea about how good the match is. But all in all, this model shows its promising capability in simulation of residential expansion process, while the user accuracy is not very high for the first model period.

5.8. Analysis of MAS/LUCC model presentation capacity

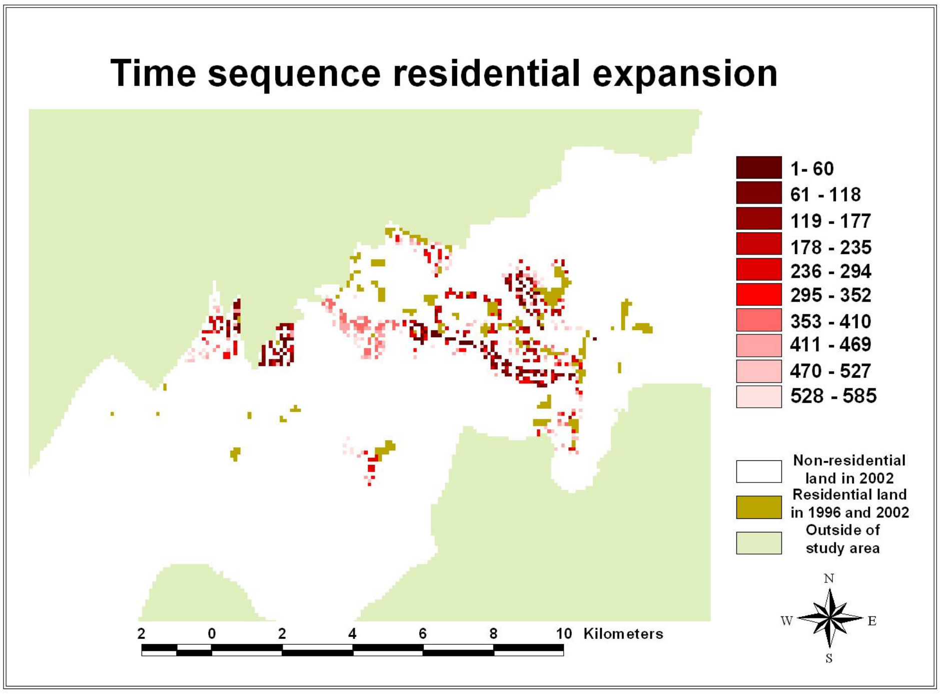
Except for residential land use distribution, the MAS/LUCC model implementation enables spatio-temporal presentation of residential expansion in micro layer.

5.8.1. Temporal presentation

As for temporal presentation of residential expansion (shown in Map 5-5), the households groups are reclassified into 10 teams according to their location choice sequences as illuminated in legend. 1-60 means the first team of 60 groups of households living in this area from the start time in simulation. Then by 61-118,…, and so on. Therefore, the different colors illuminate the time sequences of residential expansion.

It demonstrates from the simulation results that those areas near to original residential land, along the main roads, or with better supports of the government tend to get preferential developed, while the farther ones are developed after that.

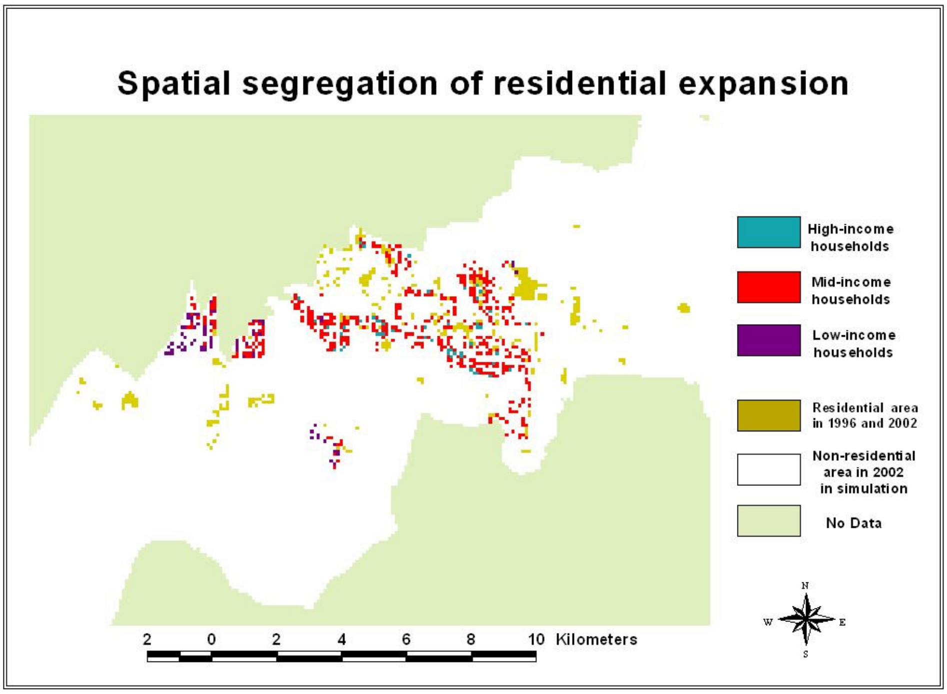
As for the district centre, although there are not many residential land developed there, some are still developed perhaps because that some households (especially of high-income) think the benefit of convenient traffic and accessibility to public facilities exceeds the cost of higher price.



Map 5-5 Temporal presentation of residential expansion

5.8.2. Spatial presentation

As for spatial presentation, except for presentation of residential distribution as a whole, the model implementation also supplies the presentation of spatial distribution of different classes of household as shown in Map 5-6. And this is visualized by joining income field of *family.ori* Table into attribute table of residential expansion.



Map 5-6 Spatial presentation of residential expansion

What the map show conforms to reality quite well: with the active real-estate market, residential segregation by income differentiations becomes obvious. Households of higher income always choose residential location of good traffic and environment conditions, while considering not much about price. Those households of lower income tend to choose residential locations with lower price in outer areas. And the choices of households of middle income are between the two types. Furthermore, this presentation reveals another fact that the rich seldom choose to live in outer areas probably because that during 1996 to 2002, the traffic and environment conditions there are not good enough for comfortable life, which is not like the conditions of developed countries.

5.8.3. Human behaviours presentation

Following the implementation flow in 5.4, the scenarios with planning control and without planning control are taken for instances of human behaviours presentation. The former senario reflets the interactions between households and the government, while the latter reflects more about the choices of households (see Map 5-7).

It shows in the scenarios implementation results, the residential expansion takes place more compact when under planning control; another is that it less tends to happen where the planning acceptance probabilities are lower. The results of these two scenarios conform to the conditions of reality to much extent, and other such scenarios can be also taken for different purposes of analysis.

5.8.4. Remarks on MAS/LUCC model presentation capacity

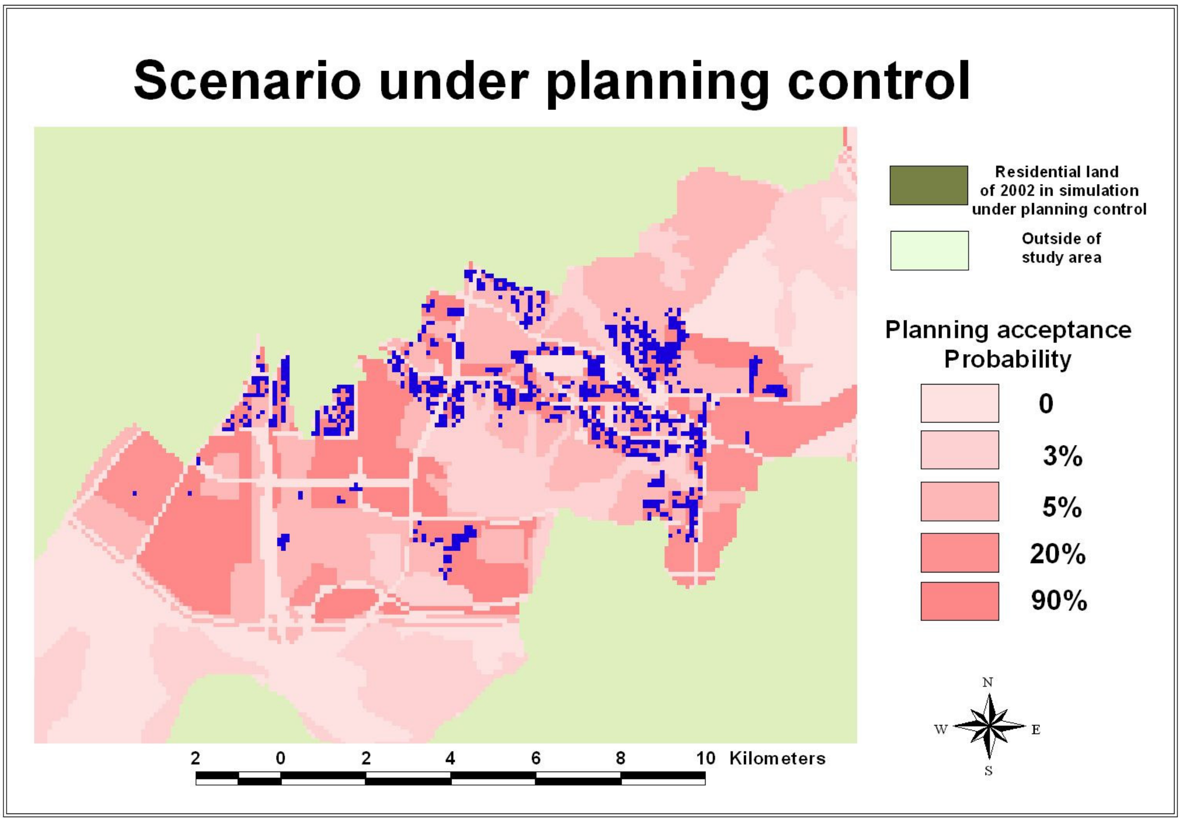
Based on the temporal, spatial and behavioural presentations of MAS/LUCC model, we can say that this model does well in these presentations. And such presentation capacity contributes to understanding residential expansion in that it sheds light on understanding residential expansion in time sequence, space segregation and behavioural differences as well as micro spatial distribution b aggregating micro choices. That is to say, we can study residential expansion under the condition of different human behaviours at different time. And further discussions of these issues can be future work of this thesis.

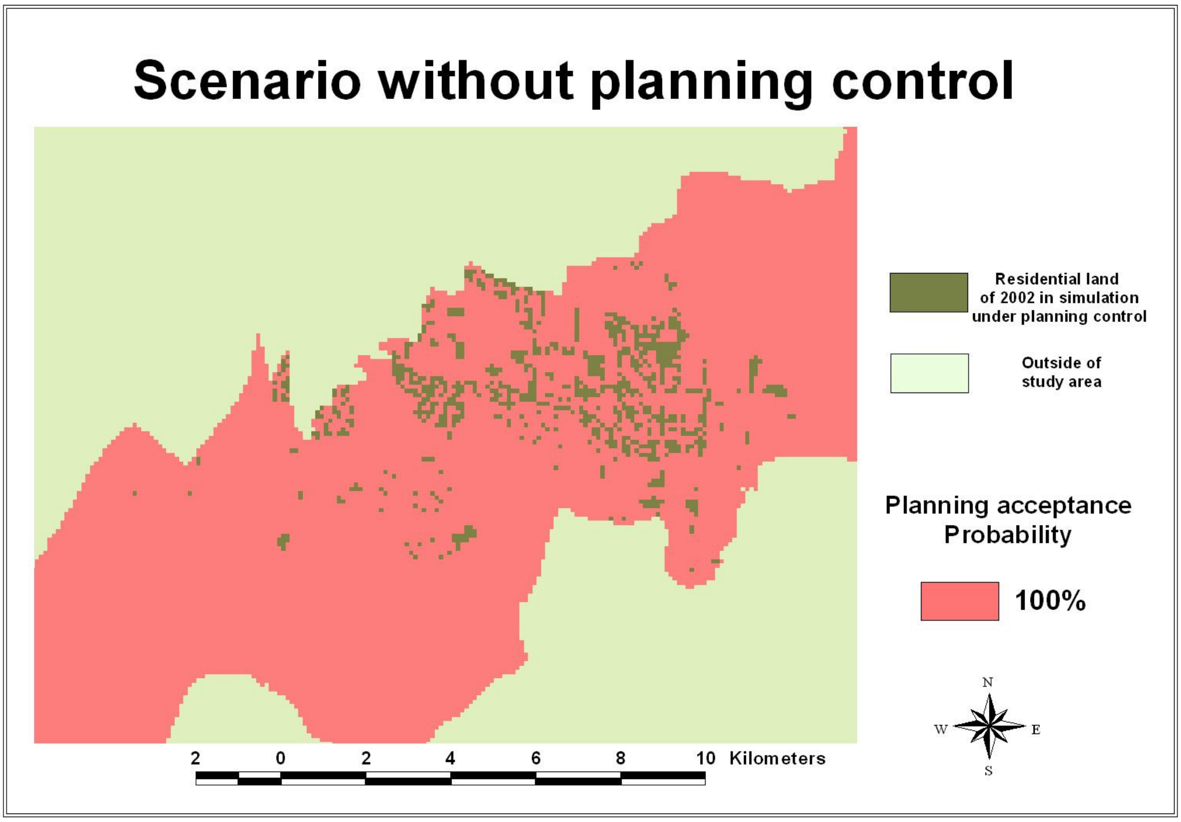
This property supplies at least two potential uses. First is that we can not only understand residential expansion by “input” and “output” with various parameters, which puzzle us a lot of why and how it happens. It can present inner and detailed relationships more clearly. Second is that it enables a means for testing different effects of different behaviors, which carry great meaning for decision makers, (especially the government) to set more effective policies and land management strategies.

Another function of presentation capacity is to calibrate the MAS/LUCC model by comparing the simulation results of extreme scenarios with data in reality. And this can also be taken given enough data.

5.9. Conclusion and discussions

This chapter focuses on model implementation details in study area from 1996 to 2002. With the simplified model of what put forth in the previous chapter, the implementation is carried out in Arc/Info-GRID. The best-fit simulation result demonstrates the suitability for understanding residential expansion process. And in turn analysis is carried out on how well the model does for presenting residential expansion in time sequence, spatial segregation and complex human behaviours. This analysis shows its capacity of presenting the effects of different human behaviours on residential expansion process.





Map 5-7 Behavioral presentation of residential expansion

Finally, this chapter arrives at the conclusion that the built-up MAS/LUCC model is acceptable for understanding interactions between residential expansion and human behaviours, while the precision needs improving. For that problem, some issues are still to be considered:

First, due to the model simplification, this implementation reflects the reality only from certain aspects. Then together with the difficulty and uncertainty in parameters settings, this model presents residential expansion in a restricted way. And these should be made up for by taking more agents with more complex behaviours into consideration in this model. Perhaps this will require more efficient programming languages for demonstrating values as well as more real data for improving calibration work.

Second are the cell size and scale issues. As for a model implementation based on grid, the cell size is important for simulation precision. The implementation in this study has not given the idea about how much will different cells sizes affect the precision. As for the scale, we have got the results that from model implementation the model does better in macro scale than in micro one. But we are not sure yet what scale is the best to apply this model. In this study, I choose a part of a district as the study area, so only after comparing the implementation results of different scales (the whole city, a portion of city, several land blocks, etc.) can we get a clearer understanding of the effectiveness of this model on different land scales.

Third is about neighbourhood effects. Although human behaviours are very important factors that affect residential expansion process, this model considers few impacts of neighbour land cells with different land uses, which are what CA model good at. In this sense, the output of residential expansion is not the result of human behaviours, but affected by other physical factors. Therefore, putting more CA rules into this model might be a proper way to solve this problem.

6. Discussions and conclusion

In this chapter, discussions on the findings and problems of this study will be carried out, conclusions of the study will be drawn and recommendations for further work will be presented.

6.1. Discussions

In this research, effort has been put on constructing a MAS/LUCC model that can represent complex residential expansion process with human behaviours. And the study is implemented by considering a series of research questions put forward in chapter one.

- How to analyse the residential expansion with the effects of human behaviors?
- How to design a MAS/LUCC model for further understanding residential expansion process with human behaviours?
- How to implement the model prototype and calibrate the established prototype?
- How to understand complex residential expansion process with this MAS/LUCC model?

During the research, some of the findings and problems encountered in this research are discussed. And then the conclusion of this research will be given based on the result of the research.

6.1.1. Methods of analysis

Understanding relationships needs logical analysis as well as representing the relationships. In this sense, DPSIR framework and MAS/LUCC are taken for reasoning complex residential expansion with human behaviors.

However, choosing a model for understanding means it is needed to take the challenge of presenting complexity by simpler ways. While, in MAS/LUCC model, we must be careful about the extent to which assumptions of this kind are still possible. There are several means for realizing this:

- Making assumptions that constrain the range of research questions, and let the simulation be more objective specific.

- Taking into consideration about more important ones, while neglecting minor ones.

- With more effective technical support, such as object-oriented language.

6.1.2. Model structure

- **General model structure**

Although the elements seem to be simple, while in fact, behaviours of agents as well as their relationships are complex. And the complexity increases with more agents taking into this model. So in my study, I comprehend the model structure in a logical way: first is to define agents as well as their properties, second is to discuss about the behaviours of different agents, third is to explore the relationships between their behaviours (how one action will affect the other), finally is to explore the interactions between agents and land use change (how human behaviours will have effects on residential expansion). In general, this modelling method makes up for the deficiencies of DPSIR reasoning in that it reflects the complexity residential expansion with human behaviours in a logic way, while at the same time it has some underlying problems by simplifying the reality which I have discussed in the end of chapter four.

In fact, model cannot represent all the things exactly, what it can do is to simplify the reality into logical prototype by considering those important factors and rules. In this sense, the model prototype is a good presentation of restricted conditions. Another cause to these problems is that MAS/LUCC are still academically promising in nature for the time being, while as for the more efficiency in practical use such as fine prediction, there may be still a long way to go.

- **Communications**

Communication is the interactions and information transferred between agents, which is similar to the concept of protocol in computer languages. Taking residential location choosing behaviours of the households as an example. In this model, the objective of households is to get commitment from the government to accept their location choosing proposals. Each time a proposal is presented to the government, it faces with the dilemma of making compromises to the household or not if the choices of the households are not the same as planning.

Communications are perhaps the most important modelling elements in MAS/LUCC models, because it determines how the whole model works. Sometimes it is very complex in that the communication acts as two-way interactions. That means, the action of agent A will affect that of agent B, and in turn the corresponding behaviour change of agent B will have effects on that of A, … and this just reflects how the real world works. Taking an example in my study: the more proposals of certain land location choice by households will increase the acceptance probability of such proposals by the government, and the increase will in turn make it more easier to for households to be accepted by choosing its neighbouring land.

Therefore, communications is the main presentation of the models' complexity, which is also the emphasis of MAS/LUCC modelling. That is to say, if we want to reflect the complexity of reality, we should first study the complex interrelationships in the real world and reflect it as the form of communications.

6.1.3. Model implementation

It is very common in the social sciences to model only a particular aspect of social behaviour. Here in the MAS/LUCC model for residential expansion, I have considered about the behaviours and interactions of two types of agents-the government and households, and only a part of their behaviours are simulated in the implementation work. For such an approach, it is assumed that a lot of social actions (like the land supply behaviour of land agents) can be completely disregarded. But we should consider representing such things that are necessary within MAS/LUCC models.

- Spatial explicit of agent behaviour,

- Representation of socio-economic-environmental linkages,
- Representation of a diversity of human-agent types,
- Representation of impacts of heterogeneous local conditions on human decisions,
- Ability to analyse the response of a system to exogenous influences, etc.

Then, several concrete issues of model implementation will be discussed:

- **Implementation platform**

I have taken Arc/Info-GRID as the implementation platform and used AML as the adopted programming language to attain my objective. It turns out to be suitable by its capacity of grids processing which is the need for land use change presentation with the rules representing Multi-agent behaviours.

However, I become to realize that this platform is not that suitable when more agents and behaviours are taken into consideration, because it is not an efficient tool for representing agents' behaviours in that: it is more conformed with agent-based modelling theory, while agents are reflected as class, and communication is represented as protocols.

Another is that we have known communication is the biggest contributor to complexity, then more efficient in communication presentation is of most importance. So taking such object-oriented language for more complex relationship is better.

- **Calibration, verification and validation**

When using MAS/LUCC for exploring land use change such as residential expansion, we must pay more attention to the challenges of calibration, verification and validation. The model put forth in my study is calibrated by fitting it to data before running it. The model is then subject to outcome validation (how well model outcomes characterize the target system) by visual judgement and calibration together with the analysis of how well the model implementation represents the conceptual model. And the model is verified by ensuring the proper functioning of its underlying programming. Although it is an acceptable calibration method in this study, it exhibits shortages in sensitivity and scale analysis.

As for sensitivity, there is a need for techniques such as active non-linear testing, which seeks out sets of strongly interacting parameters in a search for relationships across variables that are not found by traditional verification and validation. Then as for scale issues, multi-scale test is not carried out in my study, which restricts the understanding of its performances in various scales and cause problems in scale-related validation and calibration.

6.1.4. Complexity understanding

The complexity of MAS/LUCC modelling demands analysis of its suitability in space, time and complex human behaviours. Then the analysis of spatial presentation, temporal presentation as well behavioural analysis is implemented in my study. The results show that it can really present those complexities to some extent. And this presentation ability is not only the necessity in model evaluation but also helps us understand the complex residential expansion process from different aspects by different scenarios.

6.2. Recommendations and future work

Although the MAS/LUCC model demonstrate its suitability in residential expansion modelling with human behaviours. There are still many works to do in the future for the problems mentioned above.

6.2.1. Model improvement

Model is the simplified representation of reality, while much work has to be done for improving its resemblance to reality. It can be expressed in the following aspects:

- More agents should be taken into account because the new agent that joins in the model not only take actions of its own, but also generate new communications that will bring changes to the whole model interactions.

- More physical factors should be taken into consideration except for human behaviours. That is to say, as a combination of MAS and CA technology, MAS/LUCC should also embody the physical rules that exist in reality. A typical example is neighbourhood effects of land, which is considered in residential location model by Torrens (2001): Home-buying and home-owning agents negotiate the sale of properties through the help of MAS, while neighbourhood effects that influence the attractiveness of certain areas of the city are simulated using a CA.

- More conceptual rules and implementation parameters are needed to be added to this model. Because in my conceptual model, several behaviours and relationships rules have not been modelled successfully in the time being such as the moving behaviours of the households and urban renewal policies made by the government. All these need improving.

- As for modelling implementation, other platforms that are object-oriented should be adopted for improving the efficiency of the simulation and more complex presenting of the reality.

- As for calibration and validation of model implementation, more rational method based on enough real data and scientific method should be carried out such as logit regression.

6.2.2. Further research

As far as further work is concerned, it should take into account of the following aspects:

- Rethink about the analysis method: is such hybrid DPSIR-MAS/LUCC model the best for understanding residential expansion with human behaviours and if yes, then how to improving the understanding process to avoid its disadvantages? And if no, how about the better one?

- Making model improvements according to the items discussed in the previous section.

- Think about how to utilize the results of capability of MAS/LUCC model for further understanding of residential process from different aspects. And besides, think about in what aspects can it do well for government when making policies or land management strategies.

6.3. Conclusion

In this research, theoretical analysis as well as case study application has proved that the combined DPSIR-MAS/LUCC model is suitable for understanding the process of residential expansion with the effects of human behaviors.

Then the model is implemented into a study area- Hongshan, Wuhan city by simulating residential expansion from 1996 to 2002. It turns out be get a precision of 52% after calibration. It means the model is theoretically right; while as for applied to practice, it needs still a long way to go. However, this model implementation is useful for complexity analysis of residential expansion in time sequences, spatial segregation as well as complex human behaviors.

Finally in the study, we get the conclusion concerning to my research objectives in that:

- The DPSIR-MAS/LUCC model is theoretically sound and practically promising for understanding residential expansion.

- MAS/LUCC model is integrated for taking into main agent and important behaviors by restricting simulation scope. Although it can represent residential expansion clearly, it implies that the efficiency decreases with more complex agents and behaviors. Therefore, this model does better within more specific scope.

- The implementation of the model shows its reliability to some extent, while the precision is not very satisfactory for practical use such as prediction at present.

- However, the model represents its strong ability in presenting complexity of residential expansion. And it demonstrates great capability and potential for decision-making support.

This study demonstrates the suitability of using this model for understanding complex urban processes. The methods put forward here represent a move toward more theoretically sound, behaviourally realistic, and ultimately more useful understanding method especially for policy makers as well as urban planners.

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Appendix

Appendix 1: simulation source code of government examination of location choosing proposal by the household .

```
/*examination course
&routine judgement
&s t = %i%
&do &until %findplace% = 1 or %t% = [cal %i% + %k%]
      &s testflage = 1     /*set a indicate to show whether a proposal has passed or not

      /* get attraction value and the position of each cell

   &s length = [length [value val$att%t%]]
   &s lengthtemp = %length% - 2
   &s row = [substr [value val$att%t%] %lengthtemp% 3] * 1
   &s lengthtemp = %length% - 5
   &s col = [substr [value val$att%t%] %lengthtemp% 3] * 1
   &s lengthtemp = %length% - 6
   &s att = [substr [value val$att%t%] 1 %lengthtemp%] * 1

      /* check if there is unoccupied land cell

   &s nodataflag = [before [value .cv$resident%col%%row%]\ \]a
   &if %nodataflag% <> '0a' &then &do
     &s t = %t% + 1
     &s testflage = 0
   &end
   &if %testflage% = 0 &then &goto begin   /*if cannot pass, go to begin

      /*check residential density (which refers to examination by the government to avoid resi-
dential sprawl)

   &s thresh = 0.02
   &s w = 3
   &s sumR = 0
   &do m = -%w% &to %w%
     &do n = -%w% &to %w%
       &s a = %col% + %n%
       &s b = %row% + %m%
       &s nodataflag = [before [value .cv$resident%a%%b%]\ \]a
       &if %nodataflag% <> '0a' and %nodataflag% <> 'NODATAa' and %nodataflag% <> ' 'a &then
       &s sumR = %sumR% + 1
     &end
   &end
   &s squrevn = ( %w% * 2 + 1 ) * ( %w% * 2 + 1 ) * %thresh%
```

```
&if %sumR% < %squrevn% &then &do
  &s t = %t% + 1
  &s testflage = 0
&end
&if %testflage% = 0 &then &goto begin
```

/*to get acceptance probability by the government, 0 refers to refuse, 100 is accept, the number between them shows the probability.

```
&s randnum = [random 1 100]
&s nodataflag = [before [value .cv$management%col%%row%]\ \]a
&if nodataflag = 'NODATAa' &then &s [value .cv$management%col%%row%] = 0
&if %randnum% > [value .cv$management%col%%row%] &then
 &do
  &s t = %t% + 1
  &s testflage = 0
&end
&if %testflage% = 0 &then &goto begin
```

/*after examination, the following deals with values setting.

```
&run setcellvalue %col% %row% %:cur$family.number%
&s .cv$resident%col%%row% = %:cur$family.number%
&s :cur$family.att = %att%
&s :cur$family.col = %col%
&s :cur$family.row = %row%
```

/*change the value of acceptance probability of the government

```
gridedit edit newmanagement
&do m = -1 &to 1
  &do n = -1 &to 1
    &s a = %col% + %n%
    &s b = %row% + %m%
    &s nodataflag = [before [value .cv$management%a%%b%]\ \]a
    &if %nodataflag% <> '0a' and %nodataflag% <> '10a' and %nodataflag% <> 'NODATAa' and
%nodataflag% <> ' 'a   &then
    &do
      &s .cv$management%a%%b% = [value .cv$management%a%%b%] + 1
      &run setcellvalue %a% %b% [value .cv$management%a%%b%]
    &end
  &end
&end
```

/* after a households group has occupied a land cell, the environment conditions around its land cell will change

```
gridedit edit newlandenvi
&do m = -2 &to 2
  &do n = -2 &to 2
    &s a = %col% + %n%
```

```
        &s b = %row% + %m%
        &s nodataflag = [before [value .cv$landenvi%a%%b%]\ \]a
        &if %nodataflag% <> '0a' and %nodataflag% <> '5a' and %nodataflag% <> 'NODATAa' and
%nodataflag% <> ' 'a  &then
        &do
          &s .cv$landenvi%a%%b% = [value .cv$landenvi%a%%b%] + 0.2
          &run setcellvalue %a% %b% [truncate [value .cv$landenvi%a%%b%] ]
        &end
      &end
    &end
    gridedit save
```

/* after a households group has occupied a land cell, the land prices around its land cell will change

```
    gridedit edit newlandprice
    &do m = -2 &to 2
      &do n = -2 &to 2
        &s a = %col% + %n%
        &s b = %row% + %m%
        &s nodataflag = [before [value .cv$landprice%a%%b%]\ \]a
        &if %nodataflag% <> '0a' and %nodataflag% <> '10a' and %nodataflag% <> 'NODATAa' and
%nodataflag% <> ' 'a   &then
        &do
          &s .cv$landprice%a%%b% = [value .cv$landprice%a%%b%] + 0.2
          &run setcellvalue %a% %b% [truncate [value .cv$landprice%a%%b%]]
        &end
      &end
    &end
    gridedit save

      gridedit edit newresident
```

/* set indicate of passing the examination

```
    &s findplace = 1
&label begin
&end
&return
```

Appendix 2: Households generation by Monte Carlo method

Households group structure table

Record	INCOME	NUMBER	TENDENCY_T	TENDENCY_E	TENDENCY_P	COL	ROW	ATT

Households generation by Monte Carlo method

The following lists fist 32 groups of all 585 generated groups after running (They have been set to specific positions already according to column (COL) and row (ROW) number)

Record	INCOME	NUMBER	TENDENCY_T	TENDENCY_E	TENDENCY_P	COL	ROW	ATT
1	2	1	4	3	3	182	139	41
2	2	2	4	4	2	200	146	44
3	2	3	4	3	3	182	138	41
4	2	4	4	4	2	165	136	44
5	2	5	5	3	2	185	140	44
6	2	6	4	4	2	187	140	44
7	2	7	4	3	3	192	142	41
8	2	8	5	3	2	182	140	44
9	2	9	4	4	2	181	137	44
10	2	10	5	3	2	181	138	44
11	2	11	4	4	2	184	139	44
12	2	12	4	3	3	166	136	41
13	2	13	5	3	2	201	146	44
14	2	14	4	4	2	189	141	44
15	2	15	4	4	2	184	140	44
16	2	16	4	4	2	190	141	44
17	2	17	4	4	2	210	131	44
18	2	18	5	3	2	204	150	44
19	1	19	3	6	1	201	148	47
20	1	20	3	6	1	200	147	47
21	2	21	4	4	2	164	135	44
22	2	22	4	4	2	188	141	44
23	2	23	4	4	2	203	149	44
24	3	24	3	1	6	126	138	34
25	2	25	5	3	2	164	136	44
26	3	26	3	1	6	127	138	34
27	2	27	4	4	2	160	136	44
28	2	28	5	3	2	201	147	44
29	2	29	4	3	3	210	130	41
30	2	30	4	3	3	202	148	41
31	2	31	4	4	2	159	134	44
32	2	32	5	3	2	159	135	44

Appendix 3: Best fit simulation running result in Arc/Info

This is the running result in Arc/Info before and after best fit simulation residential expansion from 1996 to 2002, and the analysis is carried out in ArcView3.3 in chapter 5.