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كليـــــة الهندســــــة
قسم التخطيط والتصميم العمراني

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بحث مقدم للحصول على درجة الماجستير في
الهندسة المعمارية- تخطيط عمراني

إعداد

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إقرار

هذه الرسالة مقدمة في جامعة عين شمس للحصول على درجة الماجستير في الهندسة المعمارية – قسم التخطيط والتصميم العمراني.

إن العمل الذي تحويه هذه الرسالة قد تم إنجازه بمعرفة الباحث في قسم التخطيط والتصميم العمراني في الفترة من نوفمبر 2005 وحتى يونيو 2007.

هذا ولم يتقدم بأي جزء من هذا البحث لنيل أي مؤهل أو درجة علمية لأي كلية أو معهد علمي آخر.

وهذا إقرار مني بذلك،،،

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التاريخ: / / 200

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نمذجة النمو العمراني

Urban Growth Modeling

يهدف البحث إلى دراسة مدخل لبناء نموذج للنمو العمراني وأسلوب للتعامل مع البيانات المكانية والبيانات غير المكانية واستخدام أدوات علمية وتقنية حديثة وذلك للوصول إلى نموذج محاكاة للنمو العمراني.
ويعتمد الأسلوب المقترح لدراسة نموذج النمو لعمراني على ثلاثة مراحل: مرحلة دراسة الخلفية النظرية وذلك لدراسة وعرض المفاهيم الخاصة بالنمو العمراني. مرحلة دراسة الخلفية التقنية وتتضمن الدراسة عرض للأساليب المتبعة لنمذجة العمران بشكل عام والنمو العمراني بشكل خاص وكيفية التعامل مع المدخلات من معلومات وبيانات خاصة بنطاق الدراسة وذلك للحصول على نماذج لمحاكاة النمو العمراني. مرحلة الدراسة التطبيقية ويشمل نماذج تطبيقية تم عملها لدراسة النمو العمراني من قبل هيئات وجهات أكاديمية وبحثية مختلفة لخروج بمعايير خاصة بنماذج النمو العمراني

The main objective of this research is to recommend a methodology to model urban growth in Egypt
The methodology used to achieve the research objective contains of three stages: Literature review: includes the theoretical background - studying and presenting Urban Growth relating concepts and theories.
Model building: Contains presenting and exploring methods used with inputs "Data and Information for the study area" to obtain outputs related to Urban Growth.
Application of scenarios and models: Real Applications already have been designed and run by governmental and academic organizations to model urban growth to show the various scenarios in building each urban growth model. To conclude recommendations for building urban growth in Egypt, putting some suggestions and could be useful in building urban growth models in Egypt.

جامعـــة عيـــن شمـــس
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قسم التخطيط والتصميم العمراني

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إهداء

إلى كل من علمني حرفاً منذ الصغر وحتى الآن،

إلى جيراني وأصدقاء الطفولة وزملاء الدراسة والعمل،

إلى المنصورة وأهلها – بلدي - حيث الأصل والجذور،

إلى أخوتي أجمل نعمة من بها الله علي وعلى والدي في دنيانا،

إلى أقرب من في الأرض إلى قلبي وعقلي،

أمي

وإلى من يعتبرني حلم الماضي وأمل المستقبل

أبـــي

شكر

أتوجه بجزيل الشكر إلى السادة الأساتذة الذين قاموا بالإشراف

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كما أشكر كل من ساعد في إتمام البحث من افراد أو هيئات وأخص بالذكر الدكتورة جيرمين الجوهري والتي كثيراً ما شجعتني طوال فترة العمل بالبحث والمهندسة مروة محمد عبد اللطيف التي لم تتوان في تقديم يد المساعدة حتى يخرج البحث في هذه الصورة.

ملخص البحث

سامي محمد زكي عفيفي، نمذجة النمو العمراني، رسالة ماجستير، جامعة عين شمس – كلية الهندسة – قسم التخطيط والتصميم العمراني

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مقدمة:

يعتبر النمو العمراني من أولويات اهتمام جميع المخططين سواءً كانوا عمرانيين أو اجتماعيين أو اقتصاديين أو سياسيين، وذلك لأن لها الكثير من التأثيرات على المستويين الاجتماعي والسياسي هذا بالإضافة إلى الاستهلاك المتزايد من الأراضي الزراعية لتغطية احتياجات ومتطلبات النمو العمراني وما يستتبع ذلك من نتائج سلبية تحد من الاستدامة سواء على المستوى المحلي أو على المستوى الإقليمي وهو ما أدى إلى ظهور الكثير من النظريات التي تناقش عمليات النمو العمراني إما من ناحية المسببات أو من ناحية التأثيرات الناجمة عنها.

ومن هنا يظهر الاحتياج إلى عمل نموذج محاكاة للنمو العمراني وذلك لدراسة مدى التغير في استعمالات الأراضي واتجاهات وأشكال النمو العمراني ومن ثم دراسة ما يلزم فعله لمواجهة هذه التغيرات.

ومن ثم فإن موضوع الدراسة المقترح هو أسلوب عمل نموذج لمحاكاة النمو العمراني وتوقع شكل العمران مستقبلاً.

أهداف الدراسة:

يهدف البحث إلى دراسة مدخل لبناء نموذج للنمو العمراني وأسلوب للتعامل مع البيانات المكانية كالخرائط المساحية والبيانات غير المكانية كالبيانات الاقتصادية والسياسية واستخدام أدوات علمية وتقنية حديثة وذلك للوصول إلى نموذج محاكاة للنمو العمراني.

منهج الدراسة:

يعتمد الأسلوب المقترح لدراسة نموذج النمو لعمراني من ثلاثة مراحل:

- مرحلة دراسة الخلفية النظرية Urban Growth (Literature review)

وذلك لدراسة وعرض المفاهيم الخاصة بالنمو العمراني.

- مرحلة دراسة الخلفية التقنية Urban Growth Complexity Modeling

وتتضمن الدراسة عرض للأساليب المتبعة لنمذجة العمران بشكل عام والنمو العمراني بشكل خاص وكيفية التعامل مع المدخلات من معلومات وبيانات خاصة بنطاق الدراسة وذلك للحصول على نماذج لمحاكاة النمو العمراني.

- مرحلة الدراسة التطبيقية Application of scenarios and models

ويشمل نماذج تطبيقية تم عملها لدراسة النمو العمراني من قبل هيئات وجهات أكاديمية وبحثية مختلفة لخروج بمعايير خاصة بنماذج النمو العمراني

مكونات الرسالة:

تتكون الرسالة من خمسة أجزاء رئيسية كما يلي:

- الجزء الأول : المقدمة

ويشمل المشكلة والأسئلة البحثية وهيكل الدراسة.

- الجزء الثاني : النمو العمراني – أسس ومفاهيم

يعتبر هذا الجزء الأساس النظري للرسالة ويشمل عرض لمسببات النمو العمراني وأشكاله وديناميكياته والتأثيرات الناتجة عنه.

- الجزء الثالث: مفاهيم النمذجة

وهو الأساس الفني للدراسة ويشمل عرض لبعض المفاهيم الخاصة بالنمذجة والمحاكاة والمرتبطة بالنمو بشكل عام والأنظمة المعتمدة على مفهوم الاستثارة "الحث" والتي عادة ما تستخدم في نماذج محاكاة النمو العمراني مثل:

Cellular Automata، Agent-Based modeling, Artificial Neural Network

- الجزء الرابع: نماذج النمو العمراني

ويعرض هذا الجزء بعرض لأمثلة لنمـــاذج النمـــو العمرانـــي Urban Growth Models applications والتي تم بنائها فعلاً لدراسة النمو العمراني ودراســـة مـــدخلاتها وأسلوب التعامل مع تلك المدخلات للوصول إلى المخرجات والنتائج المطلوبة.

- الجزء الخامس: النتائج والاستنتاج

وهو الجزء الذي يشمل النتائج والتوصيات الخاصة بالدراسة ويشمل أسلوباً مقترحاً لعمل نموذج محاكاة للعمران في مصر سواء في الريف أو الحضر.

الكلمات المفتاحية: التجمعات الحضرية، النمو العمراني، النمذجة، المحاكاة، نظم المعلومـــات الجغرافية، اتخاذ القرار.

Urban Growth Modeling

Msc Thesis

By:
Eng: Samy Mohammad Zaki Afifi

June 2007

Ain Shams University
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Urban Growth Modeling

Thesis Proposed to the Master Degree of science in Architectural Engineering – Urban Planning

Edited by

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Cairo

June 2007

Urban Growth Modeling

By

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This dissertation is submitted in Ain Shams University for the degree of Msc. In Architectural Engineering – Urban Planning.

The work in this thesis was called out by the author in Department of Urban Planning, Ain Shams University from November 2005 to June 2007.

No Part of this thesis had been submitted for a degree of a qualification of any other university.

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List of Terms

UGM = Urban Growth Model

CA = Cellular Automata

ANN = Artificial neural network

MA = Multi Agent

SOS = Self organizing System

TP = Transition Potential of cell

NB = Neighborhood Effect

AC = Accessibility Effect

SU = Suitability Effect

PL = Planning Influence

SEco = Social-Economic

TR = Transition Rule

TPR = Transition Potential Rule

CRR = Confliction Resolving Rule

RIKS = Research Institute for Knowledge Systems model

SLEUTH = Slope, Land cover, Exclusion, Urbanization, Transportation, and Hillshade model

UCAM =Land Use Cellular Automata model

Abstract

Throughout the years, urban scholars have been interested in studying Urban Systems and related phenomena. Among such phenomena is Urban Growth. In its broader concept, Urban Growth includes the physical, Socio-economic and environmental dimensions (in a particular area). It involves the transition from non-urban to urban activities. In a way, Urban Growth is related to the change of land cover, which happens spatially causing various patterns; functionally in the land uses and temporally with different time rates.

Accordingly, many theories and researches attempted to explain how urban growth takes place, what its driving forces and effecting factors are and what its effects are. In this course, models and simulations were developed to aid such work.

Overall, modeling is to represent reality of the system to be studied in a simple and abstract way. In the domain of Urban planning, modeling could be designed and used for analyzing, evaluating and forecasting. Thus, it could be helpful for decision-makers to predict what the results of their decisions are. However, after the developing of complexity and non-linear theories – the most promising science in the 21st century (Cheng, 2003) –, new development wave of modeling and simulating appeared to represent these new theories and apply it in the different fields within them Urban System.

In this thesis Urban Growth System is explored; its driving and effecting factors – its negative effects. Then, the methods for modeling urban system are presented. After that, some examples of real Urban Growth models are shown to finally conclude the data required for building an Urban Growth Model in Egypt, rules, scenario, analysis and output.

Key words: Urban settlements, Urban growth, Modeling, Simulation, GIS, Decision making.

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Samy M. Z. Afifi

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Chapter One

Introduction

1 Introduction

1-1 Background

In all countries around the world, urban researches seek answers for many unsolved problems. These include issues such as urban population growth, urban gaps, and urban environment deteriorating. Among these puzzling problems are urban growth and expansion phenomenon.

Usually decision makers ask questions, such as- How large will the city become over the next few years? Where will the new urbanized areas be located? What are the consequences of future urban growth? What are the policy implications of new growth? What should be done now to avoid or mitigate negative impacts in the future?

To answer these questions, researches are constantly searching for new approaches to help. Modeling is one of these methods. It is a technique to simplify and abstract real world to virtual one in order to help in understanding urban dynamics (Benders, 1996).

In fact, thinking about urban dynamics has changed after the introduction of complexity and non-linear theories. Previously, urban dynamics was thought as a matter of cause-effect direct relations. Currently, urban dynamics is perceived as a complex urban system that has large interrelations between its consistent parts with top - down and policy constraints. This system is emergence and self-organizing (Sun 2003).

According to this change in thinking, as well as the evolution of computer science; the methods of modeling have developed from static and aggregate based on simple theories into dynamic and non-linear based on complexity theory.

In general, these methods appear to be alike as they are representing urban phenomena. Nevertheless, they are different in the theories behind each method, inputs, analysis and rules that are responsible for explaining how cities work (Torrens, 2000). They are the responsible of interaction between neighborhoods and control the simulation of forcing in the system.

By setting rules, Some experiments were conducted to build urban growth models. On the one hand to analyze these phenomena, on the other hand to help the decision makers to take appropriate decisions, by bearing in mind the reaction of their decisions. Allen and Lu (2003) argue that quantified, visualized, and spatial information on future urban growth obtained through urban growth models will benefit decision-making regarding planning, environmental impact studies, and general public education.

In Egypt, Decision makers direct their attention to managing urban growth in rural and urban settlements. Thus, they are in deep need of modeling urban growth, for either short-term time or long term plans.

Nonetheless, it is important to consider that there are still some problems facing building urban growth models. Geoffrey (2003) argues that the application and performance of the models is still limited by the quality and scope of the data needed for their parameterization, calibration and validation. Also Allen and Lu (2003, p2) note that "*To date, urban modeling and growth prediction remain largely on the frontier of the urban studies field and need further exploration*". So researches have to be done to explore and understand urban growth modeling process.

1-2 Research problem

As mentioned earlier, urban growth is a complex system. It has some characteristics that need to be modeled in order to be analyzed.

This crucial to understand the current situation and help decision makers in imagining the future.

Many methods have been developed to model urban phenomena; each has its methodology and components. Yet, the question that poses itself among these methods what is the appropriate method of modeling urban growth. Consequently, the problem of the research is the absence of – or even a methodology could be used in designing - an urban growth model in Egypt.

1-3 Research goal

The goal of this research is to recommend a methodology to model urban growth in Egypt.

1-4 Research objectives

To attain the goal of the research, there are some objectives. The first objective is to define urban growth, understand the factors and effects of the system. The second objective is to point out available methods for modeling urban growth, as well as to explore and explain how to benefit from them. The third objective is to review the international experience in urban growth modeling. Based on this, the last objective is to place some recommendations about the components needed for modeling urban growth in Egypt.

1-5 Research questions

To attain its objectives, the research poses a set of questions to achieve each objective. First, to define urban growth, the study poses questions such as:

- What is Urban Growth?
- Which factors will influence urban growth?

- Why are we in need of modeling Urban Growth? (What are the negative effects of urban growth?)
- What are the complexities related to urban growth?

Second, to investigate modeling, and explore various methods for modeling, the set of questions include:

- What is modeling?
- How could urban complexities be transformed into modeling?
- What are the methods could be used to model urban growth?
- What is Geographic Information System?
- What are the techniques used in modeling urban growth?

Third, to analyze the international experience and deduce lessons, questions cover issues such as:

- What are these models inputs?
- What are their rules and scenarios?
- What are their outputs?

Finally, to offer Suggestions for modeling urban growth in Egypt, the study answers questions such as:

- What are the needed inputs?
- What are the scenarios that could be applied?

1-6 Methodology

The methodology used to achieve the research objectives and answer its questions contains of four stages (figure 1);

Literature review: includes the theoretical background - studying and presenting Urban Growth relating concepts and theories.

Model building: Contains presenting and exploring methods used with inputs "Data and Information for the study area" to obtain outputs related to Urban Growth.

Application of scenarios and models: Real Applications already have been designed and run by governmental and academic organizations to model urban growth to show the various scenarios in building each urban growth model.

Finally Recommendations for building urban growth in Egypt, putting some suggestions and could be useful in building urban growth models in Egypt.

1-7 Thesis structure

Chapter 1 presents the background of this research. It defines its problem, objectives and questions related to them. Also, the chapter describes the methodology adopted to achieve the objectives and answer the research questions.

Chapter 2 introduces the research theoretical background. It attempts to define and understand – put the scope and limitations for - urban growth as well as the forces behind it. Moreover, the chapter addresses the negative effects of urban growth that makes it a focal point for urban scholars. Furthermore, the discussion extends to understand where such effects happen in the urban system and the complexities behind that.

Chapter 3 is considered the core of this research. It constructs the technical background, as it focuses on modeling. The chapter presents the definition of modeling and urban models. The chapter discusses the ability to link between urban growth complexity and urban models. Furthermore, it attempts to study the methods used in such types of modeling.

Chapter 4 reviews a number of previous applications and experiments for building urban growth models. The chapter attempts to examine the methodology, inputs scenarios and rules controlling each model.

Chapter 5 sums up the conclusions of the study and highlights the main finding of the research. It goes on to make recommendations that would be useful to build a local urban growth model.

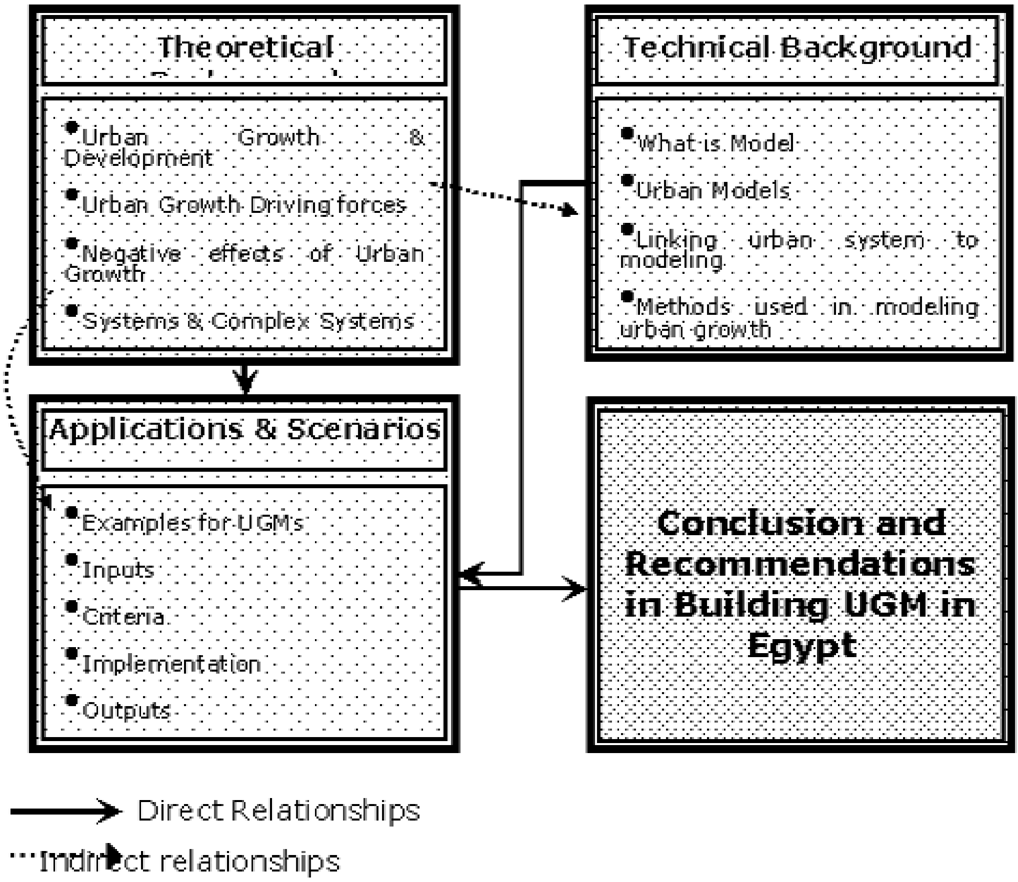


Figure 1 Research flowchart

Chapter Two

Urban Growth – Literature Review

2 Literature review

This chapter is considered the THEORITICAL BACKGROUND of the research. Section 1-1 defines urban growth and describes it as a type of urban system. Further, section 1-2 discusses the driving forces and the effecting factors, which stand behind urban growth. Then, section 1-3 tackles the effects resulting from the urban growth phenomenon, which make from it a focus point for urban scholar. Finally, section 1-4 discusses urban growth as a complex system. Consequently, chapter 2 achieves the first research objective – related to the urban growth definition, its forces and causes.

2-1 What is Urban Growth?

Urban growth is a phenomenon that takes place in the urbanized areas all over the world. "An urbanized area is a central city and its contiguously developed suburbs", (U.S. Bureau of Census data on Urbanized Areas, 2007). "Urban growth is defined as growth that makes intensive use of land for the location of buildings, structures, and impermeable surfaces to such a degree as to be incompatible with the primary use of such land for the production of food, other agricultural products, fiber, or the extraction of mineral resources", (Vancouver Comprehensive Plan 2003–2023, 2004: pA-2). Another definition of urban growth is put by Endresen (2005: p 5-1) who argues that "urban growth is defined as those areas, designated by counties within which urban growth shall be encouraged and outside of which growth can occur only if it is not urban in nature Within these UGAs, growth will be encouraged and supported with adequate facilities. Areas outside of the UGAs will be reserved for primarily rural and resource uses".

Based on Shenghe and Sylvia (2002), Junfeng (2003: p11) concludes a subjective definition that "Urban growth 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".

Urban growth has economic and social growth engines such as local or regional steering, natural increase and immigration. These engines need some change in the urbanized area, either spontaneously or in a planned way. The latter implies urban development plans, whereas the former happens naturally by people without decision makers interposing and could lead to spontaneous urban expansion.

Urban development is the use of all the available resources and methods to improve the urban environment which humans live in (ElWakil, 2006). Therefore, urban development may aim to urban expansion or not.

Thus, urban growth could be spontaneous or planned, urban expansion denotes an increase its area. This growth could be horizontal (two-dimensional) or vertical in the third dimensional. The focus of this research is to study the horizontal urban growth due to lack of three-dimensional temporal data.

In all, it could be deducted that the most appropriate and subjective definition of urban growth is the phenomenon of land transition from non-urban (empty lands, vacant ...) to urban. This would definition adopted throughout this research. So the scope of the research is to determine the transition only without putting into account the form of urban growth.

2-2 Urban growth Types

Urban growth has many types and in order to identify its various types; it is crucial to understand how the city spatially grows. Doxiadis (1968) shows that if there is a city (figure 2) in a uniform land, then the growth happens in regular concentric circles. The growth of the city happens in several phases. In the beginning, the growth happens linearly along lines of favorable and required conditions. Then, the growth fills the spaces between axes as to equalize the conditions. Following that, the growth happens again linearly along new lines of favorable and required conditions, and again fills the spaces between axes as to equalize the conditions in a non-uniform form because of non-equal slopes, heights, soils and so on...

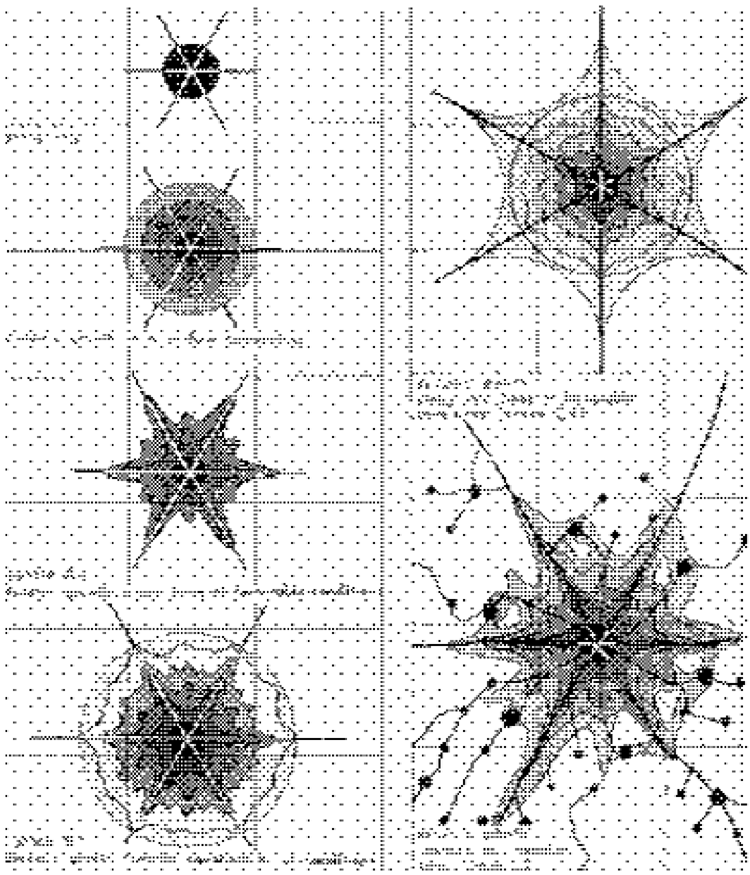


Figure 2 Urban growth phases of change (Doxiadis. 1968)

In view of that, urban growth could be divided by three types (as in figure 3). These types are:

A-*Infill urban growth*: is the conversion of non-urban lands surrounded by urban lands into urban areas. Wilson et al., (2002) note that "*Ellman, T. (1997) defines infill policies as the* *encouragement to develop vacant land in already built-up areas. Infill development usually occurs where public facilities such as sewer, water, and roads already exist*". In their study about urban transitional zones in Greater Cairo Region, Salheen and Attia (2003) delineated some zones of infill urban growth in Cairo, such as the areas between Old Cairo and Shobra such as elSabtiyyah.

B-***Expansion urban growth*** (aslo called urban fringe development): is the conversion of non-urban areas, which have limited number of urban neighborhoods to urban lands. This type of growth usually occurs in the boundary of the urbanized area. Mansheiiet Nasser in Cairo could be considered as an example to expansion urban growth (Salheen 2005)

C-***Outlying urban growth:*** is the conversion of non-urban areas some distance away from existing urban areas- usually called interior non-urban- into urban areas. Wilson et al. (2002) had divided this type into 3 sub types:

- *Isolated growth* is a characteristic of a new house or construction generally surrounded by non-urban and some distance from an existing urban area.(ibid: p2)
- *Linear branching* represents a new road or new linear development surrounded by non-urban and some distance from existing urban areas. It has further connected interior-to-urban (ibid: p2)
- *Clustered branching* – also called leapfrog development- is a characteristic of a new neighborhood or large complex.(ibid: p2)

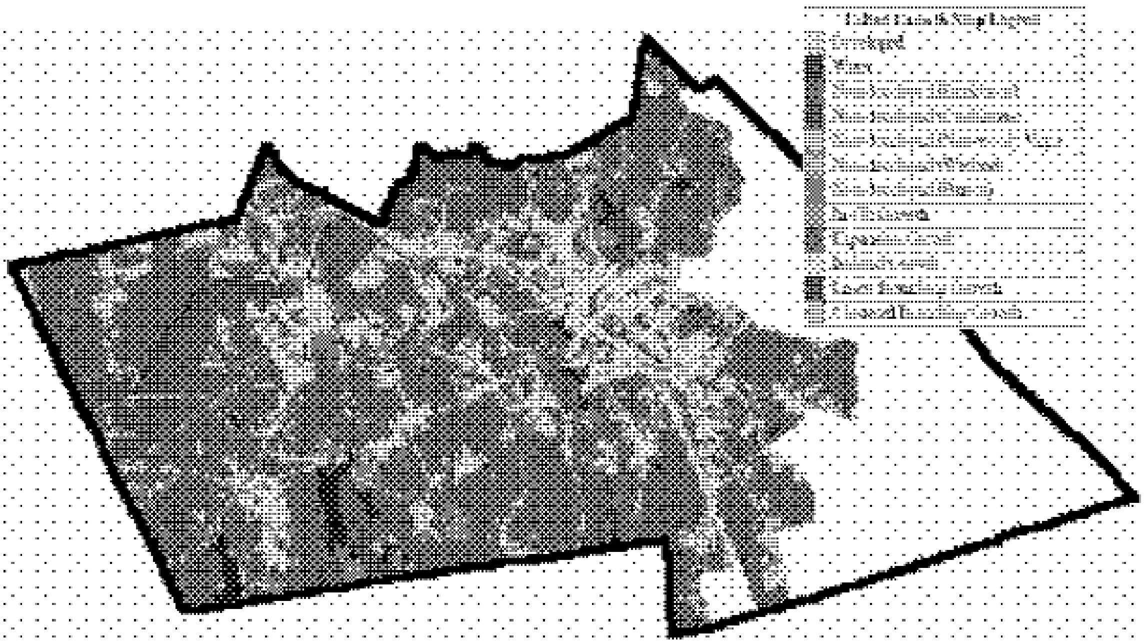


Figure 3 Types of urban growth in the urban growth map for part of the town of Colchester (1985, 1999). (Wilson, E. et al. 2002)

2-3 Urban growth driving forces and effecting factors

Each social, economic or urban phenomenon has its own forces that either motivate and accelerate it or restrict and constrain it. Among these phenomena is the urban growth phenomenon. The forces affecting urban growth are driving forces and effecting factors. The latter refers to micro scale and quantitative objects such as accessibility to roads system, whereas the former is related to macro scale and qualitative objects such as economic policy.

2-3-1 Urban growth driving forces

The value of driving forces differs from system to system, from country to country or from time to time, the driving forces could be categorized into:

- Market mechanism: In western countries, the selections of urban growth locations are directed by the capitalist production mode of profit making (Junfeng 2003). Increasing income and living standard in urban areas is a representative of market mechanism, which also affects the form of urban growth; i.e. its pattern and population density related to it.

- Government policy and control: The procedures -which are related to urban growth projects, the extent of management centralization and the exceptions affordable by government system in implementing laws, represent forces in urban growth especially on the regional level (Salah 2002).

- Transportation Technology: this contains private and public means of transportations and right of ways, Richard Bolan and Thomas Luce (1997: p2) argue, "*Accessibility is a fundamental creator of value in land and the modern ground transportation system has changed considerably in the last two decades. This system is the engine driving today's urbanization process. The interstate highway has become the dominant anchor of urban development and the competition for central land occurs in numerous locations i.e., wherever there is an interchange where the high speed limited access right-of-way is linked to local rights-of way*". This force, also, affects the location of the new urban growth either on the periphery of urbanized area – in case of small cities or bad transportation or lack of roads networks – or distant away the urbanized area.

- Growth of population and urbanization, especially rural immigrants to urban area: this phenomenon particularly takes place in developing countries.

2-3-2 Urban growth effecting factors

As mentioned earlier, urban growth effecting factors are related to micro scale and quantitative objects (Junfeng 2003). Therefore, on the one hand they could be recognized as the interrelation between land parcels and their neighborhoods. On the other hand, they could be measured. The effecting factors could be categorized as follows:

- **Physical properties of land:** The land type, its productivity – if it is an agricultural land – and its slope greatly influence its suitability to urban growth, this factor could also be called ***suitability factor***.
- **Accessibility:** Accessibility of land parcels in a city to road networks has an influence in rate and form of urban growth. The potential of land parcel to convert from non-urban to urban is high when it is near to major and minor roads or to railway, but Wu and Yeh (1997) argue that distance to roads or railways is indicator but they prefer to relate urban growth to the transport stations.
- **macro location:** The location of the land in the city, its relation to the center or sub centers of the city, the uses of neighboring locations and infrastructure such as electricity and telecommunications have influences in urban growth. for example, Salah (2002) refers to the relation between urban growth and industrial parks in Cairo urban growth.
- **Planning and policy:** The policy planning input could put a value for each location to allow the urban growth to happen that encourages urban growth in some locations such as desert lands and restricts it in other locations like agricultural lands. This control appears in master plans, management procedures and laws.

Finally, it should be denoted that from country to country and from period to period the effecting factors may differ in weight while converting land parcels from non urban to urban and the help of models could be used to determine the effect of each factor in urban growth process.

2-3-3 Why are we in need of studying urban growth?

Rapid urban growth is expected over the next 10 to 20 years because of economic development and means of communications revolution (Masser and Ottens 1999). There are some phenomena related to urban growth that lead to directing the attention of urban scholars to urban growth. Some of these phenomena are spatial such as Urban sprawl, Urban gaps and peri- urbanization, that could briefly discussed as follows:

Urban Sprawl: Urban sprawl is the diffusion of a city and its suburbs over more and more agricultural (or even vacant lands) at the periphery of an urban area to provide for jobs, recreation, shopping, transportation, government services ... . Knowing the actual square kilometers of urban expansion (sprawl) provides a key indicator of the threat to the natural environment and agricultural resources. According to Beck et al.(2003: p23), sprawl is characterized by five features which are:

- Progressive loss of open space at urban perimeters as an urban area grows and spreads into the surrounding countryside;
- Low-density character, in contrast to compact urban cores;
- Chaotic or unplanned nature;
- Dependence on the automobile; and
- Connection with the decay of inner cities.

The decision makers - under the pressure of population growth - are in conflict between Increasing – or maintaining - density to stop sprawl, and reducing density to improve the quality of life. Usually the clue to analysis urban sprawl is the comparison between main urban areas density and sprawled urban areas density. This phenomenon has a socio-economic dimension as land value increases if it is urban. In addition, It has a spatial dimension; the nearer the vacant or agricultural areas are to the urban area, the more the potentiality to convert to urban area.

Peri-urbanization: is defined as a process in which rural areas located on the outskirts of established cities become more urban in character, in physical, economic, and social terms, often in a gradually manner (Webster 2002). In Egypt, peri-urbanization is one of main urban growth forms, as in Greater Cairo Region (GCR), especially after the revolution in 1952 (Salah 2002). Again this phenomenon has a socio-economic dimension, as the farmers often need to be urban population in their characters. It has also a spatial dimension, the nearer the rural area is to the urban area, the more the potentiality to agglomerate with it.

Urban gaps: the consequence of – uncontrolled - growth for cities leads to unbalanced distribution for services and infra structure. The more the city enlarges, the more land values in central area raise which results in directing population into the outer of the city. Serag (2004) noted that 17% of housing units in Cairo are empty which is an example for urban gaps.

From discussing urban growth driving forces as well as the effecting factors and negative effects, it could be concluded that urban growth has many relations with other elements. Thus, it could be viewed as a system

2-4 Urban growth system

Previously, urban scholars used to deal with urban areas as only natural or social phenomenon. This led to wrong analysis and predictions. Recently, areas are treated as complex systems that have many interrelations inside them. In the following section, System and Complex system will be briefly introduced.

2-4-1 System

"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. 1992 in Junfeng 2003: p9). Thus, any system has some properties, which are:

- Consisting of a set of elements -or of parts- that are connected to each other by at least one distinguishing principle. Besides, the system may contain some sub-systems.
- Having a specific boundary, that separates the system from the surroundings, and defines the limits of its interactions.
- Emergence that is a phenomenon where high-level behaviors emerge naturally out of low-level interactions; and this is the key property of system, which differs it from other combinations such as sets.

2-4-2 Complex System

Commonly, any system has relations between its consistent parts. When the inter-relationships between these parts are simple or one-way direction; then the system is called a general or simple system, such as analog clock system (A gear moves another one leads the second hand to move the minutes hand and so on). While, when the system inter-relationships are complex; then the system is called a complex system (figure 4).

According to Sun. (2003), Complex systems have some typical properties which are:

1. Non-determinism and tractability: so the system is not predictable;
2. Limited functional decomposability;
3. Distributed nature of information and representation;
4. Emergence and self-organization

The first property means that the system is unpredictable. While the computer – for example - has many relations between its parts, yet it is not considered as complex system. It is only a complicated system that contains some sub general systems.

The second property indicates that the system elements are difficult to be decomposed; as the behaviors of the elements are different when they are isolated or separated.

The third property implies that when there is a system, which is composed of many parts; the emergence is different from the sum of its parts but depends on them. Cheng (2003: p16) summarizes this as "a whole that is greater than the sum of its parts or in simple terms, much coming from little".

The key property of fully complex system is the fourth property. When there is a system, which organizes itself internally without any need of any external force; this system is called Self Organizing System (S.O.S.). In this case, the system interaction requires an interaction with its environment and non-linear relations between its parts. The less the system is in need to external forces, the more the system is Self-organizing. In a SOS, the local actions and interactions of individuals are the source of the higher-level organization of the system into patterned ordered structures with recognizable dynamics (Cheng 2003). Moreover, the dynamics behind this type of systems cannot be understood by decomposing this system to its consistent parts.

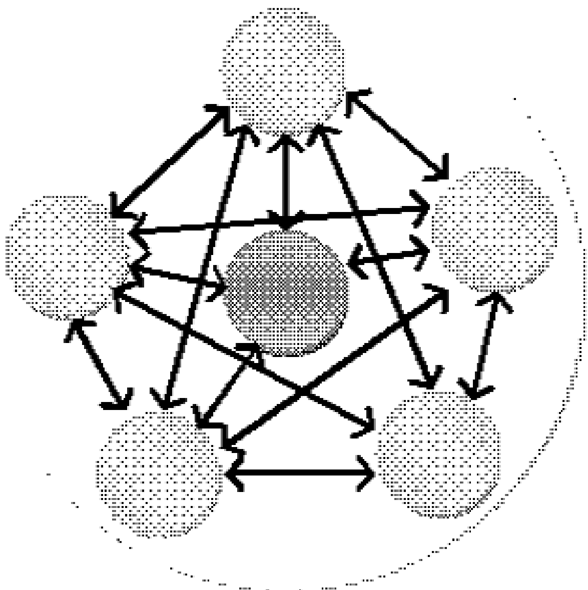


Figure 4 A diagram for a complex system (by the researcher)

As modeling could be viewed as a means of simplifying real world, it is impossible to derive a model to represent the real system without loosing some of the properties of the system (Sun, Z. 2003)

Frequently, complexity takes the form of hierarchy, whereby a complex system consists of interrelated subsystems that are in turn composed of their own subsystems, and so on, until the level of elementary component is reached (Kronert, R. et al. 2001). Hierarchy is usually used to organize and interpret various complexities and to clarify the issues of scale and organizations, and issues of constraints and mechanism.

To interpret a special phenomenon according to the hierarchy theory, when the phenomenon to be studied is put in level 0 (usually called the focal level); the mechanism understanding comes from the larger scale in the lower level (level -1 and it is a larger scale). And the significance of the phenomena will be in the smaller scale in the higher level (level +1) which also presents the boundary conditions and constraints. (Cheng 2003) as represented in (figure 5).

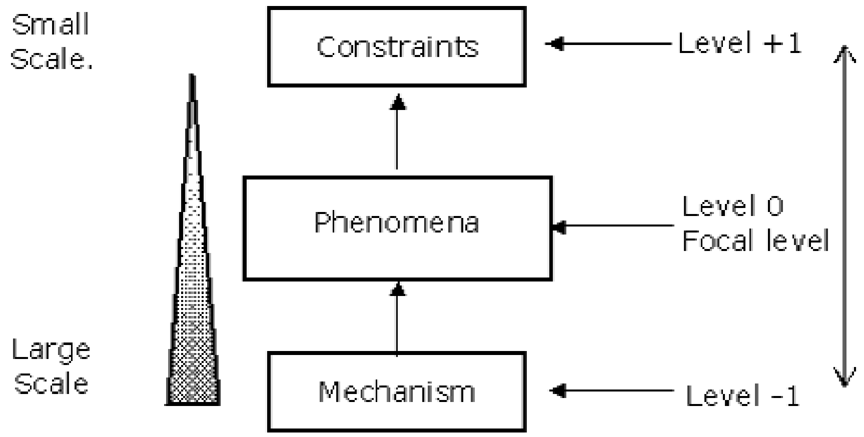


Figure 5 Hierarchy; Levels and scale (by the researcher)

2-4-3 Where is Urban Growth Occurring?

In the field of urban planning, one of the important subjects of concern is to predict the trend of land use transition (Osaragi and Kurisaki 2000). Nonetheless, for the prediction process, it is essential to understand the system under study, so as to reduce the degree of uncertainty which happens due to the numerous factors involved in the system. This could lead to several economic and environmental loss as a result of wrong decisions taken due to high levels of uncertainty.

Moeller (2005: p1) points out that "Urban Areas are the most dynamic region on earth". Also, Cheng (2003: p14) states that "Rakodi (2001) argues that one of the proposals for improving the quality of planning is an attempt to improve the understanding and analysis of the interrelated components of the urban development process in order to arrive at more appropriate priorities and sets of policies".

After the complexity and non-linear theories; a paradigm shift happened in understanding systems within them urban system. In this course, Cheng et al. (2003) argue that scientific understanding must be based on complexity theory and a multidisciplinary framework.

Generally, urban development consists of physical and functional change. The latter refers to change in land uses and activities, while the former refers to change in space from non-urban (vacant) to urban. The scope of this research is the physical change only. Nonetheless, changes in land uses must be taken into consideration when understanding the causal effect of the pattern function as these changes affect the changes in space from non urban to urban, the activities of a location influence the changes on space in another location sooner or later. Therefore, space and time that the main elements to understand an Urban Growth System.

Furthermore, in explaining the occurrence of Urban Growth, Cheng et al. (2003) argue that Urban Growth System G (figure 6) is related to three systems, as follows:

- **Developed Urban System U** which is:
    - A highly complex socio-economic system.
    - Representing concentrations of considerable urban activities at time t_1
    - Contributing in System G with developable land which could be called the pull forces in system G.
- **Developable Non-Urban System N.** which is:
    - A typical physical and ecological system. Including agricultural land, deserts, and forests ... at time t_1.
    - Offering the space for potential Urban Growth to Occur.
    - Contributing in System G with activities and stimulant factors which could be called the push forces in system G.
- **Planned Urban System P.** which is:
    - A spatial and conceptual system that is the result from a spatial planning scheme.

- Presenting the organization and activities of Urban Growth in time t_2.
- Contributing in System G with planning control which could be called The push forces in system G.

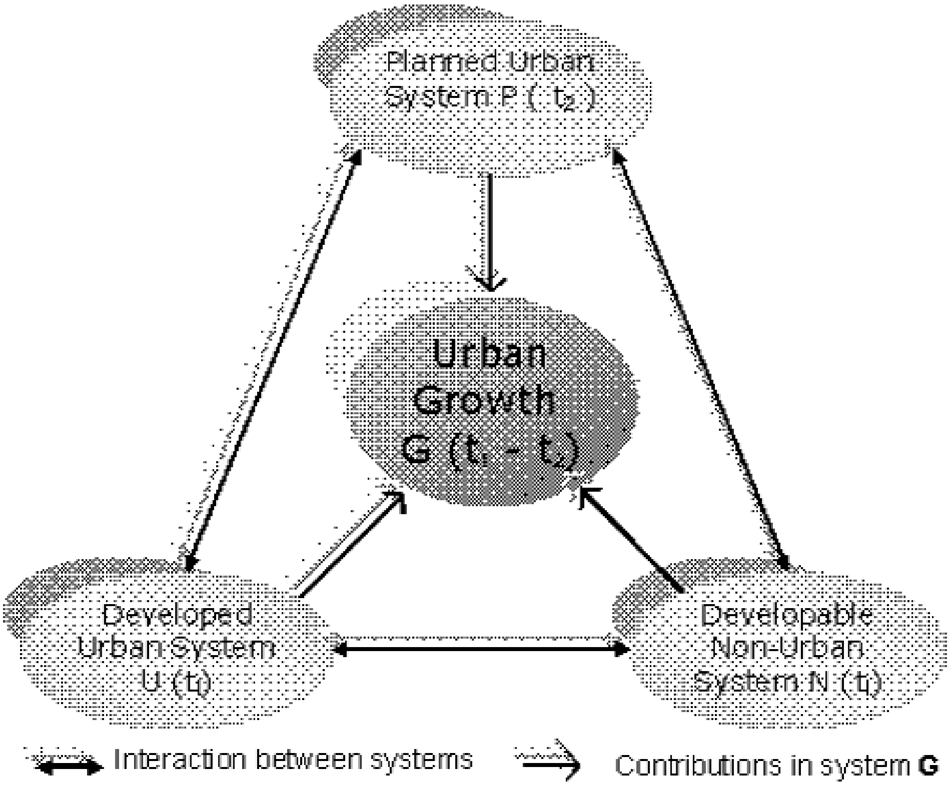


Figure 6 where is urban growth occurring? (Cheng, J. et al 2003)

2-4-4 Complexity of urban growth system

Many studies attempted to study urban areas a whole. Among these studies, Doxiadis (1968) discusses the complex interrelations between various–rural or urban - settlements in region (figure 7). Further, ElWakil (2006) groups these interrelations into natural, movement, infrastructure, socio-economic, activities and services links. These interrelations also affect the settlement and often exist in the urban area itself.

Considering urban growth as an urban phenomenon, urban growth system G also contains many views of complexities. When we see systems P,U and N and their relations to G, we can easily find that the value – and relative value- of contribution of each system in G varies according to regulations and laws controlling urban and environmental system. i.e. Urban growth results in various land uses with different levels of social, economic and environmental values.

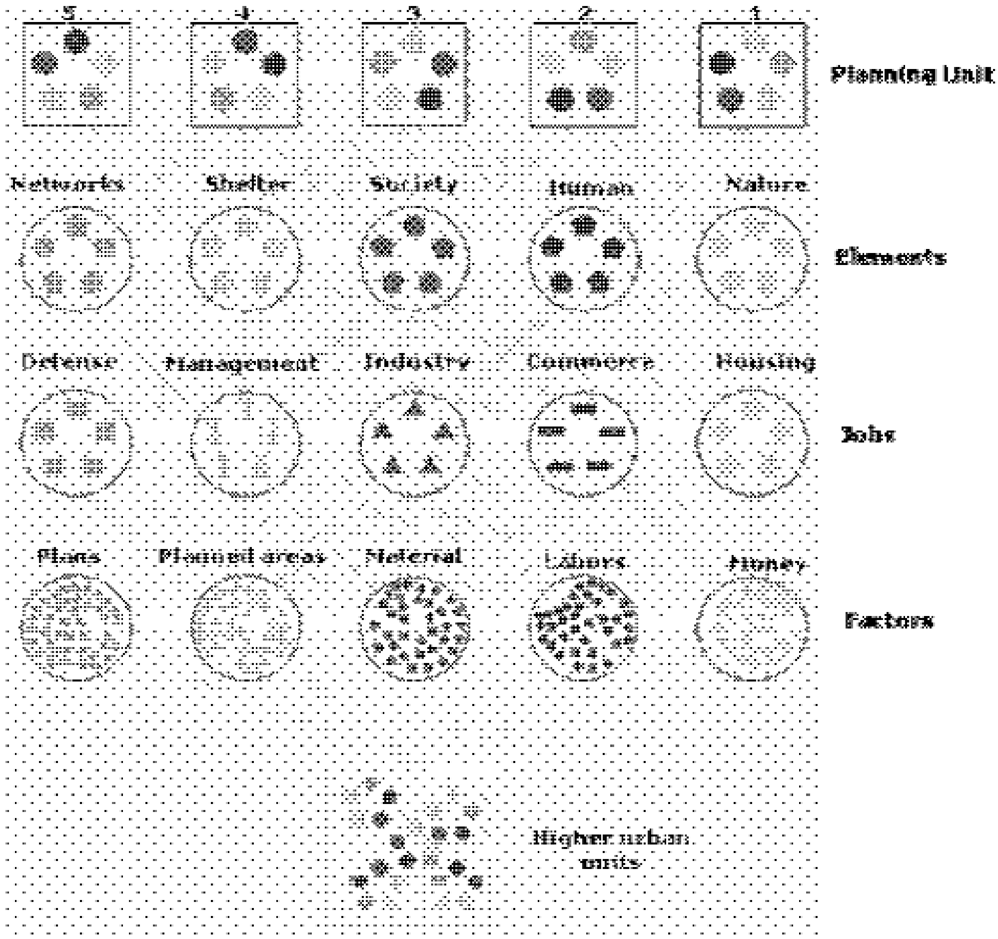


Figure 7 Integrated interrelations between urban settlements in a region (Doxiadis 1968 with modification by ElWakil 2006)

So that if we try to regroup components in the above figure to elements could be put in U, P and N systems, we can find that these relations could be categorized into spatial and decision-making complexities (figure 8).

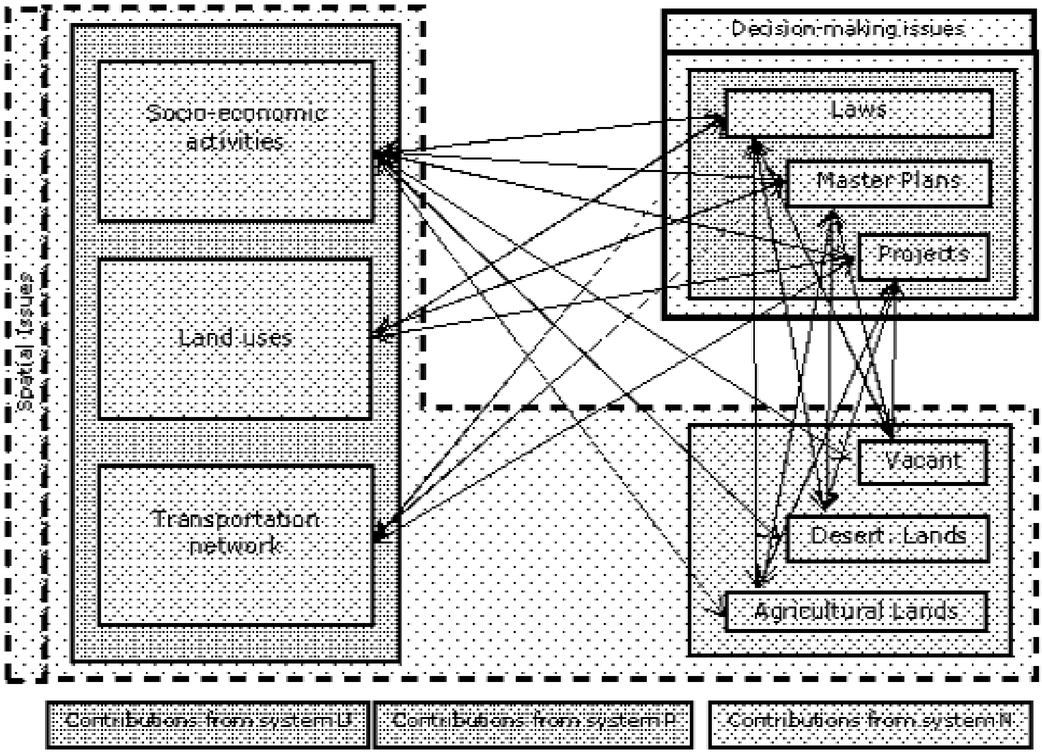


Figure 8 Relation between system contributing items in an urban growth system (by the researcher)

Cheng. (2003) has discussed urban growth complexities by many examples, from these examples:

- Urban growth has spatial complexities. For instance, when testing the potentiality of a specific location to change from non-urban to urban, the result of the test will differ according to the use and characteristics of neighborhood locations. This is called a 'Spatial dependence', which is defined as a functional relationship between what happens at one point in space and what happens at a neighboring point. This potentiality is higher (stimulation) when there are roads or urban uses in neighboring locations than if when neighboring locations are steep and mountains (constraints).

- Urban growth is also based on various-level decision-making processes, from individual land rent to a government's master plan. This is decision making urban growth complexity. The urban growth from the point of decision-making view depends on various actors, each actor has their special domain of decision-making, which are conflicting in their nature. Usually, a small shop only needs the decision-making of one private developer, which means to be uncertain, dynamic and less organized. On contrary, Large-scale projects are more certain and well planned.

- There is another type of urban growth complexities, which is temporal complexity. The temporal scales of various decision-making are different. Large-scale projects such as shopping centers or industrial parks commonly take a few years, much longer than small-scale constructions such as a shop.

Many urban scholars have discussed the interaction between land use and transportation. This interaction could be used to understand the interrelations between the three types of complexities above mentioned. This could be summarized as follows (Hanson 1995):

- Short-term (temporal) effects of land use (spatial) on transport (spatial and decision-making);
- Medium-term (temporal) effects of transport (spatial) on employment location (spatial and decision-making);
- Long-term (temporal) effects of transport (spatial) on housing location (spatial and decision-making).

From the previous discussion, it is apparent that there are many different scales of temporal, spatial and decision-making complexities related to this relation - between two elements - could be regarded at the first glance as spatial relation only. Consequently, it could be concluded that urban growth is a system that has some contribution from physical, ecological and socio-economic activities, and is full of temporal, spatial and decision- making complex interrelations.

2-5 Summary

Urban growth is the phenomenon that comprises the conversion of vacant lands to urban areas. Thus, it differs from urban development, which cares about using the available resources and methods to improve the urban environment

Urban growth phenomena have driving forces that either motivate and accelerate it, or restrict and constrain it. These forces could be categorized into Market mechanism, Government policy and control, Transportation Technology and Growth of population and urbanization. Urban growth effecting factors are related to micro scale and quantitative objects such as Physical properties, Accessibility and Macro location.

There are some phenomena related to urban growth, which direct the attention of urban scholars toward this phenomenon. Urban sprawl, urban Peri-urbanization and urban gaps are among these phenomena.

Accordingly, urban growth could be viewed as a complex system which has contributions from developable, urban and planned urban systems. The interrelation between its elements is spatially, temporally and/or decision-making complexities. Cheng (2003: p138) summarizes urban growth stating that "***Urban growth can be defined as a system resulting from the complex interactions between urban social and economic activities, physical ecological units in regional areas and future urban development plans***".

Chapter Three

Urban Growth Complexity Modeling

3 Urban Growth Complexity Modeling

This chapter is considered as the TECHNICAL BACKGROUND of the research. Section 3-1 defines modeling and simulation and explains urban growth from the modeling viewpoint. Then section 3-2 explores and discusses methods that are used to model urban growth, and explain how to benefit from them

This chapter would achieve the second research objective, which related to exploring and explaining urban growth modeling; methods, rules and scenarios.

3-1 Modeling & Simulating urban growth model

"Managing human affairs through the next century will require extremely complex and reliable computer models" (Maxwell and Costanza, 1997: p1). As urban model is one kind of application of modeling and simulation methods in, the concept of modeling and simulation has to be identified. "Modeling may refer to an abstract (or actual) representation of an object or system from a particular viewpoint." (Wikipedia, 2006). Also Benders argues that modeling means to make prototype, design, and representation of something. That means model is a simplification to -a part of- the real world. Model is an abstraction or simplification of real world (Benders 1996). In fact, Models are used in different ways and different careers from social life to economic decision to military researches.(Junfeng. 2003).

During modeling, semantic gap has to be reduced to minimum. "A semantic gap is the difference between a thing being modeled and the model's representation of that thing" (Enth, 2007). Models with a low semantic gap produce good realistic results, while models with a high semantic may give inaccurate or even complete nonsense results.

Models could be categorized into two categories. The first is physical models, which let people get visual knowledge about real world such as a doll representing a girl, a small car representing a real car, they are also used to make prototypes of a product before production to test the performance of their designs. According to Singh (2003) the objective of these models is to increase communication, to convey knowledge in Education, Training, Negotiation, Gaming .... The second category is mental models which cannot be touched and is related to procedures to be taken by a set of rules or experiences. A visit to a restaurant is an example often used; using a mental map, we do all the actions. These types of models can help in analyzing available data and understand the current state. Singh (2003) argued that the objective of these models is to reduce uncertainty for decision support in Planning, Forecasting and Back-casting. However, people usually use simulations to understand the real world. Simulation is to produce some patterns according to some pre-defined rules before it happen in real world. Usually models help in putting the rules for simulation and the models related to complex system theories focus on simulations (Junfeng 2003).

3-1-1 urban modeling and simulation

Urban growth modeling and prediction history essentially started in the 1950s. it showed less activity in the 1970s and 1980s, but has been revived vigorously in the 1990s, thanks to the improvement in spatial data availability and advancements in computer technologies and geographic information systems (GIS) (Wegener 1994). Successful modeling practices are yet to be reported. The innovative mathematic models, on the other hand, emphasize syntax and urban dynamics, but are difficult to interpret. To date, urban modeling and growth prediction remain largely on the frontier of the urban studies field and need further exploration (Maxwell and Costanza, 1997).

Junfeng.(2003) has argued that urban models are used for these reasons:

- Practical reason,

  Meaning that urban models are related to increase the understanding of urban systems, which are complex and full of uncertainty, so to understand urban system is a hard task. Another reason for applying models in urban research field is to apply urban management. With the help of model we can make different urban simulation, which can be used under some scenarios such as sustainability scenario, sprawl scenario and population increase scenario.
- Academic reason,

  Urban scholars can test and evaluate some theoretical hypotheses and ideas in a controlled environment, since different urban models work as different scenarios i.e. where various experiments can be done.
- Technological reason,

  In urban systems, different spatial simulation technologies can be applied so that they could directly or indirectly encourage the development of urban modeling and simulations.

3-1-2 Urban growth modeling elements

As illustrated in (figure 9), understanding urban growth can be summarized as five interweaving levels: policy, actor, behavior, process and pattern (Cheng 2003). To study a process, one has to put into consideration its pattern that is the temporal output of a process, and behavior, which is the decision-maker for a process as fellows:

- **Policy**

  Policy is a collection of - general - principles and behaviors put by the higher levels in the nation or organization, this collection is considered as the framework of activities in the lower levels (ElWakil 2006).

- **Actors**

  They are the activities decision makers and policy's implementers. In systems involved in urban growth (G., U., P., N. as discussed in chapter 2), the actors include individuals, householders, developers, farmers, landowners, planners and governments.

- **Behavior**

  Behavior refers to the decision-making of actors. It indicates the actions of the actors involved Spatial behavior focuses on spatial decision-making "the properties of site selection, way-finding, and land use allocation", temporal behavior on temporal decision-making "time, speed and nature of the actions). Urban growth results from direct or indirect decisions to alter the current uses of land at various levels.

- **Process**

  Process generally refers to the sequence of changes in space (spatial) and time (temporal), nothing in the physical world is purely spatial or temporal; everything is process. It indicates the dynamics of urban growth

  <u>Processes in urban growth could be categorized into:</u>

  - Spontaneous and self-organized processes (according to complexity theory)
  - global (the whole study area and landscape level) and local (neighborhood) according to hierarchy theory
  - Infill urban growth, expansion urban growth and outlying urban growth processes according to urban growth type (as mentioned in chapter 2).

- **Pattern**

Pattern refers to a regular form or arrangement of objects, In landscape ecology, patterns refer to the spatial configuration of discrete landscape elements, which can be of different geometrical nature.

Although pattern is the static interface of the system and the most quantitative part of it, but it also stimulates or constrains the potentiality of a new development process.

In urban growth it could contain roads networks, streets, land uses, population density, agricultural crops, lakes and rivers ...,etc.

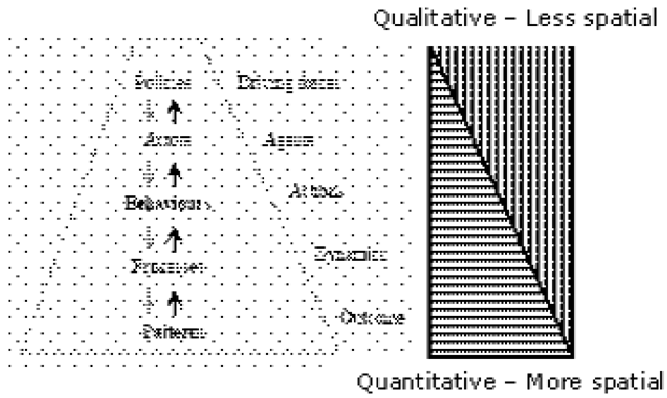


Figure 9 Relation between system contributing items in an urban growth system, (Cheng J. 2003 with modification)

3-2 Urban Growth Modeling techniques

According to that introduced in chapter two about the complexities of urban growth, urban scholars and decision makers have developed some complex and comprehensive urban models built upon some new methods and techniques similar to urban complexities.

These models lead to some relations with other discipline knowledge; such as ecology, geography, mathematics, regional science, and economics ... etc. From these methods some techniques could be presented as ABM (Agent Based Model) – or MA (multi-agent) -, ANN (artificial neural network), and CA (cellular automata) as they are the most new methods and techniques used now all over the world. Before introducing these methods, we have to introduce GIS as the root theory for dealing with any geographic phenomenon.

3-2-1 Geographic Information System (GIS)

"A GIS is a computer system capable of capturing, storing, analyzing, and displaying geographically referenced information; that is, data identified according to location. Practitioners also define a GIS as including the procedures, operating personnel, and spatial data that go into the system" (U.S. Geological Survey, 2007).

3-2-1.1 Components

The components needed to perform GIS tasks include those listed below:

A-People

This is the most important component in a GIS. People must develop the procedures and define the tasks of the GIS. People can often overcome shortfalls in other components of the GIS, but the opposite is not true.

B-Data

The availability and accuracy of data can affect the results of any query or analysis.

C-Hardware

Hardware capabilities affect processing speed, ease of use and the type of output available.

D-Software

This includes not only the actual GIS software, but also various database, drawing, statistical, imaging or other software.

E-Procedures

Analysis requires well-defined, consistent methods to produce correct and reproducible results.

3-2-1.2 Characteristics

Any geographic information system should be capable of the following fundamental operations in order to be useful for finding solutions to real-world problems.

A-Capturing data

A GIS must provide methods for inputting geographic (coordinate) and tabular (attribute) data. The more input methods available, the more versatile the GIS.

B-Storing data

There are two basic data models for geographic data storage—vector and raster. GIS should be able to store geographic data in both formats.

C-Querying data

A GIS must provide utilities for finding specific features based on their locations or attribute values.

D-Analyzing data

A GIS must have the ability to answer questions regarding the interaction of spatial relationships between multiple datasets.

E-Displaying data

There must be tools for visualizing the geographic features using a variety of symbology.

F-Output

Results of display should be able to be output in a variety of formats such as maps, reports, and graphs.

3-2-1.3 Applications in Urban Growth Modeling

You can perform analysis to obtain the solutions to a particular problem. Geographic analysis usually involves more than one geographic dataset and requires the analyst to proceed through a series of steps to reach a result. GIS usually involves in urban growth models through three types of geographic analysis, which are:

A-Proximity analysis

GIS technology uses a process called buffering to determine the proximity relationship between features.

B-Overlay analysis

The integration of different data layers involves a process called overlay. At its simplest, this could be a visual operation, but analytical operations require one or more data layers to be joined physically. This overlay, or spatial join, can integrate data on soils, slope, and vegetation or land ownership with tax assessment.

C-Network analysis

This type of analysis examines how linear features are connected and how easily resources can flow through them.

3-2-1.4 Constraints on GIS urban modeling applications

As it is system - oriented, the constraints related to GIS are actually related to software running upon this system. The computer applications – until now - are not capable of doing all the functions prospected from GIS.

3-2-2 Multi-Agents models

Agent - modeling is a concept originated in the computer sciences that allows for a very efficient design of large and interconnected computer programs. However, its applications nowadays are far more than its original meaning. During 1970s, Artificial intelligence and distributed computing researchers made some experiments and started formulating some theories about interaction of small units in the aim of problem solving. They found also that the output emerges from interaction of entities – or agents- with simpler behaviors (Chong. 2004). Nowadays as there are many networks link large number of computers and human beings, we are in need of developing Multi-Agent Systems (MAS) to understand interactions and permit them to develop and achieve certain tasks.

3-2-2.1 Components

Ferrand, N. (1996) noted that multi-agent system can be defined as a set of agents interacting in a common environment (figure 10), able to modify themselves and their environment. The main components of MAS are agents, objects, behaviors, environments, and communications.

A-Agents

Maes, P. (1994) said, "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". Then "Franklin and Graesser (1997) 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" Chong (2004: p23).

Types of Agents

Beside the definition, there are many types of agents. Chong.(ibid: p23) states five types of agents which are:

- Intelligent agents: entities that follow mental processes or simulate rational behavior.
- Personal assistant agents: entities that help users perform a task.
- Mobile agents: entities those are able to settle networking environments to fulfill their goals.
- Information agents: agents that filter and organize unrelated and scattered data.
- Autonomous agents: agents those are able to accomplish unsupervised actions.

Moreover agents are characterized by flexibility as they could be adapted according to their environment, but they also act in a complex manner to achieve their certain goals and they are autonomous as it only controls their specific actions– or goal – oriented- . Furthermore, as they are intelligent, their behaviors could change according to previous history.

B-Objects

Objects are the set of all represented passive entities that do not react to stimuli (e.g. land, buildings in urban environments).

C-Behaviors

Behaviors refer to the activities taken by the agents within the system, and such behaviors maybe toward other agents or objects

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.

D-Environment

Environment is 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.

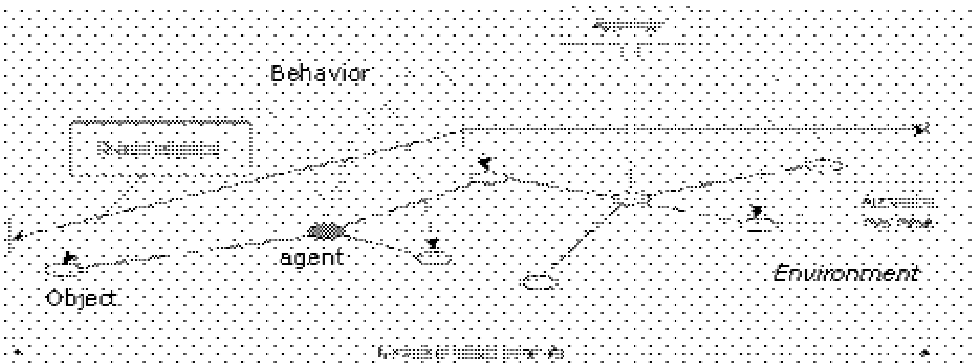


Figure 10 two-dimensional multi- agent systems related by nearest neighbors (Torrens P. 2003)

3-2-2.2 Characteristics

The interest in MAS has increased as it could help in:

- Completing a very large problem by enabling more than one agent, and providing solutions for these problems.
- Interconnecting and interoperating multiple existing systems and agents and allowing inter exchange of information and data among them.
- Providing strong tools for understanding complex systems with their agents and protocols.

3-2-2.3 Application in urban growth modeling

It can be inferred that MA are an ideal tool for understanding decision-making complexity of urban growth at a micro scale, such as a single large-scale project. Its current applications mainly focus on abstracted theoretical research or micro-behavior simulation (Cheng 2003).

3-2-2.4 Constraints on MA urban modeling applications

Actually, MAS have not been widely used in understanding urban growth, the main constraint in using this type of modeling in urban growth is the weakness in representing the bottom – up relationship which could lead to enlarging the semantic gap in urban growth models.

3-2-3 Cellular Automata

Cellular Automata (CA) is a kind of dynamic system devised by John von Neumann and Stanislaw Ulam in the 1940s. It is thought that the concept of “cellular” mainly comes from Ulam, and the “automata” – which refers to self operating comes from von Neumann (Rucker 1999). Tobler, who carried out a study in 1979, is the first person who used cellular approach in geographical planning (Tobler 1970). Later, based on GIS, Batty and Xie developed a CA based model for not only the land use samples but also the urban modeling with integrated transportation network (Kain 1987).

CA consists in discrete dynamical systems that simulate complex behaviors through interactions between the simplest elements of the system (Geoffrey 2003). CA is composed of an array of cells, each cell has a certain state from predefined discrete states, and the state of each cell is updated in discrete time steps because of local interaction between the cell and its surrounding neighborhoods. This interaction is governed by a local identical interaction rule, which is alike to any chemical and physical interaction. "Sierpinski accepted cellular automata as the initial point of science" (Yuzer, M.: p221). They are parallel processors rather than serial processors. This means that more than one particular process is active at any given time, instead of computing stage before next starts as in serial processing. According to White and Engelen (1994), Engelen et al (1997), O’Sullivan et al (2000) and Clarke (2002), the elements that comprise an elementary cellular automaton are:

- The space on which the automaton exists (its lattice);
- The cell in which the automaton resides, which contains its state(s);
- The neighborhood around the automaton;
- The temporal space in which the automaton exists;
- Transition rules that describe the behavior of the automaton.

3-2-3.1 Components

From the pervious background and according to previous references, the components of CA system could be derived as fellows:

A-Lattice

The lattice of CA describes the space in which the CA exists and evolves over time. Any lattice is composed of an array of cells, these cell could be regular (square – hexagons - triangles ...) or irregular in shape and size but it is usually shaped in square cells for simplicity.

B-Cell-states

CA cell-states characterize the attributes of finite state machines in a CA lattice. The states could be defined in a binary fashion – i.e. zero or one – as in a Turning machine, and it could be more than two values "Von Neumann, in his CA, provided for the existence of 29 cell states" Torrens 2000: p17).

C-Neighborhoods

A neighborhood consists of a CA cell itself and any number of cells in a given configuration around the cell.

D-Time

The model runs in discrete time steps, these time steps could be differed from hours to years and could be varied in the model itself.

E-Transition rules

Transition rules specify the behavior of cells between time-step evolutions, deciding the future conditions of cells based on a set of fixed rules. Torrens (2000: p17) mentioned, "Transition rules are the real engines of change in a CA". They are generally formulated as IF, THEN, and ELSE statements that rely on input from a neighborhood template to evaluate their results. The basic transition rule is presented in(Box 1 – Equation 1).

CA models are classified according to their lattice dimensions, which in turn vary according to models nature as fellows:

A- One-dimensional CA

For one-dimensional CAs, a cell is connected to **r** local neighbors (cells) on either side, as well as to itself, where r is a parameter referred to as the radius (thus, each cell has 2r+1 neighbors 2 for right and left and +1 for the cell itself)

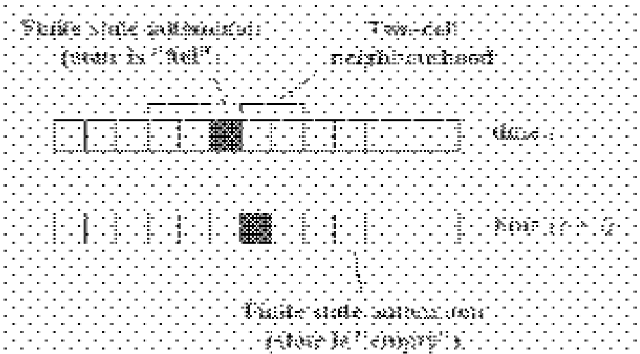


Figure 11 Example of one-dimensional CA model

In the example shown in (figure 11)

<u>Lattice</u>: 1 X 13 square cells

<u>Cell States</u>: full – empty

<u>Neighborhood</u>: 5 cells " each cell and its two neighborhood cells in right side and its two neighborhood cells in left side, r = 2"

<u>Transition Rules: consist of 2 parts</u>

Rule part A

If [cell state is "full"]
Then [proceed to the part B of the rule]
Else [end]
end

Rule part B

If [the majority of the cells in the neighborhood are "empty"]
Then [move one cell to the right along the lattice]
Else [end]
end

<u>Time</u>: t, t+1, t+2, ...

B- Two-dimensional cellular automata

Two-dimensional CA does not differ radically from one-dimensional CA in formulation; their lattice simply extends in an additional dimension.

If we were to extend our CA example from figure 11 into a second dimension, the number of lattice sites grows from 13 to 13^2 (i.e. 169). If the number of possible cell states remains the same (two), the number of possible cell states raised to the power of the number of possible lattice sites, 2^{169} , a significantly larger number than the 8192 possible configurations of the one-dimensional CA.

The neighborhood template in turn may change, the two most commonly defined neighborhood templates for a two-dimensional CA are the Moore neighborhood, which contains the cell and its eight surrounding cells – i.e. nine cells-, and the von Neumann neighborhood which contains the cell and its diagonal surrounding cells – i.e. give cells. (Figure 12) presents these neighborhood templates.

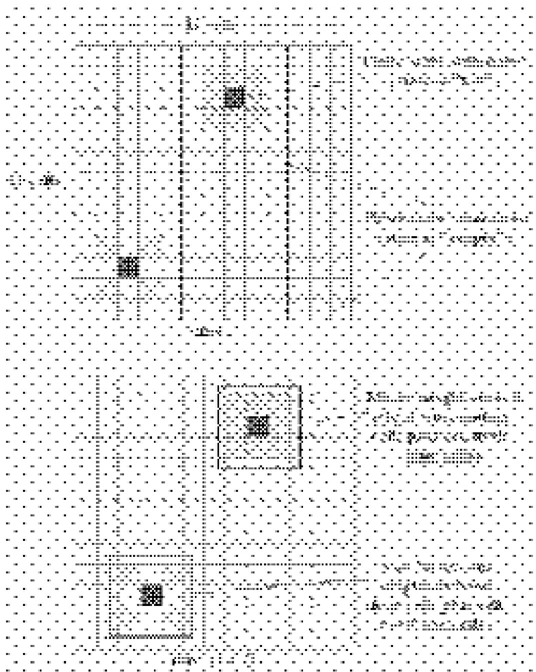


Figure 12 Two-dimensional cellular automata (Torrens, P. 2000)

- **The Game of Life**

The game of life proposed by John Conway is thought to be the most famous two-dimensional CA (Torrens, P. 2000). Its specifications are simple as follows:

Lattice: a square grid of infinite dimensions and the lattice turns in on itself to form a torus.

Cell States: alive – dead

Neighborhood: Moore neighborhoods, consisting of nine cells

Transition rules: consist of 3 sub rules

1- Birth rule

This sub rule check the potentiality of a cell to convert from dead to alive, its code is

if [cell state is "dead" in time *t*]

and if [the number of cells with state "alive" in neighborhood ≥3]

then [set state of cell to "alive" in time (*t+1*)]

end

2- Death rule

This sub rule check the potentiality of a cell to convert from alive to dead, its code is

if [cell state is "alive" in time *t*]

and if [the number of cells with state "alive" in neighborhood >3] – overcrowding –.

or [the number of cells with state "alive" in neighborhood < 2] - exposure –.

then [set state of cell to "dead" in time (*t+1*)]

end

3- Survival rule

This sub rule check the potentiality of a cell to remain alive to, its code is

if [cell state is "alive" in time *t*]

and if [the number of cells with state "alive" in neighborhood >2<3]

then [set state of cell to "alive" in time (*t+1*)]

end

This case has been published as a competition to demonstrate the existence of a configuration within the game that could generate moving configurations of stable patterns. The prize was claimed by Wilson Gosper, R. at the Massachusetts Institute of Technology (Torrens, P. 2000), whose team had coded a version of the Life CA into a computer and found 'glider guns' that were capable of firing a steady stream of wandering gliders (Figure 13). The main result of this glider is the prove of that CA could reproduce copies of itself that were as complicated in their structure (Figure 14).

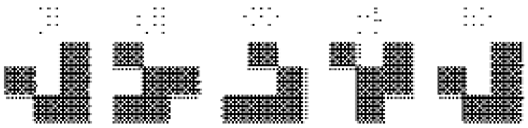


Figure 13 The four evolving stages of glider evolution under the Life CA rules. (Torrens, P. 2000)

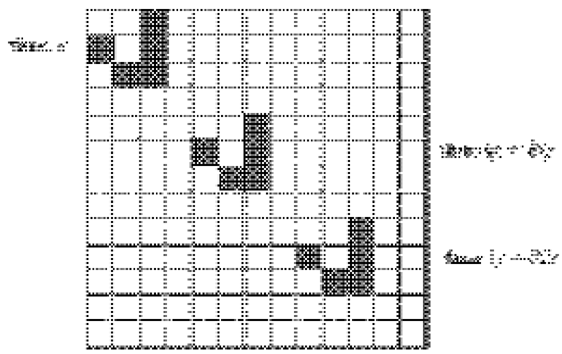


Figure 14 Glider movement, diagonally from the upper left to lower right of the lattice. (Torrens, P. 2000)

Another Example of CA is to use the parity rule (also known as the XOR rule). This example checks he potentiality of a cell to be odd or even by examine its state and the state of the neighborhood either even or odd. Let us consider this example

Lattice: any two-dimensional array of cells

Cell states: Binary states – 0 1 – .

Neighborhood: the cell and its northern, eastern, southern and western cells "i.e. five cells"

Transition rules:

if [if the parity of cell state and the states of its Neighborhood is odd in time *t*]

then [set state of the cell to “1” in time (*t+1*)]

Else [set state of the cell to “0” in time (*t+1*)]

End

The following figure demonstrates patterns that are produced by the parity CA .

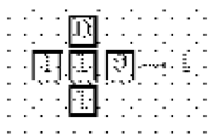


Figure 15 Patterns produced by the parity CA

The output of this CA model could be summarized in the next table

Table 1 Parity rule table.

CNESW	Snext	CNESW	Snext	CNESW	Snext	CNESW	Snext
00000	0	01000	1	10000	1	11000	0
00001	1	01001	0	10001	0	11001	1
00010	1	01010	0	10010	0	11010	1
00011	0	01011	1	10011	1	11011	0
00100	1	01100	0	10100	0	11100	1
00101	0	01101	1	10101	1	11101	0
00110	0	01110	1	10110	1	11110	0
00111	1	01111	0	10111	0	11111	1

In this table CNESW denotes the current states of the center, north, east, south, and west cells, respectively.
Snext is the cell's state at the next time step.

C- Three Dimensional model

As one-dimensional and two dimensional CA models CA could be in a three-dimensional cell lattice in the same technique but such models have not been widely developed, most likely because of the difficulty of designing, building and running CA with dimensions greater than two. "Semboloni 2000 is the only example that the author is aware of multi-dimensions" (Torrens 2000: p 50).

3-2-3.2 Characteristics

CA models are distinctive by some characteristics as:

A-CA decentralized approach

- As it mentioned above CA is based on the interrelation between cells

B-link with the complexity theory and the connection of form with function and pattern with process in a simple methodology

- As mentioned above the characteristics of CA models are similar to those of complex systems, the form of the output – pattern - comes from the functional interrelation – process.

C-Rank-size rules and power laws

- Rank-size rules or power laws drew the relationship between the frequency of occurrence of phenomena and their unit size in a linear relationship as in Zipf's rank law (figure 16).
- These rules and laws are common in CA also. Often patterns in CA will display a relatively small number of regions of the lattice in which cell states are homogenous. (Torrens 2000)

D-The relative ease of geographical information systems (GIS) and remotely sensed data (Torrens and O'Sullivan, 2001)

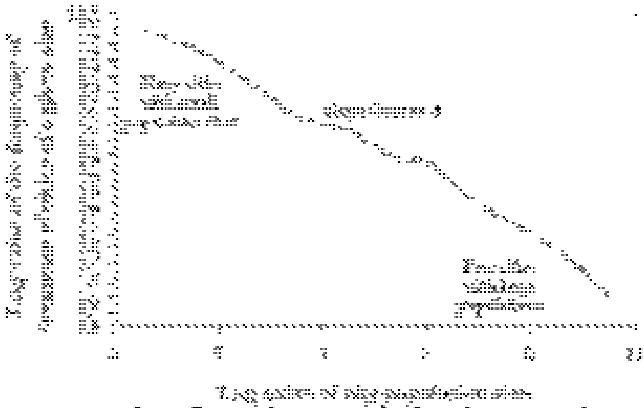


Figure 16 Illustration of Zipf's rank-size rule for the United States, (Torrens P. 2000)

E-Self-organization

- The self-organization of an urban system to a central city at the core of a swirl of edge cities and satellite settlements is an example of spatial self-organizing which is a characteristic of CA models.
- Meanwhile the formation of investment cycles into booms and slumps in equity markets is an example of temporal self-organization, which is exhibited by some CA classes independently of the rules that governed their behavior.

F-Self-similarity and fractal dimension

The patterns that are evolved from CA model showed – over time – a degree of self similarity as shown in (figure 17).

Often these patterns are fractal and can be characterized using fractal dimensions which is similar to cities which often exhibit a bi-fractal structure, characterized by two or more zones (figure 18)

Figure 17 A fractal from the Mandlebrot Set, demonstrating self-similarity, (Torrens and Alberti 2000)

Figure 18. A fractal from the Mandlebrot Set, illustrating how fringe urbanization might be conceptualized in a fractal manner (Torrens and Alberti 2000)

3-2-3.3 Application in urban growth modeling

CA models have many purposes in urban modeling; these models could be categorized as fellows:

A-Complexity and GIS theory:

In complexity, many contributions from some sciences such as informatics, biology, physics and ecology use abstract models for **exploring** such general properties of complex systems as emergence and self-organization.

In GIS, they attempt to develop more advanced spatial analytical functions based on CA modeling or they try to expand CA from raster data structure to another format.

B-Theoretically artificial urban studies:

In these studies, transition rules are linked with urban theories for **testing** theoretical hypotheses by using simulated or real data

C-Empirical case studies

CA works as a spatial **decision support system** for simulation, prediction and planning based on real case study areas (Junfeng 2003)**.**

To design application suitable for urban growth modeling by CA, some adaptations have to be made in the model. To apply CA models to represent or simulate urban systems, some radical modifications have to be done in their components. These modifications will be briefly discussed for lattices, cell states, neighborhoods, time, and transition rules.

A-Lattices

Although the representation of cities is unreasonable, and urban CA have been modified to operate on irregular lattices. However, – for simplicity – lattice in urban applications usually is an infinite plane, which contains an array of usually square equal cells.

From anther point of view, it would be reasonable that CA designed to simulate cities would be defined in three-dimensions, considering that much of the built environment of cities extends in three dimensions. However, for the lack of corresponding data needed for these models, they are not widely used for urban models. However, nowadays some research is going in representing urban areas in three-dimensional lattice and in irregular cells to afford urban CA models a greater degree of realism.

B-Cell-states

Urban CA models could have many states forms like:

- Binary values (0 – 1): developable or not developable;
- Categorized values: land use categories;
- continuous values: land suitability value and population counts.

But as White and Engelen (1997) argued that the cell-state fixture is the most innovative twist, in which there are states that are "fixed", These states are assigned to sites that are generally exempt from the urban development process (such as water bodies). and there are other states that are "functional" which are used in representing sites that are active in the development process (such as vacant lots).

C-Neighborhoods

It was seen that there are two neighborhood configurations: the Moore neighborhood of the eight cells that form a square around a cell, and the von Neumann neighborhood of the four directly adjacent cells that comprise a cross-centered on a cell. They represent direct action-at-a-distance but in urban CA models, distances between cells, which represent patterns, have great effects in their behaviors. As a result, urban CA models have modified neighborhood parameters. Distance decay effects have been introduced, often as weights applied to neighborhoods in transition calculations.

Also the introduction of cell states fixture has an effect on shaping the neighborhood 'Fixed' cells for example – could be used to remove areas of the neighborhood from the transition calculation which makes the neighborhood asymmetric.

D-Time

The real urban areas - as introduced in the previous chapter- are full of decisions that are asynchronously taken, so the use of discrete time steps in the classic approach of CA is not the best way to denote the urban areas. The urban scholars tried to improve urban CA modeling in such ways like the use of agents on a CA space to add some levels of randomness to the temporal space of the CA, or dealing with transition processes so that they are only partly sequential, fashioned in dependence of exogenous constraints (White and Engelen 1997).

E-Transition rules

Transition rules are the core of any CA models. In urban CA applications, many modifications have been done to adapt the dynamics behind urban phenomena and to explain how cities work such as (O'Sullivan et al, P.(2000), Clarke (2002) and Cheng (2003)):

- Transition rules have been opened up to external links, so that urban CA could be considered as quasi-open systems. Rules also could be probabilistic either to present some randomness in the model or to access transition rules depending on other rules – in other words, let the model operate as a complex network of co-dependent subsystems and phenomena.
- Also, and according to certain condition, transition functions are allowed to change via feedback mechanisms as a CA model develops so that to achieve some level of fitness.
- Other models and techniques in other fields like economics theory and social sciences could be used in transition rules.

There are other several figures for urban CA model adaptations. O'Sullivan, D. and Torrens, P. (2000) have linked the main components of classic CA and adaptations needed for urban CA model in (figure 19).

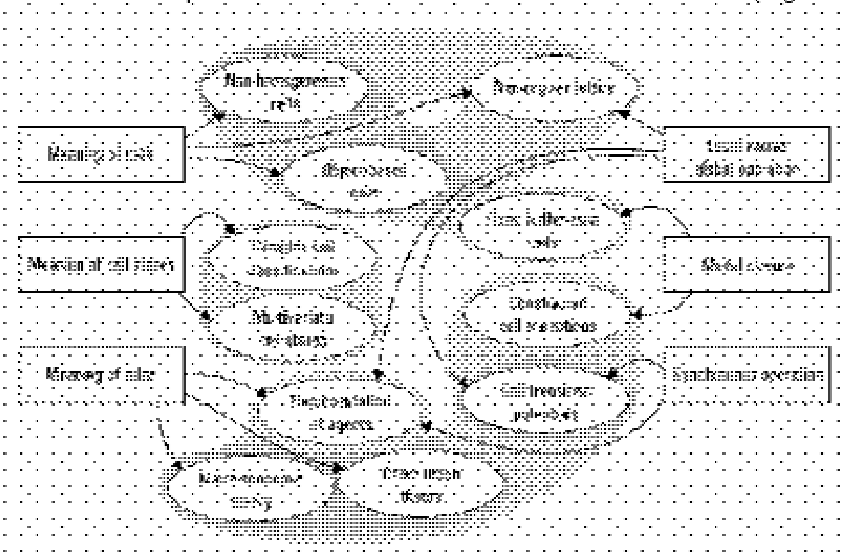


Figure 19 Various urban CA-based model variations (ovals) as responses to the representational problems of classic strict CA (rectangles). Tentative groupings of the variations are also shown (O'Sullivan, D. and Torrens, P.2000)

From the previous discussion, It could be noted that the basic CA transition rule previously discussed in classic CA models is not the best way to express transitions for urban CA models. The transition potential of tested cell is not only affected by neighborhood effect but also submitted to other influences such as (Cheng.2003):

- Accessibility: This refers to transportation accessibility, which in turn reflects macro locations – in another words accessibility to feature cells (roads, telecommunication ...).
- Suitability: which reflects – usually – natural constraints factors like: soil, slope and terrain. Generally, these data is stored in a database in GIS.
- Planning influence: it is related to man – made urban development constraints or stimulation factors.
- Social-economic influence: it is the hardest factor to model comparing with other factor; for economic reasons may some commercial areas appear or disappear. To solve this problem,

modelers add degree of stochasticity in the probablistics states to reflect some uncertainty coming from social – economic influence in the transition rules.

These influences are termed as sub-rule classes.(Box 1 – Equation 2). However, each cell in urban CA models could have more than one transition potentiality, this may happen according to the difference in rules which govern the conversion from state to another in the model. For example, the conversion from vacant to residential could be affected only by suitability and accessibility but in case of conversion to commercial, one sub class have to be applied which is the neighborhood effect. The difference in rules could occur also by applying different coefficients to sub classes to reflect their degrees of importance, which can also result in different destination cell state.

From that, when transition rules are derived for a CA model it would be destination-oriented rather than origin-oriented (Box 1 – Equation 3).

In this way, when the transition rules for different cell states are applied, it could result in the same value which means the same destination cell state. For example, if people want to calculate the changing potentialities of two different cell states (residential, industrial) to commercial land use, the transition potential formula result will be same. The relationship between original cell state, destination cell state and transition potential rules can be seen in the following table:

Table 2 Relationship between original cell state; destination cell state and transition potential rules

(Original cell state)	Land use types (Destined cell state)		
	Residential	Commercial	Industrial
Residential	Result1	Result2	Result3
Commercial	Result1	Result2	Result3
Industrial	Result1	Result2	Result3

In this table, Result1, Result2, Result3 are different transition potential rules equations results, which are used to calculate the cell's changing potentiality to different destined cell state. To each row, the transition rule is different, since the destined cell, the state is different. So the changing potential of tested cell could be attained

Sometimes – especially in cases of decision taking - the transition processes have some higher rules, i.e. have to achieve certain conditions, the decision maker does not only want to calculate the transition potentialities for certain areas, However they also need to reach a certain case states. The decision maker – for example – needs a definite number of cells with destination residential state. In that way we have to apply other rules called confliction resolving rules

To explain that Junfeng (2003: p29:31)) has presented an example as in the following figure:

A	B
C	D

Different cells in tested area

0.9	0.8
0.7	0.5

The transition potential value for residential area

0.8	0.9
0.6	0.6

The transition potential value for industrial area

Figure 20 Different transition potential values for residential and industrial area of four cells.

He presented four cells to test their potentialities to transit to either residential land use or to industrial land use. He showed the transition potential values for each land use. Additionally, he put an assumption that each of these land use type requires two cells in simulation.

This model could result in many outputs according to different confliction resolving rules. (Figure 21) shows two possible outputs If rule: **allocation according to highest potential**, is applied then the above cells will evolve to the states denoted in result 1 in (figure 21)

R	I
R	I

Result1

R	R
I	I

Result2

Figure 21 Four cells' land use changing.

But if another confliction resolving rule such as **allocation with the first choice** is applied, which means different land use have different priority. In this case, the land use changing result will be different as in result 2 in (figure 21). We can see that cell B changed to residential area although transition potential for industrial is higher. It may derive from that residential land use have the priority, it should be allocated firstly.

From the previous discussion, the destination transition rule is affected by transition potential value and confliction-resolving rules as in (figure 22):

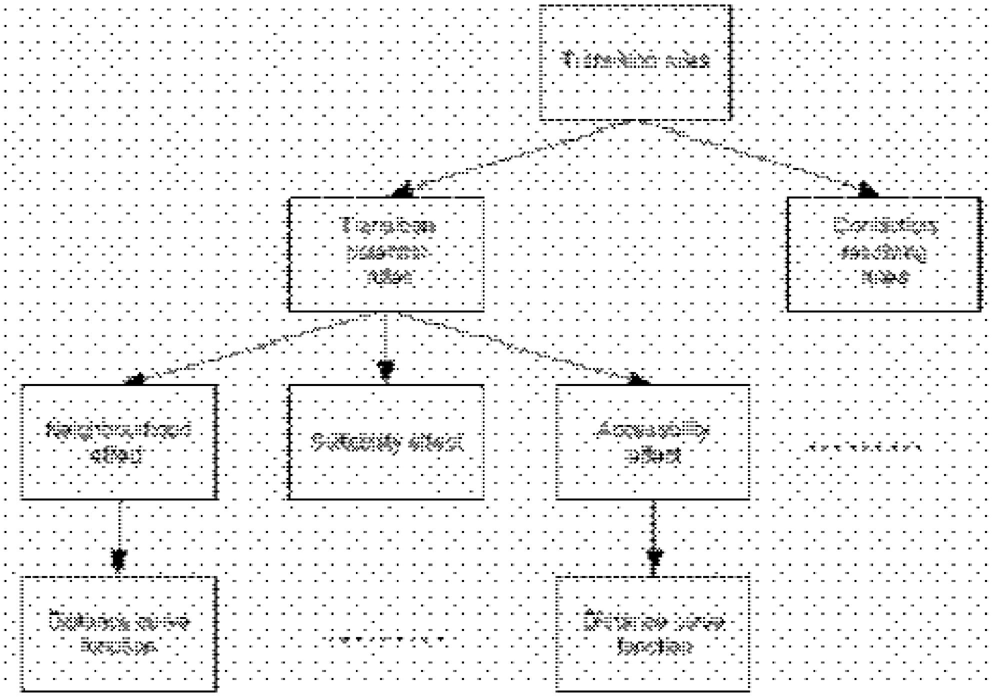


Figure 22 Transition rule structure in urban CA models (Cheng J. 2003)

In the above figure, transition potential rules include three sub-rule classes, in some sub-rule classes (Neighborhood effect), people use distance curve function as the sub-rule to reflect its influence.

Usually urban CA modelers ignore conflictions by using conflicting resolving rule of **allocation according to highest potential**. According to this rule, transition rules equal to transition potential rules. Instead of doing so, urban CA modelers assign different land use types with different selection powers, By assigning different land use demander with different weights, in which final transition rule can be formulated as a whole. (Box 1 - Equation 4).

Box 1: CA transition rules equations

(Junfeng 2003)

$$TP_{T+1} = f(S_T, NB)$$

Equation 1 Basic CA transition rules

$$TP_{T+1} = f(S_T, NB, AC, SU, PL, SEco..)$$

Equation 2 Transition potential rules in Land use CA models (urban CA models)

$$TP_{DsT+1} = f(S_T, NB, AC, SU, PL, SEco..)$$

Equation 3 Destination-oriented transition potential rules in Land use CA models

$$TP\ whole = TPr \times WR + TPc \times WC + TPi \times WI \ldots$$

Equation 4 Possible whole transition rule (combining confliction resolving into transition potential rules)

Where TP_{T+1} Transition Potential of tested cell in time T+1.
S_T --Tested cell state in time T.
NB -Neighborhood effect.
AC -Accessibility effect
SU Suitability effect
PL -- Planning influence
SEco Socio – economic influence
TP_{DsT+1} Destination transition Potential of tested cell in time T+1
TPr, TPc and TPi are the transition potential rules developed by residential, commercial and industrial investors respectively. W is their corresponding weight assigned by modelers.

3-2-3.4 Constrains on CA urban modeling applications

There are some constraints related to urban CA. Junfeng (2003) argued five main disadvantages of urban CA, which are:

A- Weak in modeling top-down influence

As there are some real phenomena emerging from micro-scale up to macro-level – i.e. a bottom- up process - such as the traffic congestion, neighborhood upgrading and decline. There are also other top-down influences just come from outside of urban system, and have strong effect on urban system development such as some planning restrictions in specific areas .

B-Coarsely cell states definition

Firstly, the cell size in urban CA model is very big ranging from 25m to 200m. which could lead to disappearing of some important linear features of urban environment, such as transport network and rivers. Secondly, there is no abstract rule governs how the cell can represent a state – for example land use type - which could result in wrong outputs.

C-Uncertainty about neighborhood size and shape

The neighborhood size should be enlarged and the shapes should be modified and varies according to each case. Many discussions is occurring in order to define a suitable and efficient neighborhood.

D-Lack of consideration about peoples' opinions/ synchronously update

Although human agent's opinions are the real determine factors in urban development process, classic urban CA rules were developed without suitable consideration of these opinions. Beside that, in the real urban system development takes place according to different time sequences not synchronously from time T to time T+1.

3-2-4 Artificial Neural Network models

Artificial neural networks are powerful tools that use a machine learning approach to numerically solve relationships between inputs and outputs (Pijanowski et al. 2001). "It consists of simple processing elements, called neurons, and connection links operating in parallel" (Singh 2003: p4).

3-2-4.1 Components

The ANN models have sub components, which are neurons, layers, and weights; they could be introduced briefly as follows:

A-Neurons

- The neuron – and called also nodes - is a processing element whose output is produced by multiplying its input signals by a weight, the number of neurons required to obtain an accurate approximation has not been obtained yet.

B-Layers

- ANN mainly contains at least one input layer, which comes from input data, and at least an output layer, which contains neurons, looks like the states, needed from the process. Meanwhile, the process contains no or some in-between layers called hidden layers - as they have no direct relationships with outer real world - whose neurons take into account those of other layers by means of connections designed to assess weights and signals. As previously mentioned with neurons, the number of hidden layers required to obtain an accurate approximation to real life has not been obtained yet.
- Almeida and Glariani (2005: p3701) argued, "The whole neurons in all layers except those in the input layer have two simple processing functions. Firstly, they collect the activation of the neurons in the previous layer and secondly, they generate an activation as the input to the next layer" and these processes are done by neurons in input

layer. In other words, each neuron collects the information from lower layer – its input layers- and applies a transfer function to make an output – in its output layer (Figure 24 and box 2).

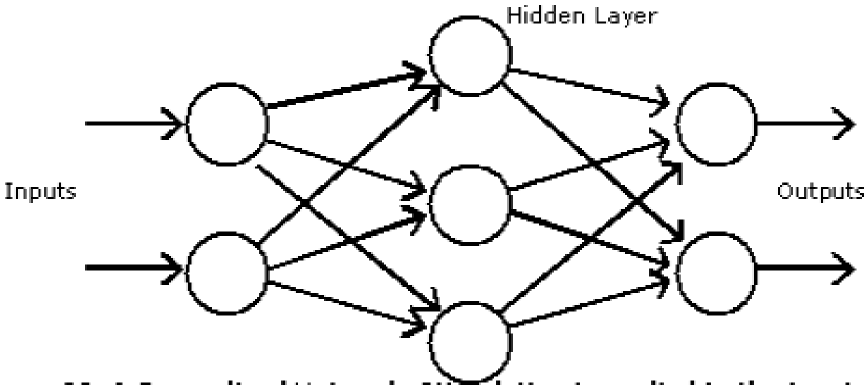


Figure 23. A Generalized Network. Stimulation is applied to the inputs of the first layer, and signals transmit through the middle (hidden) layer(s) to the output layer. Each link between neurons has a unique weighting value. (Pete McCollum, 2001)

C-Weights

- The main distinctiveness property of ANN is the values of the weights between neurons, there are many methods used for adjusting the weights. The most common learning algorithm is Back Propagation (BP) – or learns by example - in which a learning set that consists of some input examples and the known-correct output for each case is provided. So, these input-output examples are used to show the network what type of behavior is expected, and then the network is customized. (Pete McCollum, 2001)

The model process

According to (Cheng.2003, Junfeng (2003) and Almeida and Gleriani (2005)) The ANN process has the next steps:

- Selecting input data usually by extracting from GIS.
- Making input layers – or driving variables - which could be Distance from highways or roads, Distance from rivers, Variation in topography, Density of residential streets and Distance from urban areas ...

- Building neural network, in which the inputs neurons could be nominal or numerical. The output layer is a unique-neutron state as the model aims to simulate the binary state changing (from non-urban area to urban area). Neurons in hidden layer are usually selected based on back propagation in which real input-output examples are provided. The more neurons selected the slower calculation. In this step signals and weights are generated.

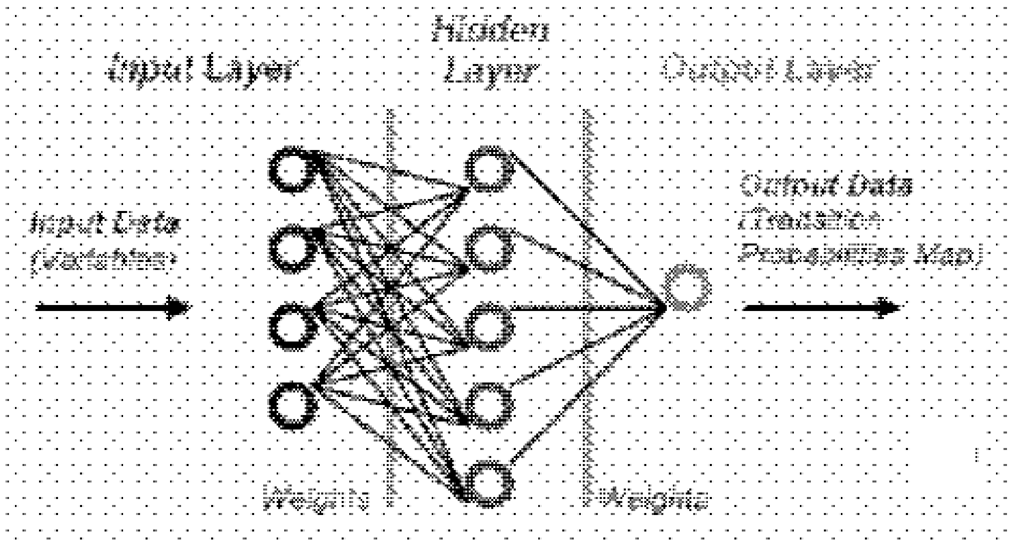


Figure 24 Generic example of an artificial neural network structure with only a single output neuron (ALMEIDA and GLERIANI 2005)

- Selecting at least two changing maps, random select parcels from these two maps use them as the neural network training and testing data respectively and using this step in evaluating weights.

Box 2 Collecting signals in ANN model

(Almeida and Gleriani 2005)

$$net_q = {}_p\Sigma\, w_{pq}\, I_p$$

Equation 5 The equation for the collection signal for receiver neurons

where q is a receiver neuron in the next layer
net_q is the collection signal for receiver neuron q in the next layer
p equals a sender neuron in the input layer
I_p is the signal from neuron p of the sender layer
w_{pq} is the parameter or weight to sum the signals from different input nodes

q then creates activation in response to the signal netq, this activation is usually created in the form of a sigmoid function (Yeh and Li, 2003) which is (1/ (1 + netq).

The activation and the collection signal (defined in equation 5) will be passed to the next layer as the input signal, These routines remain until the final signals are reached by the output layer.

3-2-4.2 Characteristics

Almeida and Gleriani (2005: p3700,3701) presented a series of ANN advantages:

- The structure of algorithms enables neural networks to be robust and noise resistant regardless of poor data.
- They can solve highly nonlinear problems in complex systems.
- The method is rather simple because no exact questions or expressions are required.
- The best level of performance can be obtained.
- There are no restrictions about using non-numeric data.
- They adapt to non-normal frequency distribution.
- Mixtures of measurement types can be used.

- They can use many variables, some of which may be redundant.

3-2-4.3 Application in Urban Growth modeling

ANN has been used in some urban growth models application. The most popular model was built by Pijanowskia et al. (2002) in which the modeler had integrated ANN and GIS to predict land cover change, where GIS is used to develop the spatial predictor variables in four steps which were:

- Designing of the network and of inputs from historical data
- Network training using a subset of inputs
- Testing the neural network using the full data set of the inputs
- Using the information from the neural network to forecast changes.(Cheng.2003)

ANN represents a powerful modeling tool for exploring nonlinear complex problems, as it is independent on particular functional relationships, requires no pre-understanding of variable relationships. (Cheng. 2003). Usually ANN is used in urban growth models as a tool for conducting values for various coefficients of the model according to its nature.

3-2-4.4 Constrains in ANN urban modeling applications

- The most observable character of ANN is the Black-box property as the driving forces is not exactly clear. Junfeng (2003:.p68) states "Only some thing come in then some results come out." which limits the model to short-term prediction only.
- No study about ANN provides a systematic approach about neural layers or neurons selections.
- It does not concern with decision-making process.

3-3 Summary

Models are simplification of the real world. They could be either physical - to let people get visual knowledge about real world – or mental, which are related to procedures to be taken by a set of rules or experiences. Simulation is to produce some patterns according to some rules before it happen in reality. Usually models help in putting the rules for simulation and the models related to complex system theories focus on simulations urban modeling and simulation

Successful modeling practices are yet to be reported. The innovative mathematic models, on the other hand, emphasize syntax and urban dynamics, but are difficult to interpret. To date, urban modeling and growth prediction remain largely on the frontier of the urban studies field and need further exploration (Maxwell and Costanza, 1997).

Urban models are used for increasing the understanding of urban systems, testing and evaluating some theoretical hypotheses. To model urban growth, five interweaving levels should be firstly understood, these levels are: policy, actor, behavior, process and pattern

Geographic information System is a computer system that is commonly used for analyzing any geographic phenomenon. In urban modeling, GIS is used in building the database and applying rules necessary for the analysis process.

Multi-agent system is a set of various agents (information, mobile and intelligent …) behaving and interacting in an environment. Recently the attention to Multi-Agent Systems been raised as it provides good method to understand complex system and its ability to solve big problems by dividing it to sub problems is high.

MAS is a significant method to model and study the top - down process but its current applications of mainly focus on abstracted theoretical research or micro-behavior simulation as it does not offer a good technique for modeling bottom up processes.

Cellular Automata consists in discrete dynamical systems. It is composed of an array of cells, each cell has a discrete state and updated in discrete time steps because transition rules based on the neighborhoods. And these transition rules are responsible for the dynamics of the model

In urban growth, the lattice is two-dimensional and state is binary (1 = urban and 0=non urban) and the transition rules has factors to measure accessibility, suitability and socio-economic issues...

CA is used in exploring properties of complex systems, testing theoretical hypotheses and as a decision support system in prediction and forecasting. It is characterized by some special properties such as; its decentralized approach, its relation with complexity theory, the ease in linking with GIS and Remote sensing and Rank-size rules and power laws

The most constrain in applying CA in urban modeling is the lack of support of top - down approach which reflects lack of consideration about peoples' opinions over time

Artificial neural networks are machine-learning approach tools that numerically solve relationships between inputs and outputs. They consist of neurons have input signals to be multiplied in weights to be finally appear in the output layer

This method is used in modeling urban growth, as it is capable for exploring nonlinear complex problems as it is independent on particular functional relationships, without the need of a pre-understanding of variable relationships, but it has not shown any concern to decision-making process.

Briefly, each method previously discussed has limitations and constraints when modeling and simulating urban phenomena, and there is a great need to have an integrated approach system by these methods to reach to best way of urban growth modeling.

Chapter Four

Application of scenarios and models

4 Application of scenarios and models

This chapter presents some applications, which were really implemented to test or forecast urban growth by specialists, universities and governmental authorizations using various methods and techniques previously mentioned.

4-1 Charleston model

Charleston model was modeled by Jeffery Allen and Kang Lu upon a GIS-based integrated approach to modeling and prediction of urban growth in terms of land use change. The model is designed to predict land transition probabilities and simulate urban growth under different scenarios.

The model was calibrated in – and mainly was designed for - the Charleston region of South Carolina which consists of the three coastal counties of Berkeley, Charleston, and Dorchester (BCD).There, urban growth far exceeded population growth at a ratio of 6.2:1, almost triple the national average (2.3:1). The average annual growth rate of this region is 7.24%, four and a half times greater than the U.S. average (1.33%). This model was built in order to develop an operational model for regional urban land use change and to predict spatial extents of future urban expansions through to the year 2030 using various growth scenario.

The process, According to (figure 25), begins with collecting data, then three successive sub models have to be run with different growth scenarios. The sub models have to be integrated to get different potential urban extent in 2030. Each of these extents have to be checked and assessed for errors and then would finally be presented to decision makers.

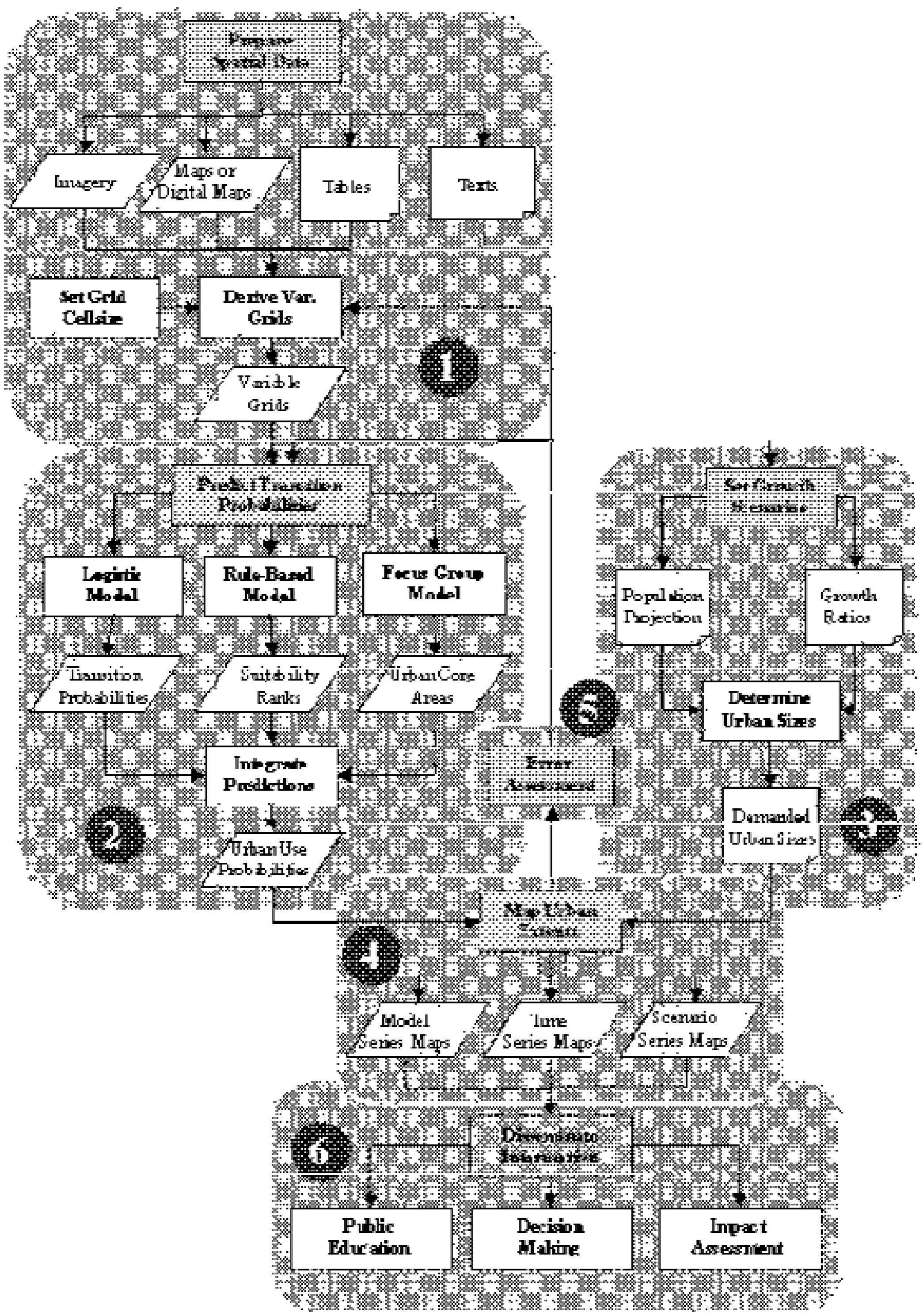


Figure 25. Flowchart of the Charleston urban growth model.(Allen, J. and Lu, K. 2003)

4-1-1 Model inputs

The Data is collected in many forms either in paper maps or digital maps or remote sensing tools, The data have to be converted to raster format and in same resolution. A (30 x 30 m) resolution was used in the model, which is equal to the spatial resolution of the LandSat TM imagery used to derive urban land use data. However, in model intermediate calibration a smaller resolution is used to reduce time and effort consumption.

The states used in the model are a binary state:

- Man – made or urban category and it contains residential, commercial and services, industrial, transportation, communication, utilities, industrial and commercial complexes, and mixed urban or built-up land.
- Non urban (Natural and semi natural) category which contains other uses like forests and rivers

A linear interpolation method was used to estimate the values for the desired year to match this data with another available data in another year; otherwise, the data set closest to the desired date was selected.

4-1-2 Model mechanism

The modeler built the model based on being composed of three sub models and a fourth one used in integrating these sub models, these sub models are:

A-logistic regression sub model:

This sub model is used for Identifying the significant variables and rules that distinguish urban areas from rural and forest environments.

There are many variables used in the model to measure physical suitability, accessibility, policy constraints, and initial conditions.... These variables were categorized to five categories so that each has a special weight value, these categories are

- Forest, slope, wetland, and distance to waterfront;

- Distance to major roads, distance to major node, road density, distance to waterline, and distance to sewer line;
- Population density and cost distance to central business district; Existing urban and distance to existing urban
- Corporate boundary and protected land.

Then a linear regression equation (Appendix 3) is sequently applied in the historical data to test the coefficients values. For each of the 5 years, urban areas was predicted upon the input coefficients and compared with the observed ones. This method is used to examine the reliability of the logistic model over time and to test the implied assumption that the relationships revealed by the historical data will hold over different time spans

The linear regression equation used is:

$$ln \{ P_i / (1 - P_i)\} = \alpha + \sum \beta_i X_{ij}$$

Equation 6 Linear regression equation in Charleston model.

Where P_i is the estimated probability that the ith land cell unit (i = 1,· · ·, n) is urban

is a constant. α

j is a factor within a number of factors equal k

β_i is a coefficient for each j (j = 1, 2, · · ·, k)

X_{ij} is a predictor variable for each j (j = 1, 2, · · ·, k)

B-Rule based sub model (Relative probability sub model):

The logistic regression model relies on historical data for calibration but it cannot reflect the effects of new land use policies. Therefore, the modelers of Charleston model composed another sub model that is responsible for determining the spatial interactions of neighborhood, distance, patch size (parcels), and site-specific characteristics (Figure 26). This model if constructed properly can generate very important information for decision-makers.

Similar to logistic model, the modelers grouped rules for rating, ranking, and weighting variables into five categories. This sub model runs in five steps:

1. Assigning a value for each variable from a predefined classification (0-10 in this model). Then each ranked grid (Rij) is determined by dividing this value by its maximum value in classification (10) so that its range falls between 0 and 1.
2. Assigning the weight factor (wij) and the exponential factor (k) are to each ranked grid.
3. Calculating the total ranked suitability score (Σ wij Rkij) for each land unit (i) then it is divided by the maximum score (max (Σ wij Rkij)) found in the region to generate a relative urban transition probability ranging between 0 and 1.
4. Merging the unsuitable lands map (Eim) which shows areas that are excluded from urbanization process either according to natural causes or because of policy constraints, into one map.
5. Overlaying Urban map (U i) with the previous map so that current urban units remain urban in the future.

The relative urban transition probability Prob(i) in terms of ranked suitability with constraints can be calculated based on the following formula.

$$Prob(i) = \{(\sum w_{ij} R^{k}_{ij}) / \max(\sum w_{ij} R^{k}_{ij})\} (1-U_i)\prod(1-E_{im}) + U_i$$

Equation 7 The relative urban transition probability equation in Charleston model.

Where Prob(i) is the relative urban transition probability.
R^{k}_{ij} is the rank of cell ij for the exponential factor (k)
w_{ij} is the weight factor of cell ij
U_i is the current urban grid.
E_{im} represents the land excluded from urbanization potentiality

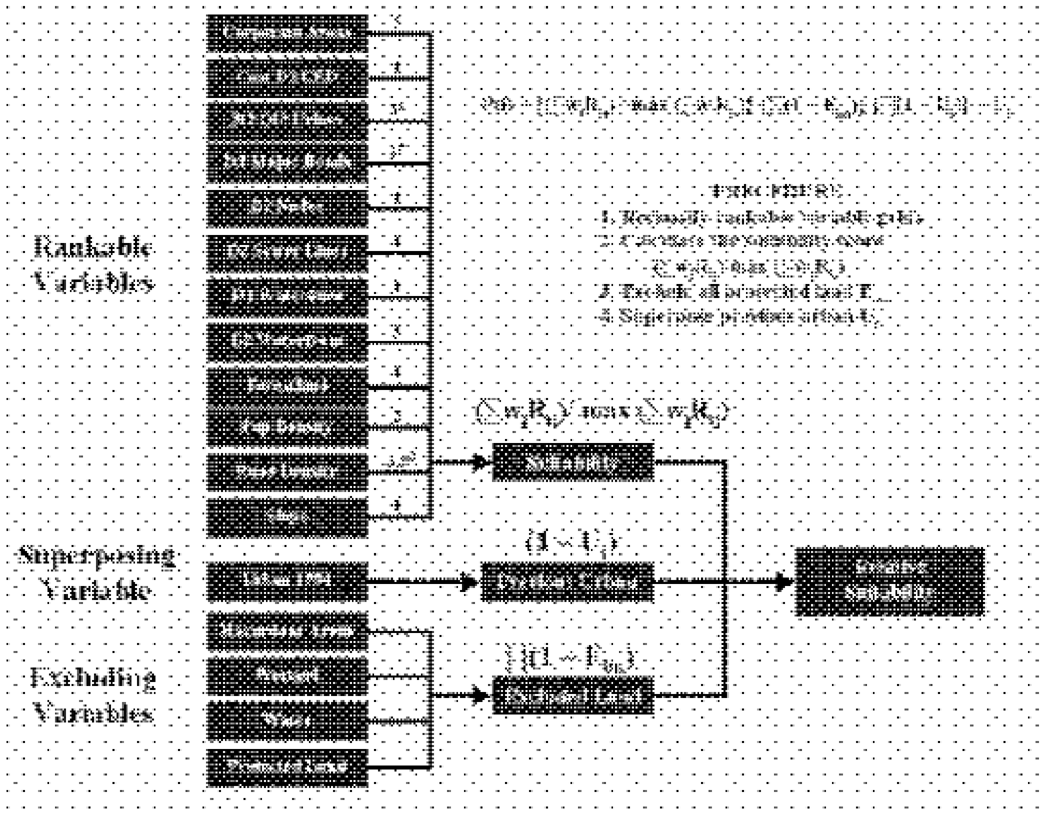


Figure 26 Structure and algorithms of the rule-based suitability model.(Allen, J. and Lu, K. 2003)

C-Focus group involvement sub model:

This sub-model represents the human input layer in the whole model. In this sub-model, the growth scenarios and evaluate predictions are set.

The procedure of this model is:

1) Forming the focus group which consists of local experts, planners, developers, landowners, conservationists, and community leaders who have a thoughtful knowledge of the region and urban growth factors.

2) making some sessions to collect their opinions by interviews, meetings, and workshops.

The focus group is important also in evaluating the results of computer-based logistic and suitability predictions. Every person of the focus group then draws the boundary of the study area in the target year (in Charleston case study year 2030) based on his or her personal knowledge. Finally, the map has to be modified to reflect subsequent focus group predictions during and after evaluation meetings.

D-Integrated model

This model is used to collect the output of the three other sub-models by scoring weights for each model output. After several trials in Charleston model, the weight of the focus group prediction was reduced to 10% and the other two predictions were weighted at 45% each. This weight combination appeared to eliminate the strong effect of the arbitrary boundary of the focus group prediction.

The output of each sub-model in the Charleston case study is presented in (figure 27).

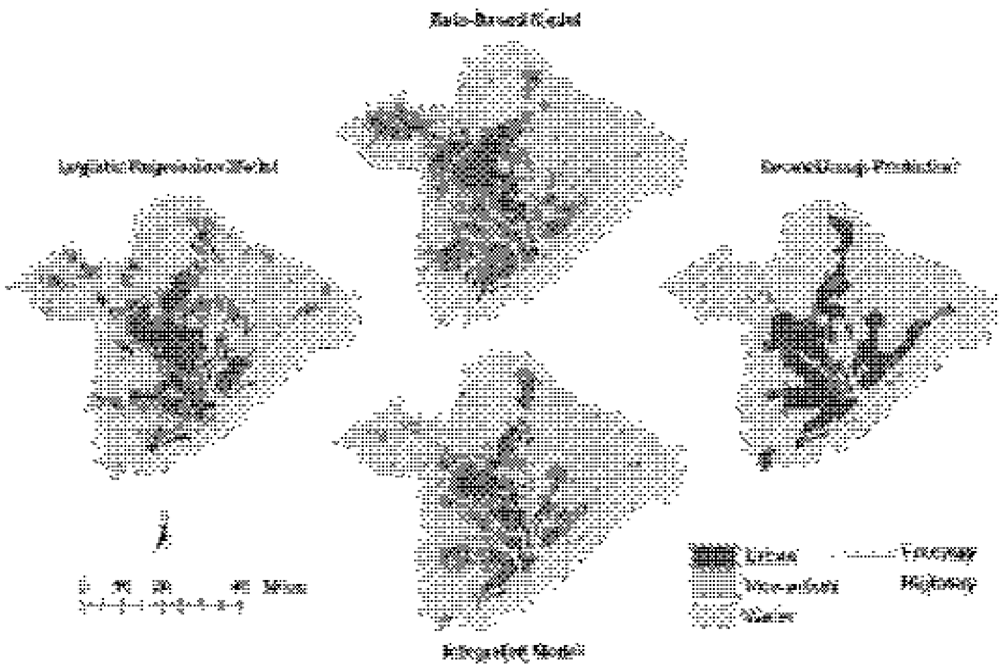


Figure 27. Comparison of the urban extents predicted using four different (sub-models).(Allen, J. and Lu, K. 2003)

After getting the integrated model, the modelers used different growth ratios as growth scenarios to determine future urban sizes as they reflect the relationship between population growth and urban area consumption by taking into account four factors, which are the internal historical growth trend, change in external driving forces, focus group output, and regional physical capacity (figure 28). The growth ratio is calculated according to equation 8 as fellows:

$$r = ((A_1 - A_0) / A_0) / ((P_1 - P_0) / P_0)$$

Equation 8 Growth ratio equation.

where r is the growth ratio
P_0 is the start-year population
P_1 is the end-year population
A_0 is the start-year urban area
A_1 is the end-year urban area

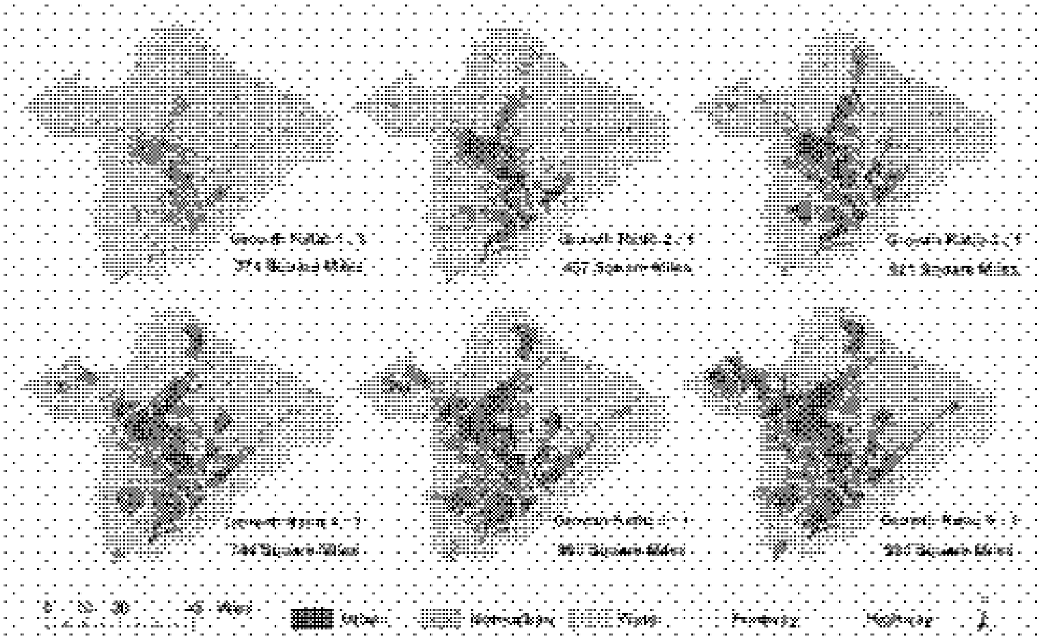


Figure 28 Scenario-series map of urban growth in the Charleston region as predicted using growth ratios of 1:1–6:1. (Allen, J. and Lu, K. 2003)

4-1-3 Model outputs

The results from this model are not only maps representing various scenarios, but also some statistical sheets, which contain:

- The results of prediction success rates of the logistic regression models built for the region and its three counties.
- Parameter used in the sub model for urban growth. (Table 3)
- A statistical summary of commission and omission errors of the four models.

- Summary of predicted urban growth in the Charleston region to 2030 (figure 29)

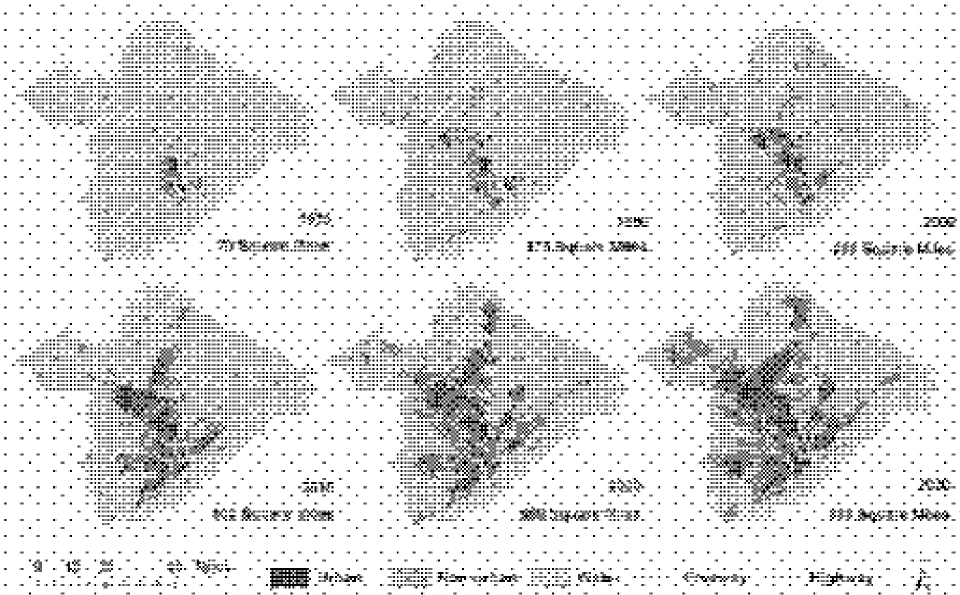


Figure 29 Time-series map of urban growth in the Charleston region from 1973 to 2030 as predicted using a growth ratio of 5:1. (Allen, J. and Lu, K. 2003)

Table 3 Parameter estimates of the logistic regression model for urban growth in the Charleston region.

Variable Name	B	Std. Error	Exp(B)
Corporate boundary	.8593	.0344	2.3614
Cost distance to downtown	-.0069	.0006	.9931
Distance to existing urban	-.3459	.0093	.7076
Distance to major roads	.0586	.0075	1.0603
Distance to node	-.0331	.0076	.9675
Distance to sewer line	.0022	.0041	1.0022
Distance to waterline	.0123	.0056	1.0124
Distance to waterfront	.0779	.0082	1.0811
Existing urban	9.3329	1.3433	11304.1474
Forest land	-.1587	.0274	.8532
Population density	.0003	.0001	1.0003
Protected land	-.8587	.3538	.4237
Road density	.3060	.0056	1.3580
Slope	.0456	.0305	1.0466
Wetland	-.6463	.0471	.5240
CONSTANT	-2.4788	.0847	.0838

4-1-4 Model criticism

By the end of the this model process it was found that logistic regression model is appropriate for predictions over a short term (5–10 years) rather than over a long term. However, integrating the rule based model and the focus group involvement model technique with the logistic model is better for long-term prediction. (Allen, J. and Lu, K. 2003)

Moreover, this model has some other critics, as it does not show any capability to change the variables over time according to any social, economic, or political conditions, also the ranks values taken according to distance is measured for whole grid without making limitation by areas of effects.

4-2 Fractal LUCAM Model

The objective of this model developed for estimations about land use in urban sites is to obtain the data, which will contribute to the formation of growth orientations, on the basis of the data about the land use and the needs of the user in the synthesis phase of planning studies. Development of this model (LUCAM) has been founded upon CA developed by Engelen and White, and the simulation model for estimations about settlement land use (Engelen, White, Uljee, 1997).

Original ways have been followed in data formation and assessment methods. These methods have been employed to test the model in Bursa settlement in Turkey and to evaluate the results. In this model, each cell represents a kind of urban land use (residence, industry, trade, facility, vacant. The main features, the operation system and assessment system of this cellular automata based model are mentioned below.

4-2-1 Model inputs

A-Lattice:

Changeable according to study area.

B-Cells:

Square 100 x 100 m

C-States:

Vary according to area of study. Usually they are Vacant (V), Residence (R), Industry (I), Trade (T), Facility (F)

(Figure 30) shows the land use map used in the model built for Bursa city in Turkey

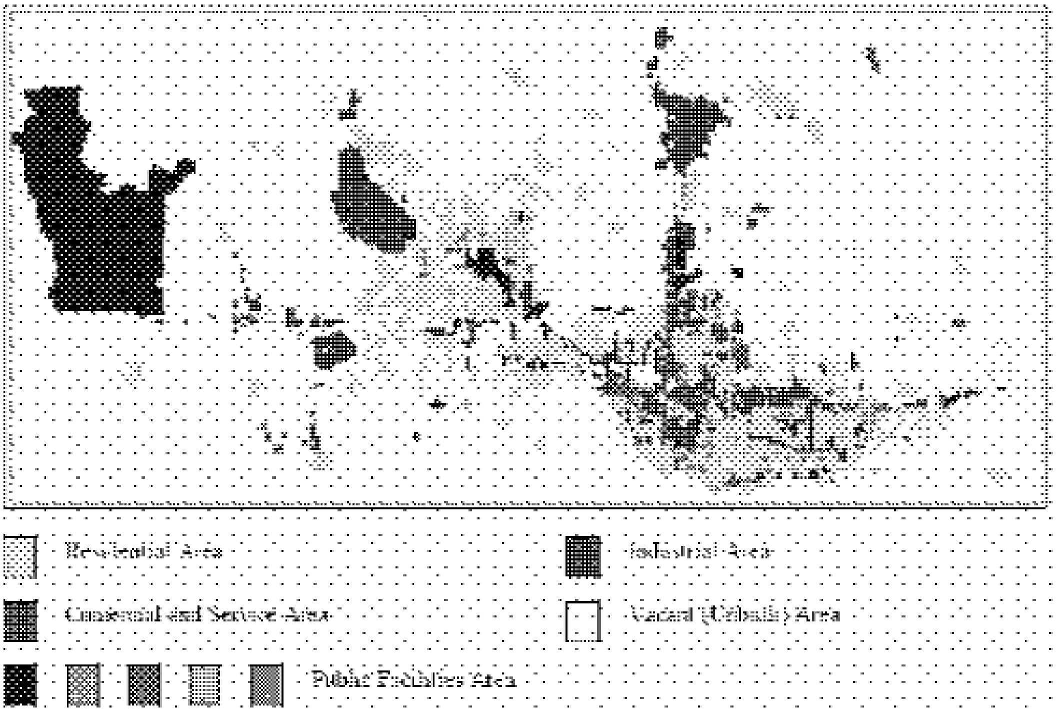


Figure 30 Existent Land Use of Bursa Settlement (YUZER, M. 2004)

4-2-2 Model Mechanism

As the model is based on CA approach, the mechanism of the model depends on neighborhood and transition rules

A-Neighborhood:

Cells that remain in the 6 cell distance from the main cell. The total number of the Neighbor cells is 168 (+ the center cell itself). It means that each cell could have an effect upon a cell at a distance of 849 m (which equals 600 $\sqrt{2}$) (figure 31).

B-Transition Rules:

The transition takes place in the model according to a hierarchy from the lowest to highest conditions as shown in (figure 32) In this hierarchy the higher condition could be transformed into the lower from it, but there cannot be a transformation from the highest to the lowest condition. Empty cell can be transformed into any other function but an industrial cell can only be transformed into a trade or service function. (White, Engelen, 1997).

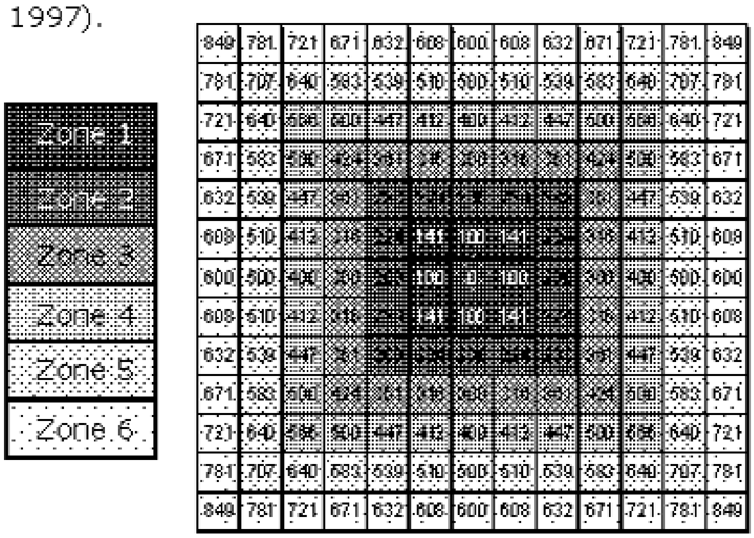


Figure 31 The Neighborhood in the LUCAM model (By the researcher)

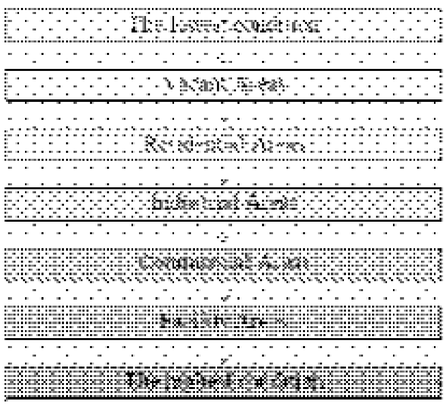


Figure 32 Hierarchy of Urban Land Use Area, (Yuzer, M. 2004)

The transition process for each cell is controlled by the following equation:

$$P_{ij} = (\Sigma_{k,d}\ m_{kd}) / \Sigma h$$

Equation 9 The transition rule in LUCAM model.

Where P_{ij}: is the transition potential from state i to state j

m_{kd}: is the weighting parameter applied cells in state k in distance zone d.

Σh : is the some of central cell and neighbor cells.

The rules governing the transformation process are:

- The facilities exist in the settlements as unchanging function areas which means that it cannot be transformed to another function unless there is an extraordinary condition or There is a need for another facility for public use. For this reason, the cells defined as facility enter the model as they are, do not have any impacts on other cells and do not have any kinds of transformation.
- Empty cells have no weight and they directly contribute to the transformation potential.

The next table represents an example of weighting parameters that could be used in a LUCAM model to be applied on each Cell according to its distance to calculate the transformation potential. If a cell is tested to transform from empty land to residential, the focus would be on the third vertical block, a trade function in the forth distant zone will contribute in this process by 0.1 and an industrial function in the fifth distant zone will contribute in this process by 0.03. and so on. The end-condition of a cell, which tests all the states shows the highest possible potential of that cell.

Table 4 The Weighting Parameter to be Applied on Each Cell to Calculate the Transformation Potential (White, Engelen, 1994).

	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

First the operation is applied on all cells and by this way the scheme following transformation is drawn up, then its is tested by dividing the study area into sub-areas with small areas to examine the potential transformations from states to others. After the scheme is created by using transformation parameters, the process is operated for the second time to form a basis for the model in case the projected population or the settlement capacity is not achieved. The model is operated until the set size is achieved.

4-2-3 Model Outputs

The model would be operated sequentially to reach some certain values according to external data such as planning requirements or demographic data. (Figure 33) represents Bursa settlement area land use after first transformation process in year 2020. And table 5 shows the values obtained from the same transformation. It could be noticed that the facility areas did not have transformations of any kind and their number and position remained the same because of the pre-discussed reason.

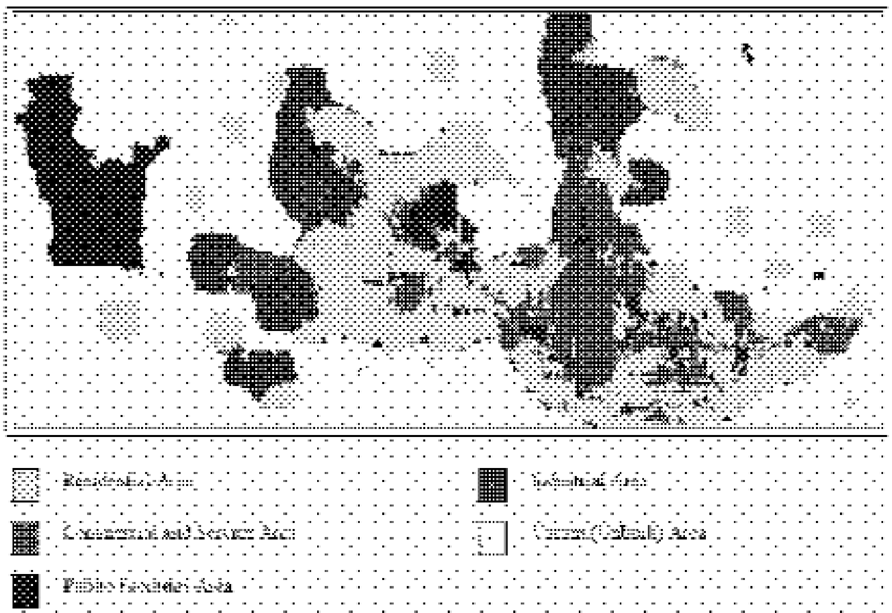


Figure 33 Bursa settlement area distribution after first transformation (Yuzer, M. 2004)

Table 5 Land use of Bursa settlement after first transformation Yuzer, M. (2004)

	1995		2020
	Area (ha)	(m2/persan)	
Population	1.184.144	----	2.813.394
Residential Area	2531	25.3	5228
Commercial and Service Area	660	6.6	1993
Industrial Area	749	7.5	2355
Public Facility Area	1759	17.5	1759
Overall Settlement Area	5699	56.9	11335
Vacant Area	23447	234.4	17811
Total Area (ha)	29146	291.3	29146

Based on population growth, the modeler found out that the required area size should be 15958 ha in 2020. In this case, the model could have been re-operated. However as it was agreed that there would be a growth in facility areas as well, one-stage operation of the model was deemed suitable.

4-2-4 Model criticism

This model has some advantages such as its simplicity, probability to linkage with GIS and capability of the model to be organized in different forms depend on local properties.... However, this model does not make attention to nature of the land or the effect of transportation and the socio economic forces in the micro level.

4-3 SLEUTH model

SLEUTH is a modified cellular automaton model, which consists of an urban growth sub model and a land cover change transition sub model (Clarke, K. C., 2002). The urban growth model is the main component of SLEUTH, which is tightly coupled with the land cover change transition model. The Model is composed of grid of pixels, Moore neighborhood cells (discussed in chapter three), binary states (non- urban & urban) and four transition rules built upon five coefficients. The name of SLEUTH is conducted from the layers used in the model, which are: Slope, Land Cover, and Exclusion – a layer contains lands cannot be developed, Urban extent, Transportation network and Hillshade layer, which is used for visualization.

4-3-1 Model inputs

SLEUTH begins with an initial set of conditions. These conditions are defined by input raster image data, which are considered as layers of information that create non-homogenous cellular space and influence cell transition suitability. SLEUTH uses several types of geographic data to generate an initial system configuration and transition suitability surface:

Slope Topography: which mostly creates the most probable area available for urban development. Flat expanses are the easiest to build upon. The more slope increases, the less Lands become hospitable for urban growth, and eventually become impossible to develop due to structural infeasibility. CRITICAL_SLOPE is the point where structures are no longer built due to slope constraints.

Land-use: Land-use classes additional to urban may be modeled in SLEUTH. This is an optional input, and was not utilized in most SLEUTH application yet.

Exclusion Areas: Areas that are not available to urbanization are included in the exclusion layer such as water bodies, parklands, and national forest. The exclusion layer is not necessarily binary and may include levels, or probabilities, of growth resistance.

Urban: A binary classification: urban or non-urban. "Urban" definition may vary according to applications. Methods used for define urban include digitizing city maps and aerial photographs, thresholding remotely sensed images or block densities from census data. For calibration, four urban layers at least usually are required in order to calculate best-fit statistics.

Transportation: The more the accessibility Increase, the more the tendency of urban corridors to reach out from the city center along modes of transportation. To include the dynamic effect of transportation in calibration, several road layers that change over time are desirable. SLEUTH is initialized with the earliest road layer. As growth cycles, or "time", pass and the date for a more recent road layer is reached, the new layer is read in and development proceeds. The roads may have binary states, and also may be weighted to simulate one section of road's greater attractiveness to urbanization relative to another section of road.

Hillshade: A grayscale background image gives context to the spatial data generated by the model, this layer can greatly assist the visual examination and analysis of model output image it is not an active input for model simulation

Appendix (1) presents aerial photos and survey maps showing the successive hillshade and urban growth for the Isleta quadrangle, New Mexico in the United States from 1935 to 1996. In addition, it shows the slope, excluded areas, land use, urban areas and road network maps for the same area consequently.

4-3-2 Model Mechanism

4-3-2.1 Growth Coefficients

SLEUTH model contains five coefficients, or parameters, affect how the growth rules are applied. most of these coefficients have an integer value between 0 and 100. The five coefficient values are:

A- Dispersion Coefficient: The dispersion (diffusion) coefficient controls the number of times a pixel will be randomly selected for possible urbanization. and how many “steps”, or pixels, make up a random walk along the transportation network.

B- Breed Coefficient: The breed coefficient determines the probability of a pixel newly urbanized by dispersion growth becoming a new spreading center and determines the number of times a road trip will be taken in urban growth.

C- Spread Coefficient: The spread coefficient determines the probability that any pixel that is part of a spreading center (a cluster of pixels of three or more in a Moore neighborhood as the game of life's rule discussed in chapter three) will generate an additional urban pixel in its neighborhood.

D- Slope Coefficient: The slope coefficient affects all growth rules in the same way. When a location is being tested for suitability of urbanization, the slope at that location is considered. The slope coefficient acts as a multiplier. If the slope coefficient is high, increasingly steeper slopes are more likely to fail the slope test. As the slope coefficient gets closer to zero, an increase in local slope has less affect on the likelihood of urbanization (Figure 34).

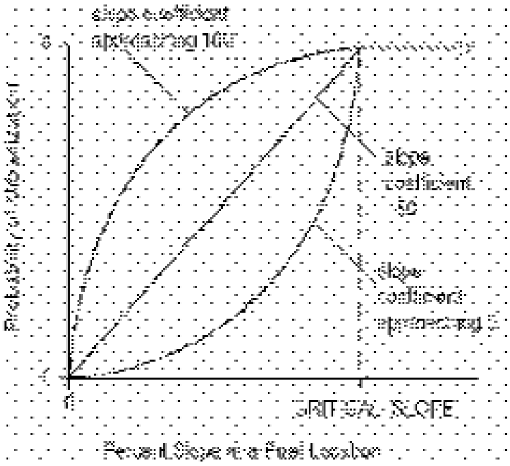


Figure 34 Slope coefficient in SLEUTH model, (Candau, J. et al 2002)

E- Road Gravity Coefficient: the maximum search distance from a pixel selected for a road trip for a road pixel is determined as some proportion of the image dimensions. The applied value is derived from the road gravity coefficient

Table 6 shows the Growth parameters used in urban growth model for Isleta, New Mexico in USA.

Table 6 Growth Control Parameters - Urban Growth Model Calibration - Isleta, New Mexico, 1:24,000-scale quadrangle (Hester, D. 2000)

Coefficient	Beginning		Ending		Step
	Value	Meaning of value	Value	Meaning of value	
Diffusion	1	growth occurs only for cells adjacent to existing urbanized cells	100	growth can take place anywhere	20
Breed	1	growth will only take place around existing urban centers	100	every new center can begin to grow on its own	20
Spread	1	- urban center cannot spread outward	100	urban center can spread outward in any direction	20
Slope Resistance	1	percent slope (integer value)	20	percent slope (integer value)	5

Road Gravity	1	no search distance allowed	20	maximum # of cells to search outward for existing road	5

4-3-2.2 Growth Dynamics (Rules) in SLEUTH model:

According to Candau et al. (2002), the Growth Dynamic implemented in SLEUTH UGM is defined through 4 steps which considered the transition rules for this type of CA models:

A-Spontaneous growth

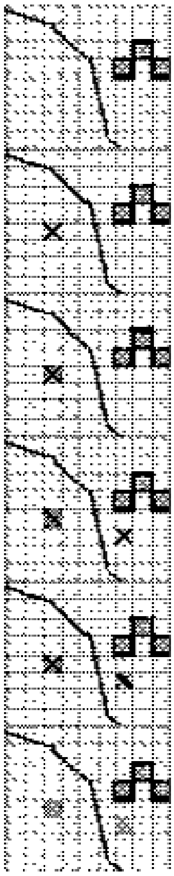
This type of growth simulates the occurrence of a new urban settlement on the landscape without necessary relation to preexisting infrastructure or urban areas. The stochasticity of the process is indicated by random. If the cell is already urbanized or excluded from urbanization, it will not change, and therefore the ability to transition depends on the cell's own current value. Spontaneous growth could be expressed as

$$U(i,j,t+1) = f\,[\,dispersion\_coefficient,\ slope\_coefficient\ ,\ U(i,j,t),\ random\,]$$

Equation 10 Equation for Spontaneous growth

WhereU(i,j,t+1) and U(i,j,t) are cell states (urban and non urban)) at coordinate (i,j) at times t , t+1

Table 7 Spontaneous growth example and pseudo C programming language code. (Project Gigapolis, 2002)

	Spontaneous Growth:
	F(dispersion_coefficient, slope_coefficient)
	{
	for (p < dispersion_value[1])
	{
	select pixel location *(i,j)* at random
	if (*(i,j)* is available for urbanization)
	{
	(i,j) = urban
	New Spreading Center Growth
	}
	}
	} end spontaneous growth

B-Spreading center growth (Perpetuation of Change)

New spreading center controls the likelihood that one of the newly established spontaneous growth settlements will become a center for continued growth in other words Determines whether any new spontaneously created urban cells will spread or 'attract' more of like kinds of land use, e.g. build one house, someone else will build another one nearby. Spreading growth is expressed as:

[1] *dispersion_value = ((dispersion_coeff * 0.005) * sqrt (rows_sq + cols_sq))*

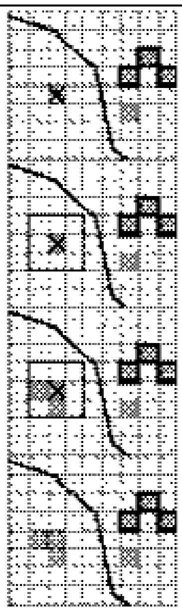
$$U'(i,j,t+1) = f[\text{breed-coefficient},\ U(i,j,t+1),\ \text{random}]$$

Equation 11 Equation of Spontaneous growth

where (k,l) are nearest neighbors to (i,j).

If the cell is allowed to become a spreading center, two additional cells adjacent to the new spreading center cell also have to be urbanized. Thus an urban spreading center is defined as a location with three or more adjacent urbanized cells (as in John Conway's rulefor game of life in chapter three).

Table 8 Spreading growth example and pseudo C programming language code.(Project Gigapolis, 2002)

	New Spreading Center Growth:
	F(<u>breed_coefficient</u>, <u>slope_coefficient</u>)
	{
	  if (random_integer < *breed_coefficient*)
	    if (two neighborhood pixels are available
	        for urbanization)
	      (i,j) neighbors = urban
	} end new spreading center growth

C-Edge growth (Adjacent Expansion)

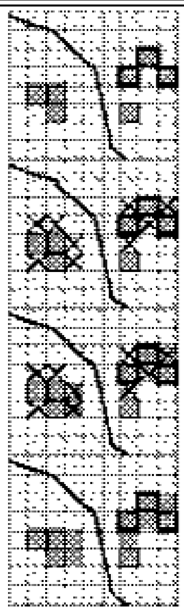
This rule models outward growth from existing spreading centers. as well as infill growth. This growth propagates both the new centers generated in step of spreading growth in this time step, time (t+1), and the more established centers from earlier times. It can be expressed by

$$U(i,j,t+1) = f\,[\ spread\_coefficient,\ slope\_coefficient,\ U(i,j,t),\ U(k,l),\ random\ ]$$

Equation 12 Equation of edge growth

Where (k,l) belongs to the nearest neighborhood of (i,j).

Table 9 Edge growth example and pseudo C programming language code.(Project Gigapolis, 2002)



```
Edge Growth:
F(spread_coefficient, slope_coefficient)
{
   for (all non-edge pixels (i,j))
      if ((i,j) is urban) and (random_integer
            < spread_coefficient)
         if (at least two urban neighbors exist)
            if (a randomly chosen, non-urban
                  neighbor is available for urbanization)
               (i,j) neighbor = urban
} end edge growth
```

D-Road-influenced growth

Type of growth generates spreading centers next to routes of transportation and simulates the tendency for new growth to follow lines of transportation.

If a road is found within a given maximal radius (determined by road_gravity_coefficient) of an urbanized celldefined by initial conditions or spontaneous or spreading or edge growth, a temporary urban cell is placed at the point on the road that is closest to the selected cell.

$$U'(k,l,t+1) = f\,[U(i,j,t+1),\ road\_gravity\_coefficient,\ R(m,n),\ random\ ]$$

Equation 13 Equation of Road-influenced growth

Where i,j,k,l,m, and n are cell coordinates,
R(m,n) defines a road cell.

Next, this temporary urban cell conducts a random walk along the road (or roads connected to the original road) where the number of steps is determined by the parameter dispersion_coefficient.

The random walk on the road may be expressed by

$$U''(i,j,t+1) = f[\, U'(k,l,t+1), \text{dispersion\_coefficient}, R(m,n), \text{random} \,].$$

Equation 14 Equation of spontaneous road-influenced growth

Where(i,j) are road cells neighboring (k,l).

If the location of the temporary urbanized cell at the end of the random walk is defined by (p,q), the new adjacent urban spreading center will be defined by

$$U'''(i,j,t+1)= f[U''(p,q,t+1), R(m,n, \text{slope\_coefficient} , \text{random} \,]$$

Equation 15 Equation of spreading center road-influenced growth

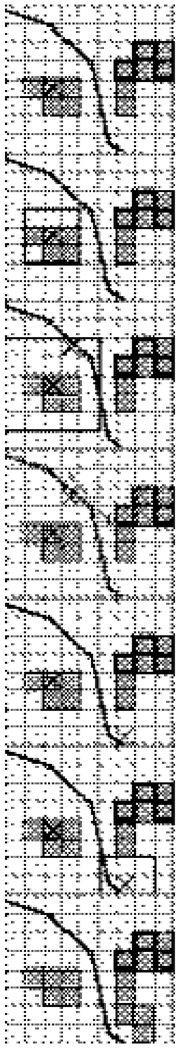
The final location of this temporary urbanized cell is then considered as a new urban spreading nucleus. If a neighboring cell to the temporary urbanized cell (on the road) is available for urbanization, it will happen (randomly picked among possible candidates). If two adjacent cells to this newly urbanized cell are also available for urbanization it will happen (randomly picked among candidates). the new adjacent urban spreading center will be defined by

$$U''''(i,j,t+1) = f\,[\, U'''(p,q,t+1), \text{slope\_coefficient}, \text{random} \,]$$

Equation 16 Equation of newly urbanized cells because of spreading center according to road-influenced growth

Where *(i,j)* and *(k,l)* belong to the nearest neighborhood of *(p,q)*

Table 10 Road-influenced growth example and pseudo C programming language code.(Project Gigapolis, 2002)



```
Road-Influenced Growth:
F(breed_coefficient, road_gravity_coefficient,
dispersion_coefficient, slope_coefficient)
{
   for (p <= breed_coefficient)
   {
      road_gravity = value which is a function of
            image size and road_gravity_coefficient
      max_search = maximum distance, determined
by
            road_gravity, for which a road pixel is
searched
      (i,j) = randomly selected pixel, urbanized within
the
         current growth cycle
      road_found = search outward from (i,j), up to
            max_search, for a road pixel
      if (road_found)
      {
         walk along the road, in randomly selected
               directions, for a number of steps
determined
               by the road_value and the
               dispersion_coefficient
         if (a neighboring pixel is available for
urbanization)
            (i,j) neighbor = urban
            if (two neighbors of the newly urban pixel
                  are available for urbanization)
               two urban pixel neighbors = urban
} } } end road-influenced growth
```

These growth rules occur sequentially, and the cell state is updated after the application of each rule across the entire space. Figure (35) summarizes the consequence operation rules for a single cycle in a SLEUTH UGM.

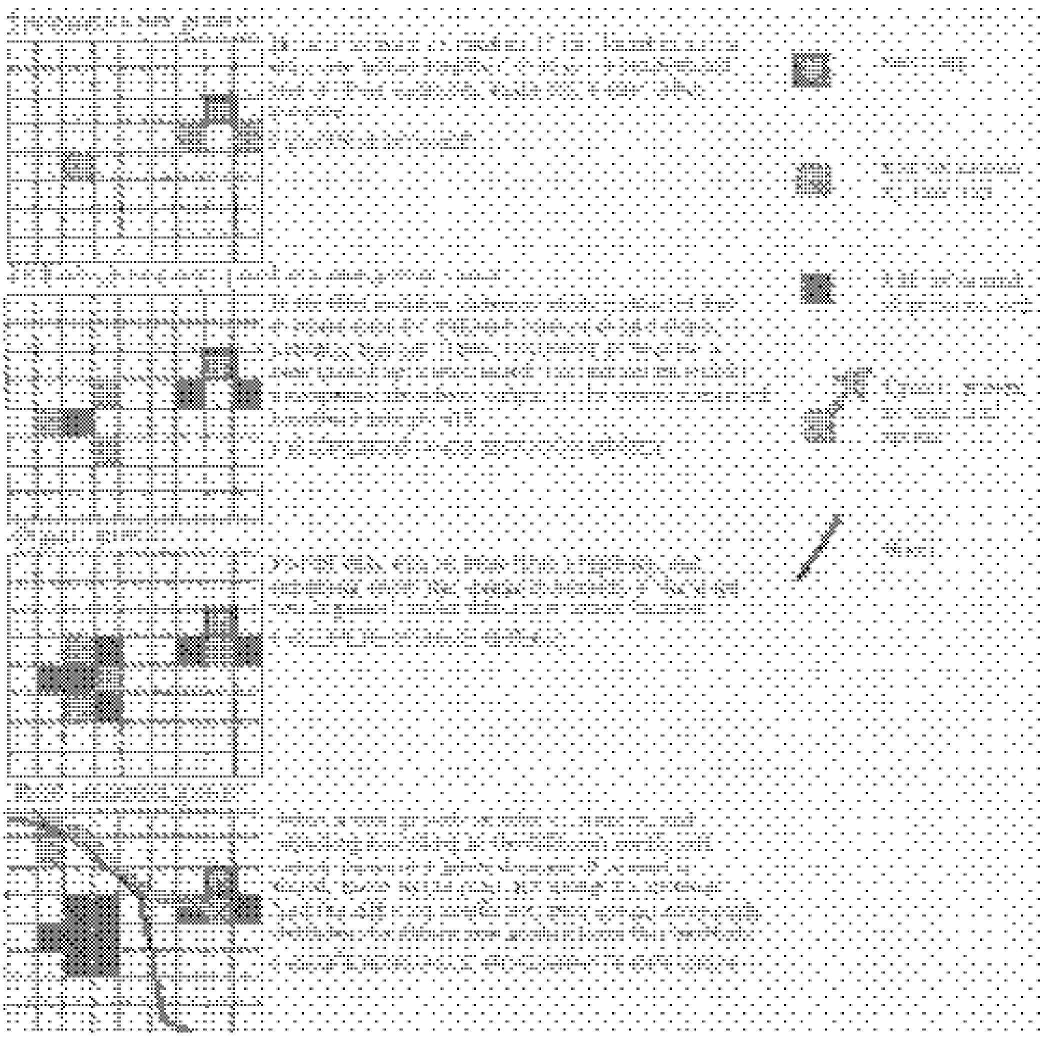


Figure 35 SLEUTH UGM operation rules for a single cycle (year).(Clarke, K. C. et al.1997)

4-3-2.3 Self-Modification

If the growth rate exceeds or falls short of limit values in a growth cycle - which is the basic unit of SLEUTH execution – after setting a unique value for each coefficient, model self-modification is applied. Self-modification will slightly modify – change - the coefficient values to simulate accelerated or depressed growth according to system state

There are two states, which lead to self-modification. They are:

A “boom” state occurs if the growth rate exceeds the CRITICAL_HIGH value and indicates a period of accelerating growth. Each of the coefficients is increased to encourage the continuation of this trend.

A “bust” state occurs when the growth rate is less than the CRITICAL_LOW. In such an instance, the coefficients will be lowered in order to decrease the rate of growth throughout the system

The algorithm used to apply self-modification to the coefficients is given below:

$$growth\_rate = number\_growth\_pixels / total\_number\_urban\_pixels * 100$$

Equation 17 urban growth rate in SLEUTH model

where number_growth_pixels is the number of newly urbanized pixels from the current growth cycle

total_number_urban_pixels is the amount of urban pixels from the current and previous growth cycle

$$percent\_urban = (100 * (total\_number\_urban\_pixels + road\_pixels) / (total\_number\_pixels - road\_pixels - excluded\_pixels))$$

Equation 18 Percent urban in SLEUTH model

Whereroad_pixels is the number of road pixels used for the current growth cycle

excluded_pixels is the number of pixels in the exclusion layer with an absolute exclusion value.

A-Algorithm used for self-modification in case that growth rate is above CRITICAL_HIGH value

```
if (growth_rate > CRITICAL_HIGH) {
slope _ res =slope _ res −(percent _ urban * SLOPE _ SENSITIVITY )
road _ grav =road _ grav +(percent _ urban * ROAD _ GRAV _ SENSITIVITY )
 if (dispersion < MAX) {
dispersion = dispersion * BOOM;
breed = breed * BOOM;
spread = spread * BOOM;
}
}
```

WhereCRITICAL_HIGH is the growth rate threshold above which a boom state exists for the system.

Slope_res, road_grav, dispersion, breed, and spread represent the coefficient values slope_resistence, road_gravity, dispersion, breed and spread respectively.

SLOPE_SENSITIVITY, ROAD_GRAV_SENSITIVITY, and BOOM (as well as BUST used in the bust state) are used to modify the coefficient values and are defined in the application scenario file. MAX is the maximum value of a coefficient.

B- Algorithm used for self-modification in case that growth rate is below CRITICAL_LOW value

```
if (growth_rate < CRITICAL_LOW) {
slope _ res =slope _ res +(percent _ urban * SLOPE _ SENSITIVITY )
road _ grav =road _ grav −(percent _ urban * ROAD _ GRAV _ SENSITIVITY )
 if (dispersion > 0) {
dispersion = dispersion * BUST;
breed = breed * BUST;
spread = spread * BUST;
}
}
```

WhereCRITICAL_LOW is the lower limit for growth_rate, below which the system enters a bust state.

Slope_res, road_grav, dispersion, breed, spread, SLOPE_SENSITIVITY, ROAD_GRAV_SENSITIVITY are as above in the above case state.

C-Algorithm used for self-modification in case that growth rate is higher than CRITICAL_LOW value and below CRITICAL_HIGH

```
if (CRITICAL_LOW< growth_rate < CRITICAL_HIGH) {
```

slope _ res =slope _ res ±(percent _ urban * SLOPE _ SENSITIVITY)
road _ grav =road _ grav ± (percent _ urban * ROAD _ GRAV _ SENSITIVITY)
}

where CRITICAL_LOW, CRITICAL_HIGH, Slope_res, road_grav, dispersion, breed, spread, SLOPE_SENSITIVITY, ROAD_GRAV_SENSITIVITY are as above in the above case state.

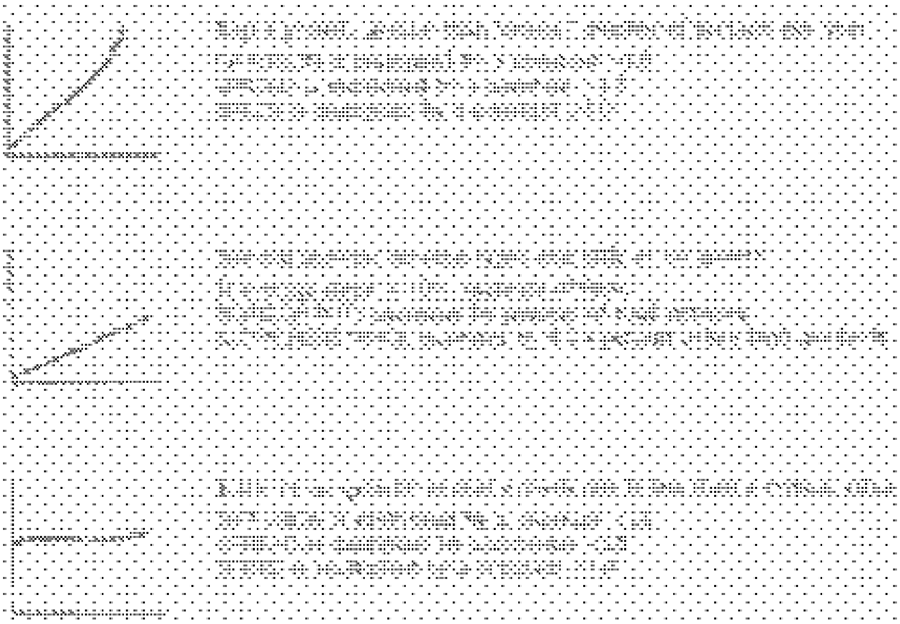


Figure 36 Self-modification adjustments to the growth parameters .(Clarke, K. C. et al.1997)

Table 11 shows the values of Self-Modification Constants used in UGM of Isleta, New Mexico, USA. In addition, (figure 37) represents curves produced by self-modification for the coefficient used in the model of historical urbanization in the San Francisco Bay area from 1900 to 1990.

Table 11: Self-Modification Constants - Urban Growth Model Calibration - Isleta, New Mexico, 1:24,000-scale quadrangle

Constant	Value
Critical High	1.03
Critical Low	0.97
Boom	1.1
Bust	0.9
Critical Slope	15

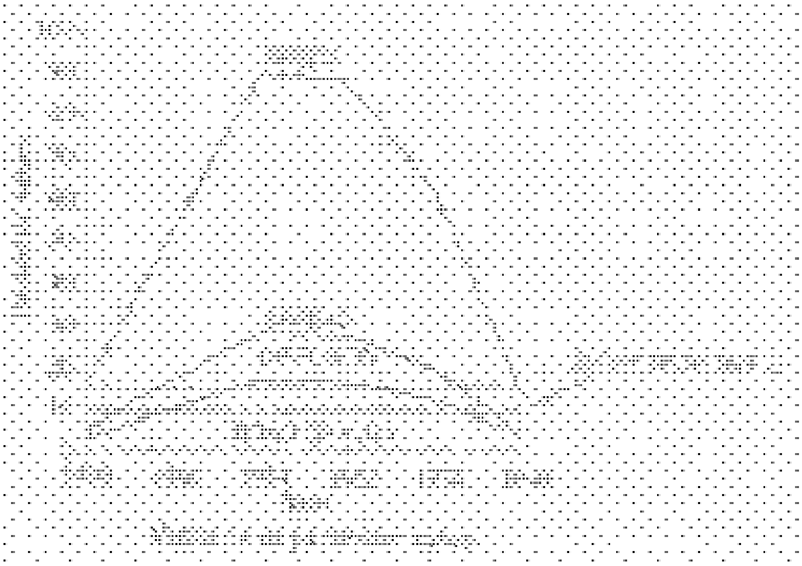


Figure 37 Diagram of average parameter values produced by self modification during the period from 1900 and 1990 in the model built for San Francisco Bay area. (Clarke, K. C. et al.1997)

Fitting simulated data to historical spatial data collected from maps, aerial photography or other remotely sensed data. Input requirements for SLEUTH is initialized with the earliest data, i.e. The oldest temporal snapshot mapped is used as a seed to the calibration phase (signifying the date furthest in the past) and growth cycles (often one cycle = 0ne year) are generated. As growth cycles complete, "time" passes. Dates where historical data exist are referred to as control years. When a completed cycle has a corresponding control year, an image of simulated data is produced Applying Monte Carlo fashion simulation (Appendix 2) and linear regression (Appendix 3) to best fit of maps in control years

Calibrating the UGM is an iterative process. Coarse, fine, and final.

The coarse phase calibrates in low resolution, small number of Monte Carlo iterations and large increments in applying coefficients.

Once the coarse calibration step was completed, the "best fit" growth control parameters recorded in the calibration results file would be averaged and entered to Fine calibration phase in which the increments would be narrowed and a larger number of Monte Carlo iterations are used

Final Phase then begins with the best-fit values found in the file produced in the fine calibration phase; the range of possible coefficient values is narrowed. Ideally, the ranges will be narrowed so that increments of 1 - 3 may be used and a larger number of Monte Carlo iterations and high-resolution maps will be used. A summary of the coefficients values in the three phases for the model built for Chiang Mai in Thailand is given in (figure 38).

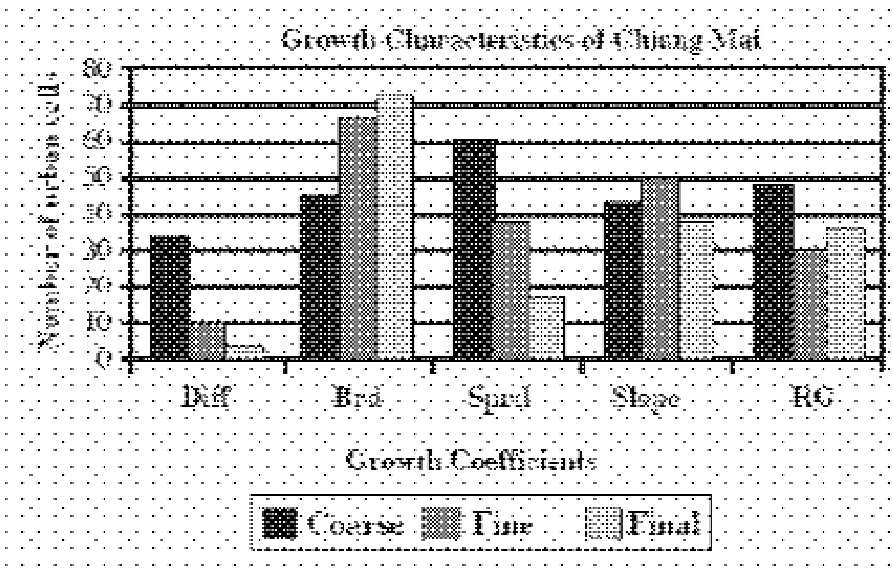


Figure 38 A summary of the coefficients values in Coarse, Fine and Final phases for the model built for Chiang Mai in Thailand (Sangawongse, S.(2006))

The UGM will be executed to predict the future urbanization - based on historical data - from the most recent temporal snapshot, the most recent transportation layer, the exclusion and slope layers, and the background hillshade (which would be the seed for predicting future urbanization) to the target year using average growth control coefficient

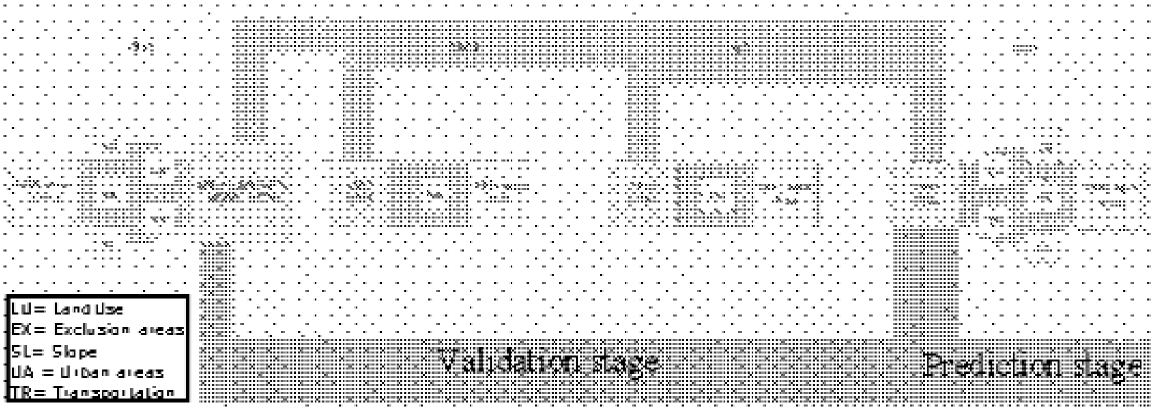


Figure 39 Urban Growth Model Calibration Process, Isleta, New Mexico, USA (Hester, D. 2000)

4-3-3 Model outputs

SLEUTH model forecasts of land use change are simulated through a number of Monte Carlo iterations; which produces a probability future growth map. (figure 40). Future growth could be projected under different policy scenarios such as current growth rate, managed growth, and ecologically sustainable growth. This could take place by changing the coefficients values and exclusion areas map

4-3-4 Model criticism

The application of SLEUTH model offers many advantages in modeling urban growth and land cover change, because of its cellular data structure, thereby making it possible to integrate with raster-based data from remote sensing (Jantz et al., 2003).

Results showed that SLEUTH has an ability to address many regional planning issues, but spatial accuracy and scale sensitivity must be considered for practical applications. However, the model does not show the ability to answer the socio-economic complexities and top – down interrelationships.

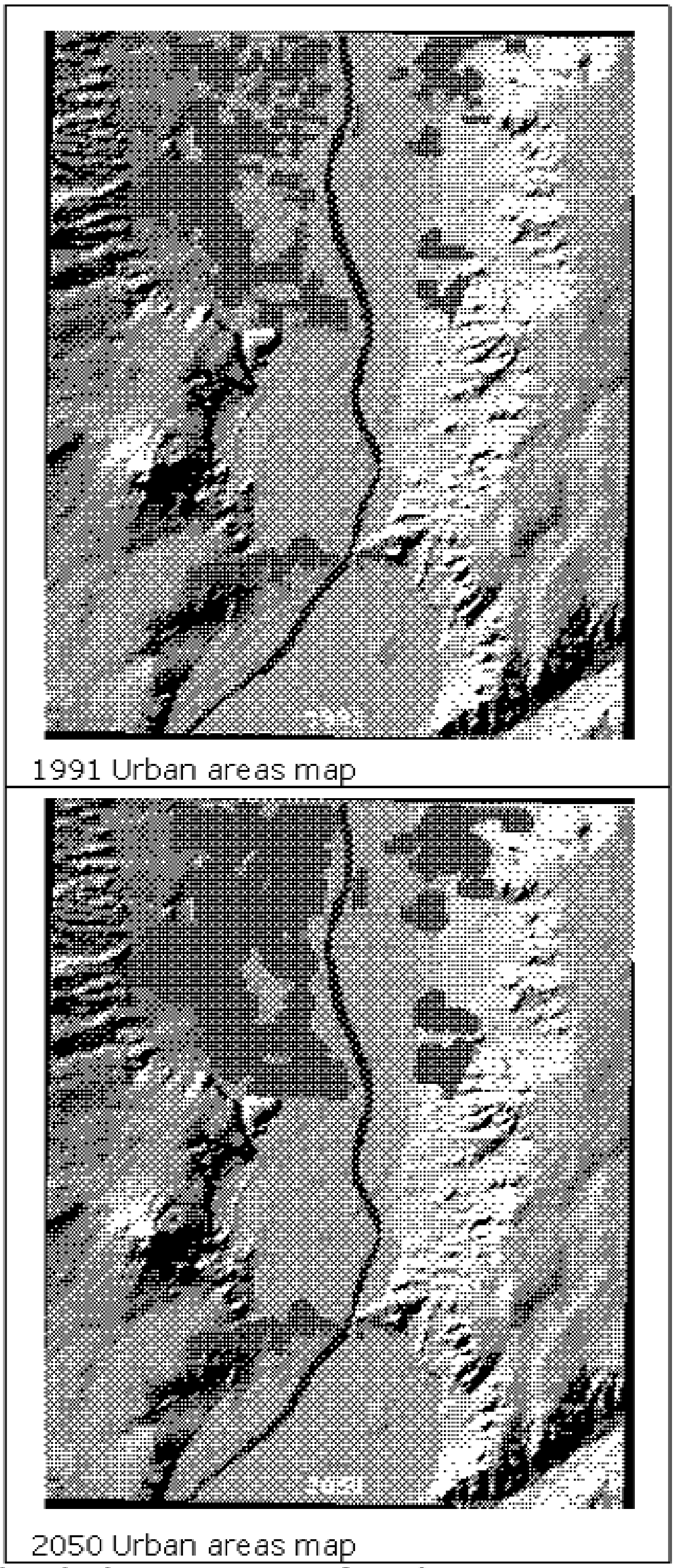


Figure 40 Predicted urban areas at 2050 for, Isleta, New Mexico, USA, (Hester, D. 2000)

4-4 RIKS models

RIKS, Research Institute for Knowledge Systems is a spin-off company of the University of Maastricht, RIKS developed kinds of Decision Support Systems for the design of policies in order to manage the behavior of river basins, coastal zones, cities, regions, environmental and eco-systems. Most of these Decision Support Systems consist of integrated dynamic simulation models, representing the main processes making and changing the area and issues in study area. (Research Institute for Knowledge Systems, 2006). Most of the dynamic simulation models are realized with CA modeling methods.

Almost all RIKS models can be divided into two hierarchical parts (as introduced in chapter 2) (figure 41):

- Macro sub model: This is responsible for generating the land use requirement depending upon simple trends rules or calculated from economic, demographic, social characteristics of study area.
- Micro sub models: Those allocate the land use requirement from macro sub model in detail. by 'exogenous' links of CA model. The cell states changes (land use changes) are not entirely determined by transition rules in Micro models, but will be influenced with different land use requirements per year, which were calculated from Macro model. (figure 42).

As the main engine of RIKS models is the micro sub models, which will allocate different land use in study area, (changing cells' states by evolution), we would focus on these types of models.

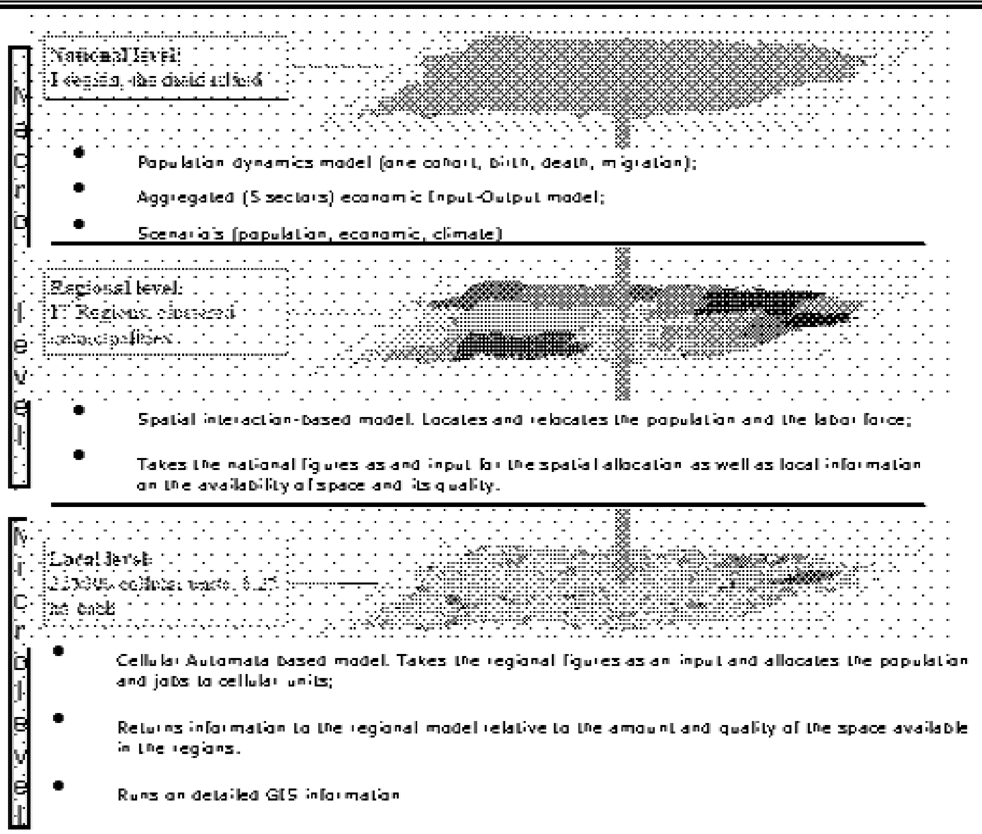


Figure 41 The Xplorah model (a kind of KIKS models) represents processes at three levels: National, Regional and Local. (Engelen, G. et al. 2003)

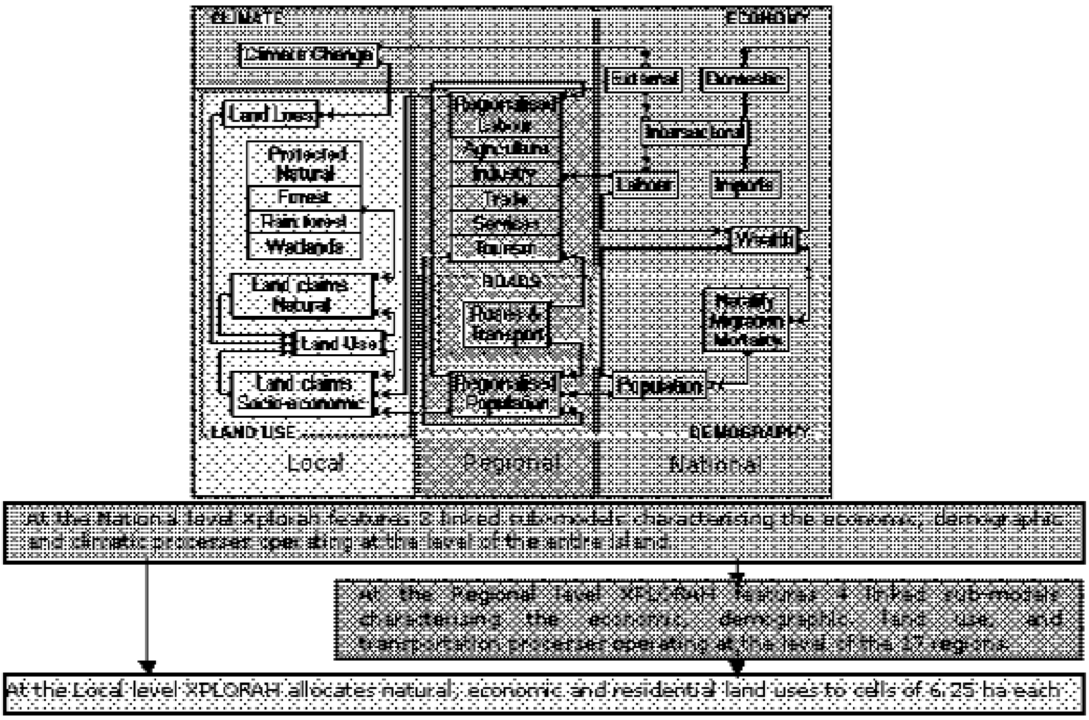


Figure 42 Xplorah model levels responsibilities. (Engelen, G. et al. 2003)

4-4-1 Model inputs

Micro sub models in RIKS models are almost common in their characteristics such as:

A-Lattice:

- It consists of a 2-dimensional rectangular grid of square cells
- The grid size and shape varies according to the application, but is typically less than 1000 by 1000 cell.
- Each cell in the grid represents an area ranging from 50 to 500 m square.

B-Cell states:

They represent the major land use type in parcels. In RIKS models, they are divided into two categories "as discussed in chapter three": Functional cell state such as Commercial, Residential, Industrial etc, and featured (fixed) cell states e.g. Beach, Forest, and River. To the former kind of cell (functional), they are active in the simulation process and can change their states if necessary. While featured cells cannot change their states in evolution process but they will only influence the changes of functional cells.

4-4-2 Model Mechanism

A-Cell neighborhood:

The neighborhood is defined into circular regions, with a radius of 8 cells (196 cells), located in 30 discrete distance zones (0,1, 2 , .$\sqrt{}$:2, 5 ,$\sqrt{}$;8) (Figure 43).

Since the cell varies from 50 to 500 m square. The neighborhood radius represents a distance ranging from 400m to 4km, the modeler uses number 1,2,3,4,5...30 represent the different distance from given cell to central cell (0,1, 2 ...8).

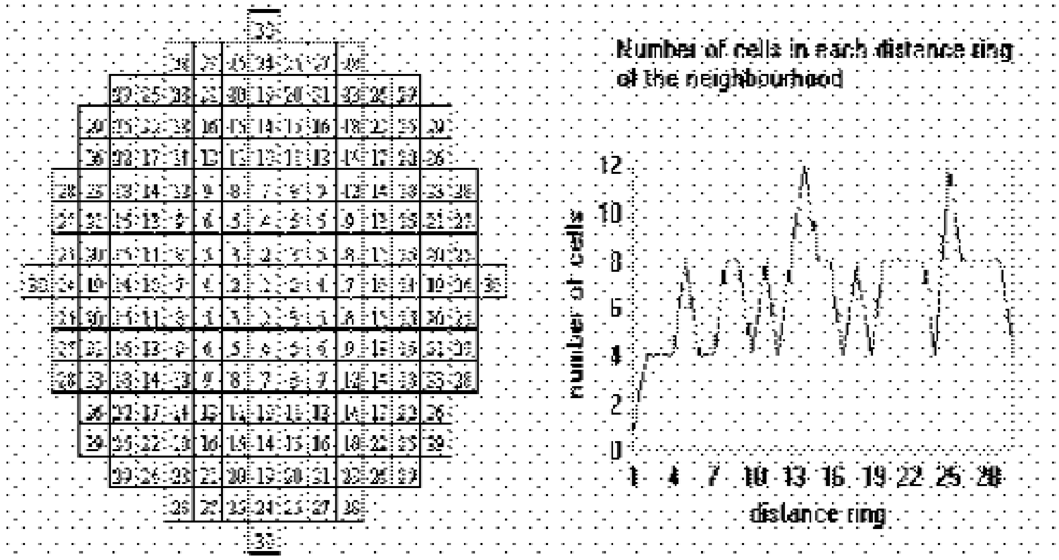


Figure 43 The cells' location in the neighborhood of RIKS models. (Junfeng, J. 2003)

The model defines different neighborhood weights to reflect possible interactions of various land use types. These interactions are divided into the attraction (positive) and repulsion (negative) influences. These different influences are called neighborhood effect. In addition, each cell in a neighborhood will receive a weight according to its state and its distance from the central cell as cells that are more distant in the neighborhood will have a smaller effect. The interaction can be calculated by the following formula.

$$N_j = \sum_x \sum_d W_{kxd} I_{xd}$$

Equation 19 Neighborhood effect: RIKS models (White and Engelen 2000)

Where: N_j is the neighborhood effect of the center cell has a land use j.
W_{kxd} is the weighting parameter applied to land use k at position x in distance zone d of the neighborhood, the transition rule is a weighted sum of distance functions calculated relative to all other land-use functions and features

I_{xd} is the Dirac delta function, which has a binary value. i.e. I_{xd} = 1 if the cell is occupied by land use k; otherwise, I_{xd} =0

(Figure 44) represents the different interaction W_{kxd} between functional cells and featured cells.

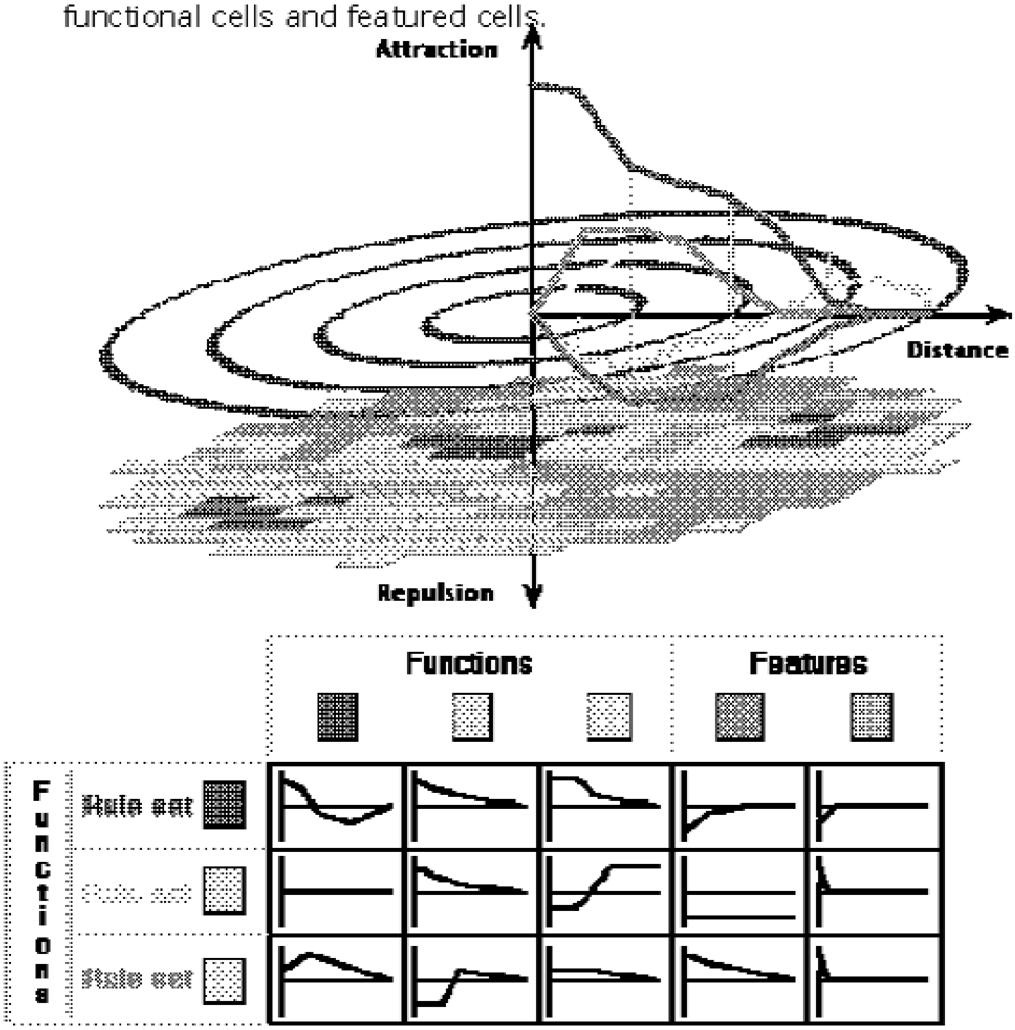


Figure 44 The neighborhood configuration and their interactions in RIKS models (Engelen, White et al.2000)

B-Transition rules

As mentioned in chapter three, the transition potential of cells is not only determined by neighborhood effect, but also with the influence of other factors as fellows:

- <u>Physical suitability</u>
  - Suitability for each land use is presented in the model

in the form of maps, which calculated OVERLAY-TOOLs in any GIS package. (Figure 45)

- The suitability of a cell for a particular land use K is expressed by means of a dimensionless value between 0 and 1.
- The suitability maps are calculated based on physical "elevation, slopes", ecological "aquifers, flooding areas", technical, economic and historical factors "actual land use, agricultural capacity, forest reserves" determining the physical appropriateness of a cell to receive the land use.
- The micro-model returns overall information to the macro-model relative to the suitability for each land use K and for each Region i:

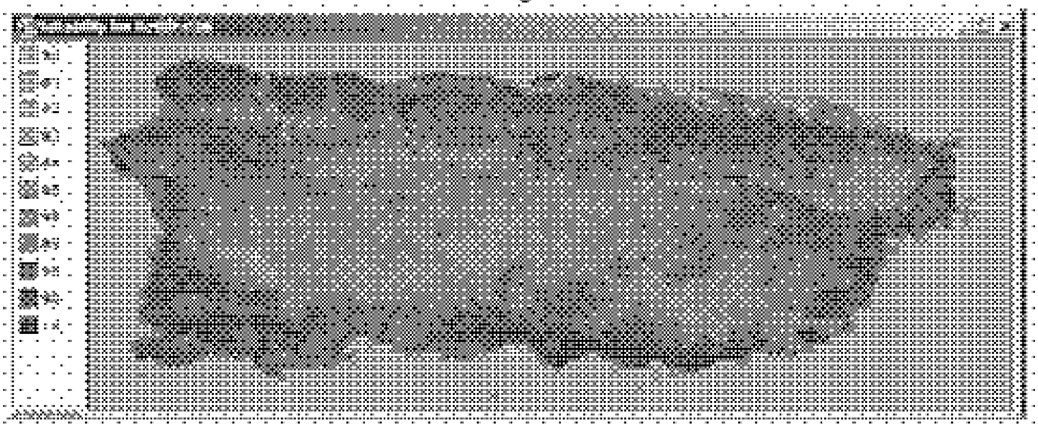


Figure 45 Suitability map for the land use function Residential, main island of Puerto Rico. (Engelen, G. et al. 2003)

- Accessibility
  - It is a spatially distributed measure (on a map) expressing, in values ranging between 0 and 1. (Figure 46)
  - The importance of accessibility varies according to land use. Commercial land use requires a different

convenient transportation quality comparing with convenience needed for residential land use. RIKS modelers reflect this difference by the method of giving different land use different coefficients as shown in the following equation:

$$A_j = a_j / (D + a_j)$$

Equation 20 Accessibility effect: RIKS models (White and Engelen 2000)

Where: A_j is the value of accessibility

D is the Euclidean distance from the cell to the nearest cell through which the network passes.

a_j represents the importance of accessibility to different land use types.

- In XPLORAH project, it is implemented as a composite measure taking into consideration access to the following 4 different infrastructure elements of the transportation network: (1) Primary roads, (2) Secondary roads (3) Tertiary roads, and (4) Local roads.

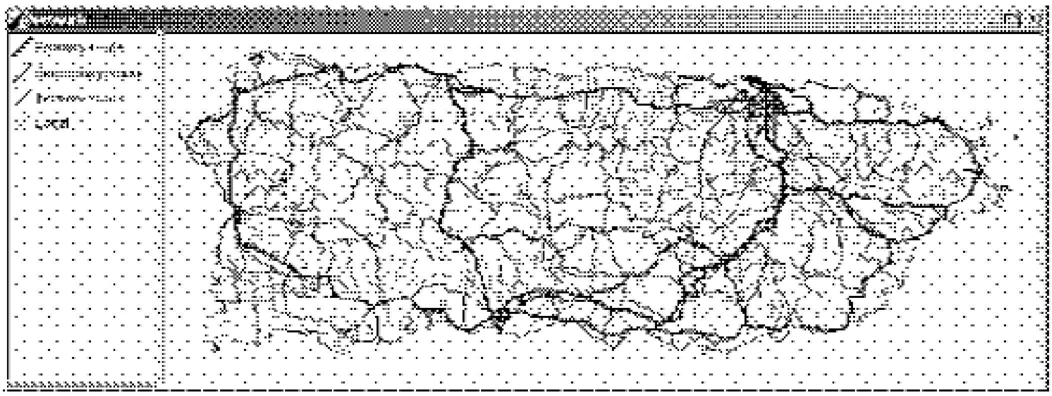


Figure 46 The road network of the main island of Puerto Rico - Local roads are not represented. (Engelen, G. et al. 2003)

- As cells may change during a simulation from one category into the other (Built-up to Non built-up or vice versa), the accessibility will change too this is because of the underlying assumption that is the Built-up area is equipped with a fine-grained transportation infrastructure, while the Non built-up area is not. Thus, access to the transportation infrastructure from a Built-up cell is easier. This also leads to effects on accessibility could take place according to changes in the network, such as extensions of the networks.

- Zone suitability
  - Zoning is a dimensionless binary measure distributed spatially on a map determining whether a cell may (= 1) or may not (= 0) be taken in by a specific land use. (Figure 47)
  - The zoning status of a cell can change in time. For each cell and land use K, the model allows to define the zoning status for multi-zoning periods with the assumption that once a land use is allowed to occupy a certain cell in a specific time, it would be allowed for this land use to occupy this cell for the remaining simulation time.

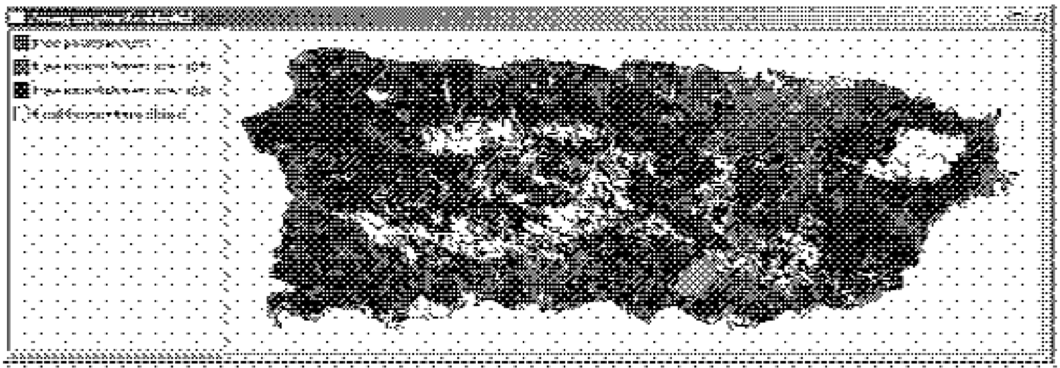


Figure 47 Zoning map for the land use function Residential. , main island of Puerto Rico. (Engelen, G. et al. 2003)

In fact the above factors have been included in most RIKS models (figure 48) and the transition potential rules are presented in following way.

$$P_j = vA_jS_jZ_jN_j$$

Equation 21 Transition potential rule based on Neighborhood effect, accessibility, suitability, and zoning status: RIKS models (Engelen, White et al. 2000)

Where: P_j is the transition potential of cell for land use j
A_j is the accessibility of the cell to road network
S_j indicates the intrinsic (physical, environmental, historical...) suitability of the cell for land use j
Z_j represents the zoning status of the cell for land use j, in many case, we can look it as a kind of policy suitability, contrasting to physical suitability.
N_j is the neighborhood effect on the cell for land use j.
v is a scalable random perturbation term.

With the help of v, most of the final transition potential Pj will change very little to overcome the problem of some unpredicted influences in simulation context. Therefore, the final simulation result may look like reality more.

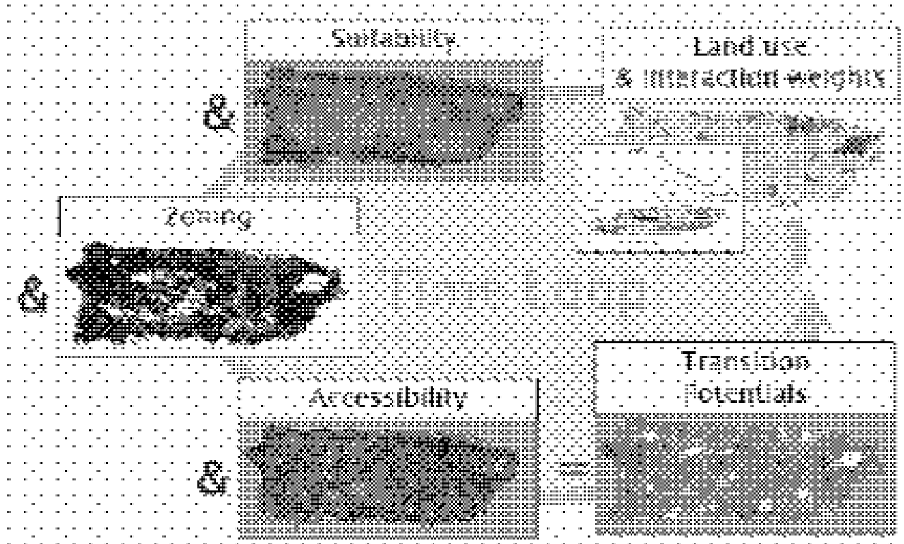


Figure 48 Suitability, Zoning, Accessibility, and spatial interaction in the cell neighborhoods determine the dynamics at the Local level. (Engelen, G. et al. 2003)

4-4-3 Model outputs

The outputs from RIKS models software are many. (Figure 49) shows the interactive comparison and analysis of maps containing category, ordinal and numerical data done in the XPLORAH project in Puerto Rico.

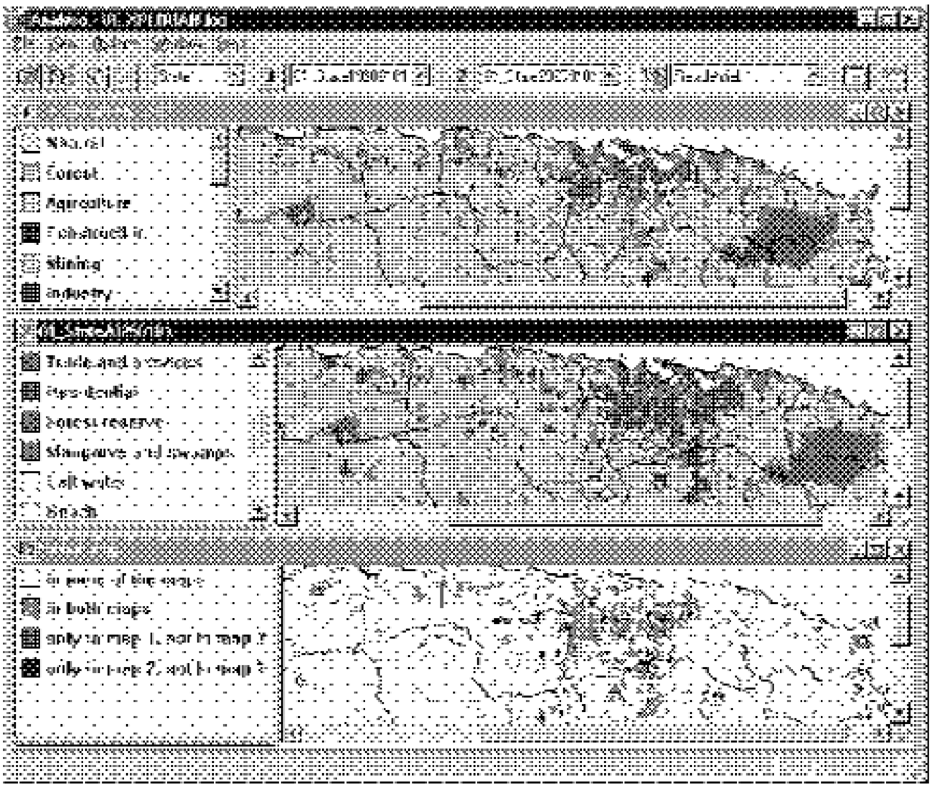


Figure 49 The ANALYSE-TOOL enables the interactive comparison and analysis of maps containing category, ordinal and numerical data. , main island of Puerto Rico. (Engelen, G. et al. 2003)

4-4-4 Model criticism

RIKS models overcome some of the disadvantages of CA models. Firstly, they have a radical up - down approach as the national and regional scale affects the behaviors between cells in the local level. Secondly, the effect of social, economic, political and environmental inputs is clear in these models. However, the effect of historical data does not disappear but in some rules but by the users not automatically, in other words semi-automated process.

4-5 Wuhan model

This Model was built by Jianquan Cheng (2003) to understand the spatial processes and their temporal dynamics on two interrelated scales (municipality and project). Projects are special land use or dynamic spatial development proposals initiated usually by various types of actors such as investors, planners, developers, landowners and work units.

The author used a dynamic weighting concept in a multi-stage framework composed of four stages: project planning, site selection, local growth and temporal control. This framework enables the interactions between the top-down and bottom-up decision-making involved in land development for large-scale projects with using CA modeling technique. So, this approach could be called Project-based cellular automata modeling. The author tested this framework in a fast growing city, Wuhan in the P.R.China from 1993 to 2000. Here we would present the stages of applying this model.

4-5-1 Model inputs

The data used in this model are raster – format data about land use, population density, road network and master plan.

4-5-2 Model Mechanism

The model process has four stages, as illustrated in (figure 50), which are:

A-Project planning stage:

- This stage is a typical top-down non-spatial decision-making process based on the systematic consideration of physical and socio-economic systems. The project here can be called an 'agent' which lead this approach to behave as agent based modeling.
- This stage results in proposals for development projects with determining the total areas have to be covered by these projects

$$L(t)|_{t=n} = L_d$$

Equation 22 Equation for area needed to a development project. In Cheng model. (Cheng J. 2003)

Where L_d is the actual (or planned) area of land development project d in the whole period [t=1~n]

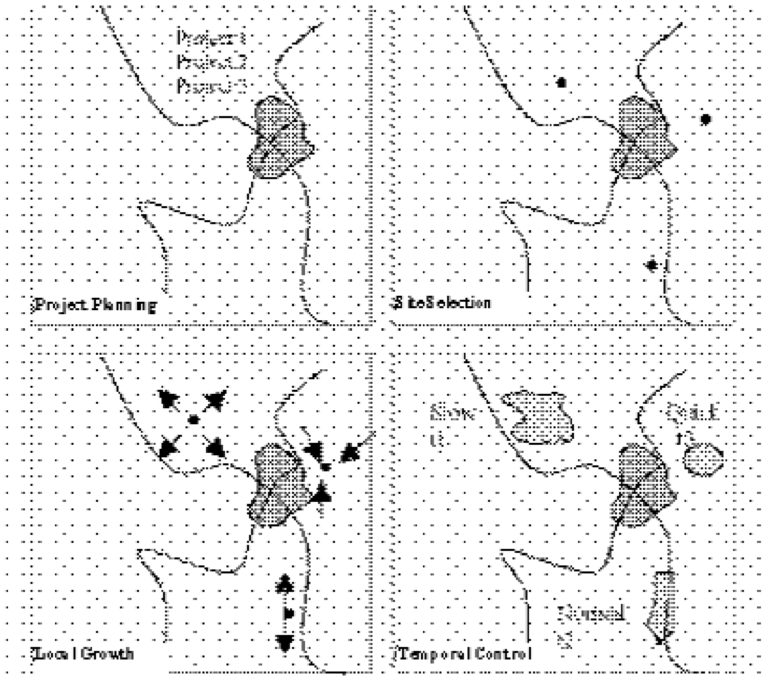


Figure 50 The conceptual model for the decision making process. (Cheng J. 2003)

B-Site selection stage:

- This stage is a typical spatial decision process involving municipal decision-makers. This aims to systematically optimize and balance the spatial distributions of socio-economic activities as each project has specific socio-economic functions planned.
- This stage is the static projection of the projects planned at the first stage and results in a number of potential spatial sub-systems It represents growth boundaries and seeds for the next stage.
- It is a spatial decision making process which takes is govern by some rules. These rules are represented by various physical, socio-economic and institutional factors and are differentiated

between planned projects in terms of influential factors, weights and constraints as in equation 23.

$$Sites=Neighborhood*Center(x,y), \quad Center(x,y) = {}^{m}\prod_{i-1} cons_{i}$$

Equation 23 Equation For sites selection in Cheng model

Where : $cons_i$ is the critical constraints used in determining the project's sites.

The constraints operate at global (ecological, the economic, social, institutional and accessibility to transport infrastructure and city centers / sub-centers), regional (availability of developable or developed land and its density in a neighborhood) and local levels (physical conditions such as slope, soil quality and geological condition). Table 12 represents site selection rules for five projects in Wuhan city studied by Cheng model and (figure 51) shows the factors and constraints maps in the model.

Table 12: Site selection rules used in Cheng model for 5 areas. (Cheng J. 2003)

	Zhuankou	Wujiashan	Guanshan	Changqing	The rest
Cells -Ld Functions	1390 Manufacturing	314 Economic zone	514 High-tech zone	160 Residential	3170 Mixture
Global constraint	<300 m to major road	<300 m to major road	<300 m to major road; <4.2 km to the university street	<300 m to major road; <3.5 km to sub-centers; >560 (person/ha) in net population density.	Close to city centers/ sub centers <3.5 km to sub-centers; >560 (person/ha) in net population density.
Regional constraint	Density of developable land > 62% in a 4.5 × 4.5 km² square; & > 90% in a 2 × 2 km² Square	Density of developable land >69% in a 1 × 1 km² square; Density of developed area >18.7% in a 2 × 2 km² Square.	Density of developable land >68% in a 3 × 3 km² square	Density of developable land >60% in a 1 × 1 km² square; Density of developed area >10% in a 2 × 2 km² square	Higher density of developed areas
Local constraint	Agricultural, Village	Agricultural, Village	Agricultural, Village, hill	Agricultural, pond	Agricultural, pond, Village, hill

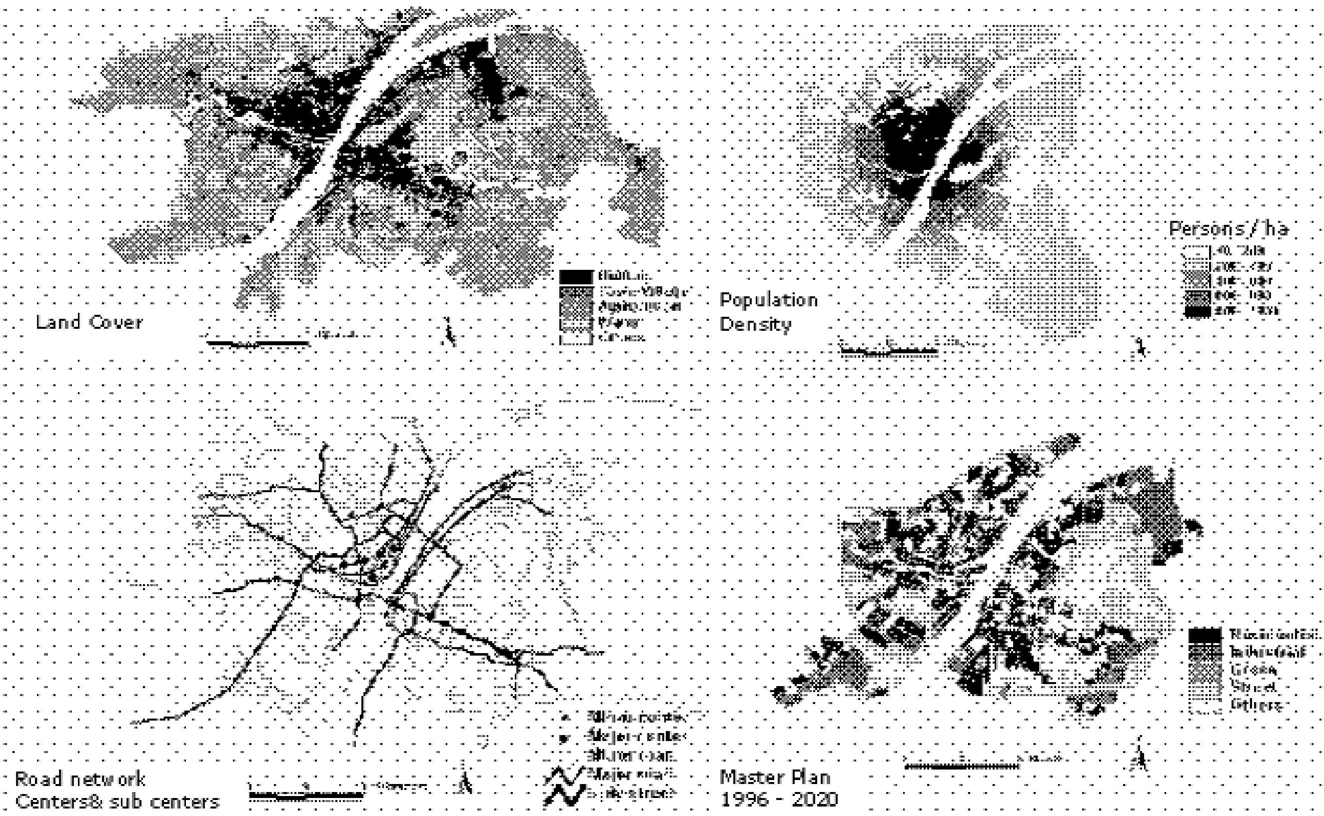


Figure 51 Spatial factors and constraints for Site selection stage in Wuhan, China (Cheng J. 2003)

C-Local Growth Stage:

This stage is the engine of this model. It is responsible for defining development density, intensity and the spatial organization of development units. . Based on CA, The author was able to explore the dominant causal factors locally. The stage is dominated by the bottom-up approach.

In this model, the cell state is binary (1 – land cover transition from non-urban to urban, 0 – not). The cells selected in each iteration will be changed from 0 to 1. The following equation defines the probability of land transition of each cell j at time t

$$P_j(t) = (1+\ln(§)^{\alpha})\ (^{k}\sum_{i=1} W_i(t) * V_{ij}(t)^{m} \prod_{i=k+1} \omega i)$$

Equation 24: development potential of each cell in Cheng model.

Where $P_j(t)$ refers to the probability of land transition in cell j at time t.

i is a constraints from m constants, k non-restrictive and m-k restrictive constraints .

ωi is a binary variable (0 or 1) representing restrictive constraints. ωi =0 means that a cell is absolutely restricted from transition into urban use in relation to constraint i,

$W_i(t)$ is the relative weight value of factor i to be calibrated from data

$V_{ij}(t)$ is the standardized score (within the range 0~1) of factor i at cell j at time t according to $[V_{ij}(t) = (X_{ij}(t) - min) / (max - min)]$ as X_{ij} is the value of factor i at cell j at time t.

$(1+\ln(\xi)^{\alpha})$ is a stochastic disturbance is introduced in which. ξ is a random variable within the range [0~1]. α is a parameter controlling the size or strength of the stochastic perturbation

D-Temporal control

This stage manages the local growth speed from a global perspective. For example, The rate of local growth (which could be quick, normal, and slow) is governed by numerous factors resulting from top-down (e.g. financial resources allocation from higher-level organizations and master and land use planning control) and bottom-up decision-making (e.g. man-power allocation and facility supply". The stage is primarily a top-town procedure and conditioned by a bottom-up one for controlling local temporal patterns. It is considered as a guide or constraint to the local growth stage.

In his model, Cheng used standard logistic curve to control the speed of urban growth as fellow

> The value controls the his logistic curve "λ" is determined in the middle time of the whole process when t = n/2 this is defined by $L(t) = L_d / \lambda$

Then the parameter of the curve(z) is defined by

$z= L_d(e^{cn} -1)/(e^{cn} -L_d)$ where $c = 2\log [(Ld -\lambda)/(\lambda-1)]/n$

The equation of the curve is

$$L(t) = z / [1+((z-1)X(e^{-ct}))]$$

Equation 25 the logistic curve used in temporal control in cheng model

The values have been used in the model for λ are 4/3 for quick growth, 2 for normal growth and 4 for slow growth as in figure 59

Finally Dynamic weighting means that factor weight is not a constant but a function of temporal development amount which suggests a dynamic feedback between weights factors and area of development every time iteration.(Table 13 and figure 52).

$$Wi\ (t) = f_i\ (Lt)\ i= c,\ r\ (0\sim1)$$

Equation 26: Dynamic weighting of factors in Cheng model.

Where $W_i(t)$ is the weight of factor I in time t
c is the center factor
r is the road factor

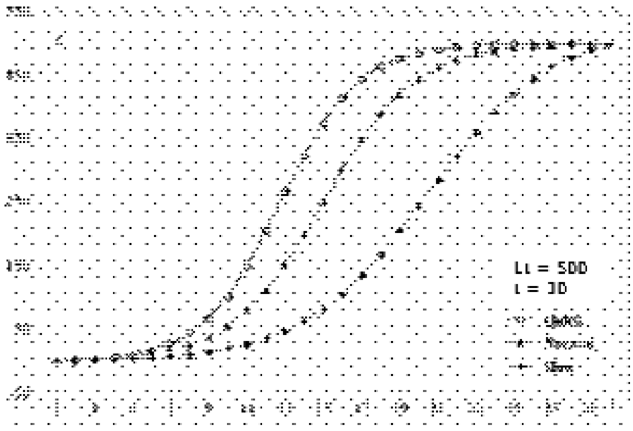


Figure 52 Illustration of temporal development patterns

4-5-3 Model Output

As the model was basically designed to test the temporal effect of assigning values for road and center factors, the output of the model was two maps for urban growth for the same area with two growth scenario. (Table 13 and figure 53)

Table 13 The dynamic factors weights assigned for Zhuankou project (Wuhan, China) in statically (Zhuankou-1) and dynamically (Zhuankou-2)

	Zhuankou-1	Zhuankou-2		
Dynamic weighting	-	<15%	15-55%	>55%
Major road (MR)	0.2	0	0.5	0.05
Minor road (OR)	0.3	0	0.1	0.15
Centers (CE)	0	0.7	0	0.5
Neighborhood	0.3	0.3	0.1	0.15
Master planning	0.2	0	0.3	0.15

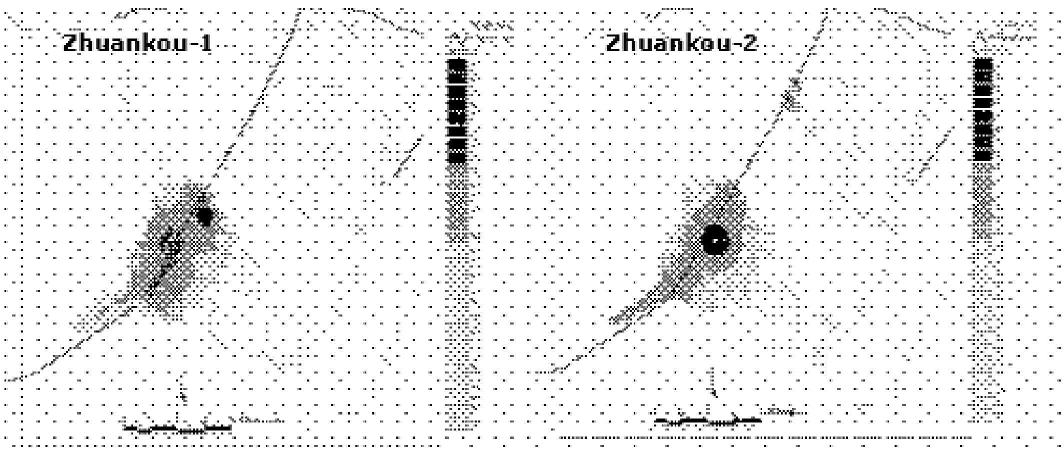


Figure 53 Development phases according to Zhuankou in Wuhan , China

4-5-4 Model criticism

This model was mainly designed to study the spatial-temporal processes by building by project-based model, so the model could be considered as a multi-agent CA model that can easily be interpreted with reference to decision-making and socio-economic. The author argued that the availability of detailed socio-economic enables to link the model with micro-scale multi-agent.

We can easily notice that experts opinions are essential in each stage of the process but the most important rule appear during assigning dynamic weighting for road and center factors as these values greatly affects the final output of the model.

4-6 UrbanSim Software Application

UrbanSim is a system to simulate the urban region development, including land use, transport, and impacts of the environment, on periods of twenty or more of years. (Waddell, P. et al.(2001, 2003)) It has been developed since the late 1990's to provide some operational tools to support the evaluation of land use, transport and policies of the environment and plans in metropolitan regions.

(Figure 54) represents the process of the development of the politics proposed in this model as fellows:

The process begins with a visioning, or setting goals, then defines objectives of the goals to be achieved through development, then identifies policies to answer goals, different scenarios to reach policies.

These steps are institutional, often relate to decision-making processes and could be non – spatial.

The operations done by UrbanSim begin with modeling scenarios that results in some outcomes. These outcomes present indicators which need to have some assessments in order to make new visions and goals and so on ...In this way it could be understood that UrbanSim is a tool to help to organize and civic issues, not a tool to model the behavior of voters or governments.

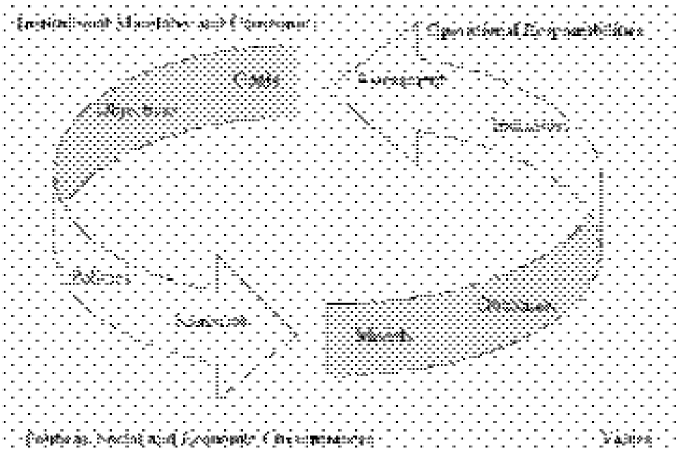


Figure 54 The proposed policy development process in UrbanSim, (Waddell, P. et al. 2002)

4-6-1 Model inputs

Data Store is the model database. The input data are parcel files from tax assessor offices, business establishment files from the state unemployment insurance database or from commercial sources, census data, GIS overlays representing environmental, political and planning boundaries, and a location grid... These data are used to construct the Object Store, Representations of agents in the world (as houses and enterprises), and objects they operate on (as buildings and land parcels), are contained in the Data Store The Data Store – as a database - can be queried or updated, and it supports to filter on attributes of the entity. The data integration process for UrbanSim is depicted in (figure 55). Data could be quered and updated by special models (could be considered as commands) such as postQuery – postUpdate ... .

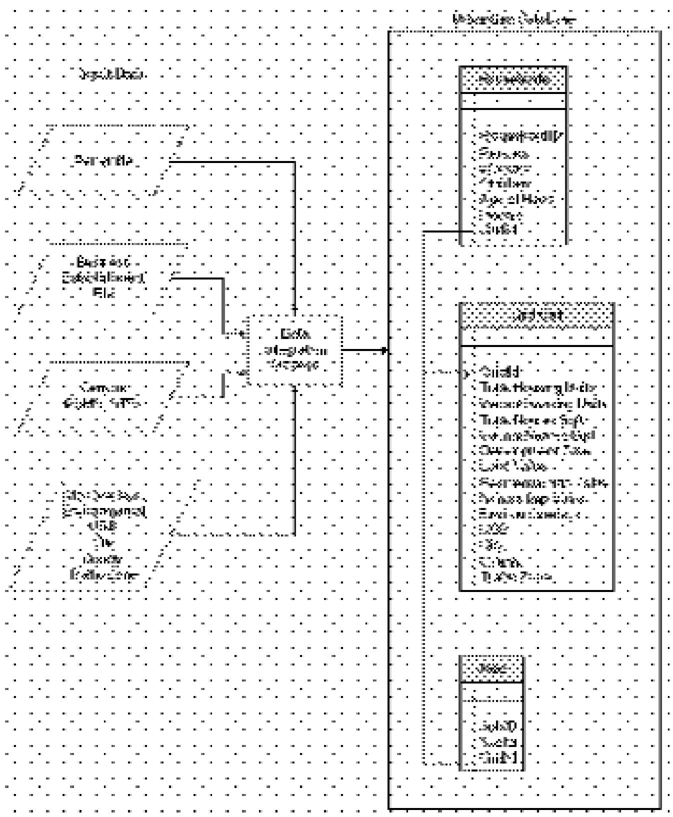


Figure 55 The data integration process for UrbanSim. (Waddell, P. et al. 2003)

The spatial data are represented in grid cells. Each cell could have many land uses according to its size and its location among urban areas. If the spatial data are represented in 150 × 150 meters like (figure 56) which shows one grid cell in a central Seattle neighborhood of Queen Anne, over a digital orthophoto and parcel boundaries, this cell has many land uses, this land uses could be converted to development type according to rules like these in table 14, these rules based on the combination of housing units, nonresidential square footage, and the principal land use of the development. If the cell contains 98 housing units and non-residential square footage, the cell would be would be classified as a development type of R8, or high-density residential.

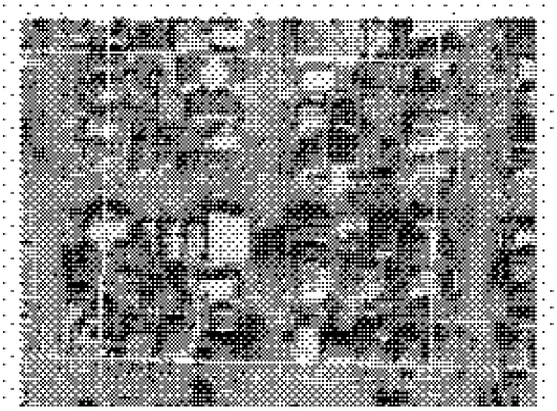


Figure 56 one 150×.150 grid cell in a central Seattle neighborhood of Queen, (Waddell, P. et al. –b 2001)

Table 14 the rules for classifying grid cell development into types. (Waddell, P. et al. –b 2001)

1	R1	[illegible]	[illegible]	0	999	Residential
2	R2	[illegible]	4	0	999	Residential
3	R3	[illegible]	[illegible]	0	999	Residential
4	R4	[illegible]	[illegible]	[illegible]	[illegible]	Residential
5	R5	[illegible]	[illegible]	[illegible]	[illegible]	Residential
6	R6	[illegible]	[illegible]	[illegible]	[illegible]	Residential
7	R7	[illegible]	[illegible]	[illegible]	[illegible]	Residential
8	R8	[illegible]	[illegible]	[illegible]	[illegible]	Residential
9	M1	[illegible]	[illegible]	[illegible]	[illegible]	Mixed_Use
10	M2	[illegible]	[illegible]	[illegible]	[illegible]	Mixed_Use
11	M3	[illegible]	[illegible]	[illegible]	[illegible]	Mixed_Use
12	M4	[illegible]	[illegible]	[illegible]	[illegible]	Mixed_Use
13	M5	[illegible]	[illegible]	[illegible]	[illegible]	Mixed_Use
14	M6	[illegible]	[illegible]	[illegible]	[illegible]	Mixed_Use
15	M7	[illegible]	[illegible]	[illegible]	[illegible]	Mixed_Use
16	M8	[illegible]	[illegible]	[illegible]	[illegible]	Mixed_Use
17	C1	[illegible]	[illegible]	[illegible]	[illegible]	Commercial
18	C2	[illegible]	[illegible]	[illegible]	[illegible]	Commercial
19	C3	[illegible]	[illegible]	[illegible]	[illegible]	Commercial
20	I1	[illegible]	[illegible]	[illegible]	[illegible]	Industrial
21	I2	[illegible]	[illegible]	[illegible]	[illegible]	Industrial
22	I3	[illegible]	[illegible]	[illegible]	[illegible]	Industrial
23	GV	[illegible]	[illegible]	[illegible]	[illegible]	Government
24	Vacant Developable	[illegible]	[illegible]	[illegible]	[illegible]	Vacant Developable
25	Undevelopable	[illegible]	[illegible]	[illegible]	[illegible]	Undevelopable

4-6-2 Model Mechanism

UrbanSim has many components, which could be categorized to:

4-6-2.1 Models

- UrbanSim uses a collection to react models, (as shown in table 15), to represent the different actors and processes in the urban environment, Each model has:
    - A model definition file which describes it, its related objects and their behaviors.
    - Agents that could be shared across models.
    - Methods such as init – run – nextscheduledRunTime – onCreate- onchange – onRemove … which encode the behavior of agents in the simulation under certain conditions - or events - .
- Models in their behaviors have many approaches:
    - Some models are aggregate and non-spatial such as the economic and demographic transition models that deal with the interface to external macro-economic changes.
    - Some Other models are top - down discrete choice models of an agent such as location choice model that take a bird view approach to make choices about alternative locations.
    - There is also bottom – up model - the developer model - which takes a worms eye approach to make choices between locations – or grid cells – to select the best to develop. This model is affected by market information that reflects the state of the market as a whole.

Table 15 Main models in UrbanSim (Waddell, P. et al. –b –p10 with modification)

Demographic and Economic Transition Models	**Household and Employment Mobility Models**	**Household and Employment Location Models**	**Real Estate Development Model**	**Land Price Model**
The Demographic Transition Model simulates births and deaths in the population of households without an assignment to a specific housing unit and is affected by external population control totals and other decision makers externalities	The Household Mobility Model simulates the probabilities of households to move. Based on historical data. If some households decide to move, they are placed in limbo to indicate they have no current location, and the spaces for the formerly occupied are made available.	The Household Location Choice Model chooses a location for each household that has no current location (could be from Demographic Transition Model or. Household Mobility Model) . each household is assigned to its most desired location among vacant housing units randomly selected from the set of all vacant housing according to evaluations (contains grid cell attribute - price, density, … -, neighborhood characteristics - density, local accessibility to retail, … -, and regional accessibility to jobs, …). for their desirability to the household, through a multinomial logit model.	The Real Estate Development Model simulates developer choices about where development and redevelopment of existing structures will occur. Each year, the model test all grid cells on which development is allowed and creates a list of possible transition alternatives (representing different development types with the option of not developing), The probability for each alternative being chosen is calculated in a multinomial logit model. According to criteria related to characteristics of the grid cell (current development, policy constraints, land and improvement value), characteristics of the site location (proximity to highways, arterials, existing development, and recent development), and regional accessibility to population.	The Land Price Model simulates land prices of each grid cell as the characteristics of locations change over time. The model is calibrated from historical data using a hedonic regression to include the effect of site, neighborhood, accessibility, and policy effects on land prices. It also allows incorporating the effects of short-term variations in local and regional vacancy rates on overall land prices. Criteria used to calculate land prices are same as of Real Estate Development Model
The Economic Transition Model is responsible for modeling job creation and loss without an assignment to a specific Employment Locations and is affected by Employment control totals and other decision makers externalities	The Employment Mobility Model determines which jobs will move from their current locations during a particular year using a similar approach to the Household Mobility Model. It also assigns no current location to jobs decides to move	The Employment Location Choice Model is responsible for determining a location for each job that has no location. location (could be from Economic Transition Model or. Employment Mobility Model) For each such job is assigned to its most desired location according to evaluations (contains grid cell attribute - price, type of space, … -, neighborhood characteristics - employment in each other sector , average land values, … -, and regional accessibility to population …). for their desirability to the job, through a multinomial logit model.		

4-6-2.2 Model coordinator

- The Model Coordinator is responsible for managing the collection of models present in a simulation. It is responsible for determining the implementation sequence of models, resolving any data dependencies one model may have on another, and notifying a model when another model has changed data it is monitoring. In other words it schedules models to run and notifies them when data of interest have changed.
- It has some methods as runSimulation – excuteEvent – getOrdering....

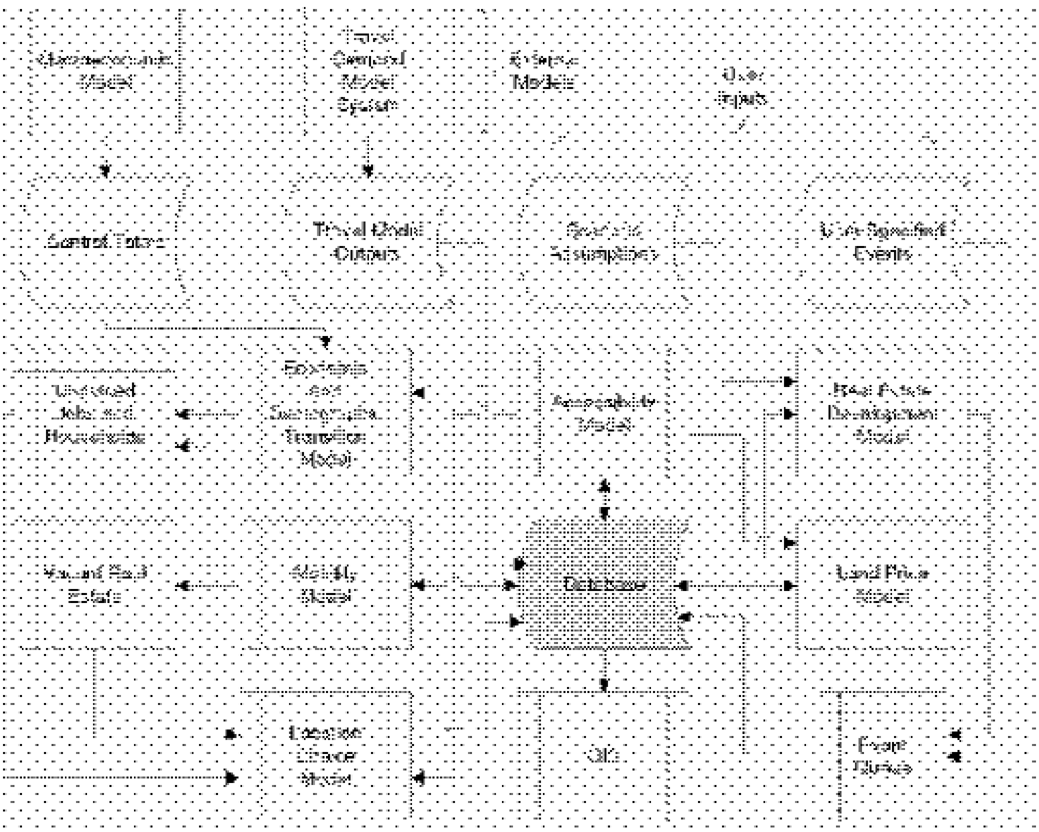


Figure 57 UrbanSim Model Structure (Waddell, P. et al. 2005)

4-6-2.3 Translation and Layer of the aggregation

- The Translation and Layer of the aggregation (T/AL) is responsible for the conversion processes that take place between various levels of spatial and temporal aggregation resulting from queries or updates and objects in the Object Store. In other words it performs a range of data conversions to mediate between the Object Store and the models
- Methods are like those of Data Store i.e. postQuery – postUpdate... .
- For example, models can query for zonal population totals. The Translation/ Aggregation Layer calculates these totals and maintains them independent of the information in the Object Store, which consists of population information at the lower level - grid cell level -. (Figure 58)

4-6-2.4 Scenarios

- An UrbanSim scenario is a collection of policy assumptions that could enter the model to test their potential consequences on outcomes such as urban form, land use mix, density, and travel patterns.
- Land use regulations, projects packages and infrastructure provision could be seen as the influence done by the government on the land development process. They set restrictions (constraints) or probabilities on development alternatives (See figure 59).

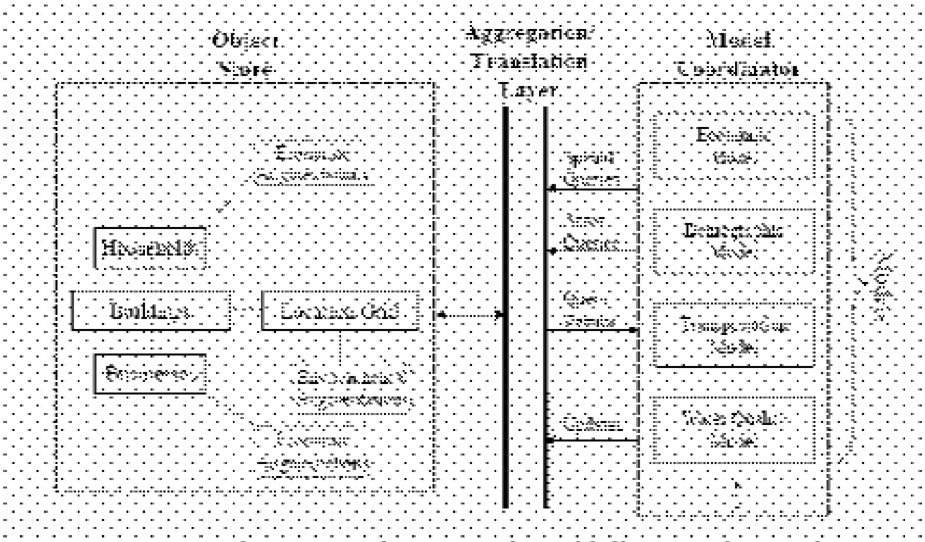


Figure 58 UrbanSim architecture (Waddell, P. et al. 2001)

PLU - Planned Land Use - : a set of restrictions on development options
County, City: Development regulations may be coded for an a specific city or county within the metropolitan area.
Overlays: wetlands, floodways, steep slopes, or other environmental features may be used to specify environmental regulations that affect development constraints

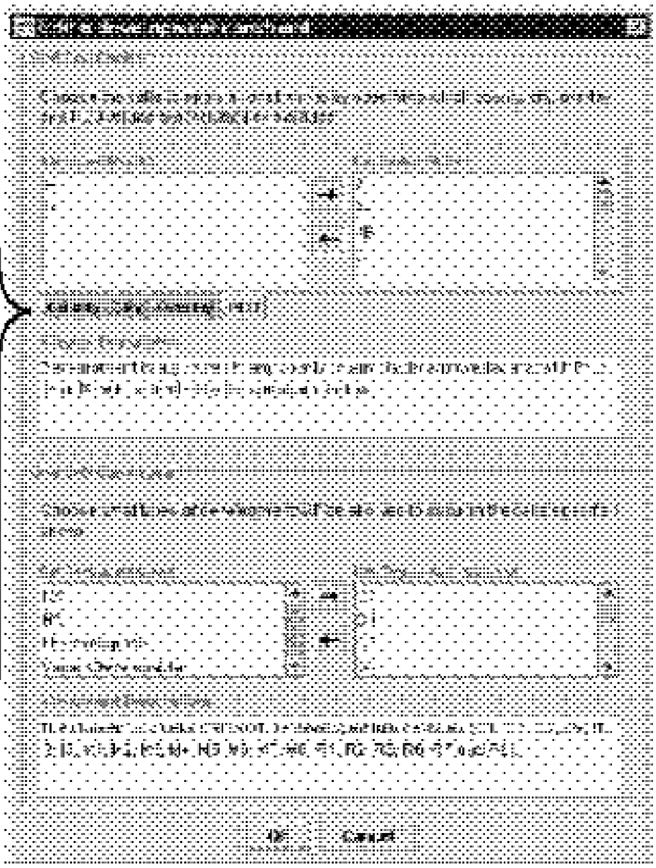


Figure 59 UrbanSim User Interface for Entering development Constrains (Waddell, P. et al. –b 2001)

4-6-2.5 Model application in urban growth modeling

Urban growth modeling is mostly related to Real Estate Development Model (also called developer Model). In real estate development model, the independent variables could be categorized into

- Site characteristics
  - Existing development characteristics
  - Land use plan
  - Environmental constraints
- Urban design-scale
  - Proximity to highway and arterials
  - Proximity to existing development
  - Neighborhood land use mix and property values
  - Recent development in neighborhood
- Regional accessibility
  - Access to population and employment
  - Travel time to CBD, airport
- Market Conditions
  - Vacancy rates

The real estate development model has successive steps as fellow:

1. Defining all valid development type transitions T from development type d1 to another development type d2 for all locations in the model L
2. For each location *l* at time t, defining all valid development type transitions T_{lt}. Where $T_{lt} \in T$.
3. Then for this cell, assigning the probability of transitioning P_{lt} to devtype d, where $P_{lt} \in T_{lt}$.
4. The final output will be L_{dt} which is the set of location and development type pairs at time t, where d is the devtype for all locations and are defined to be the outcome of the chosen transition - one probable transition is one that includes no change – and are given a Monte Carlo sampling of P

The patterns of development in a certain region could differ according to some the development scenarios like:

- Focusing development within centers and urban transitional zones connected by means of transportation.
- Diverting development into new or existing satellite settlements.
- Forbidding development outside an Urban Growth Boundary (UGB).
- Focusing development along primary transportation corridors
- Encouraging development of deteriorated areas.

These Scenarios could be applied to a combination of user-specified spatial overlays (such as Land use plan, surrounding urban areas, floodway and water streams, high slope areas, Urban Growth Boundary, ….) to represent constraints on conversion from development type to another. These 'binding according to scenario' constraints are not subject to market pressure, these are alternatives. If a cell has some conversations to different types, the constraints will eliminate certain conversions choices. if it is needed to test the effect of a constraint, then we would need to 'relax' this constraint within one scenario and compare the scenario results to a more restrictive policy. These effects may appear in another model, For example if we apply an UGB restriction for a specific regions, we may find the effects in the land price model as it may leads to rapid housing price inflation.

4-6-3 Model Outputs

The main outputs of the model are maps that show the urban growth for each scenario pre-discussed as shown in table 15.

4-6-4 Model criticism

UrbanSim is characterized by

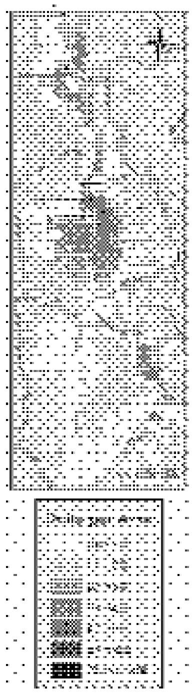
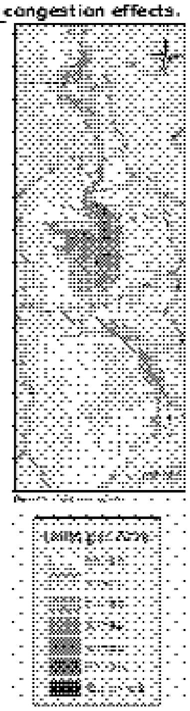
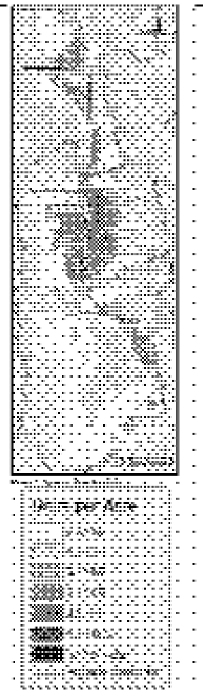
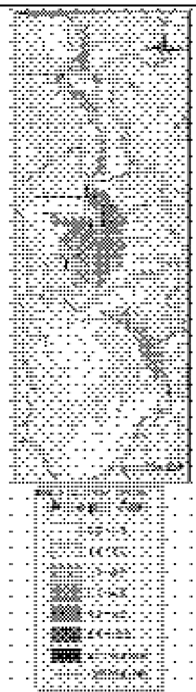
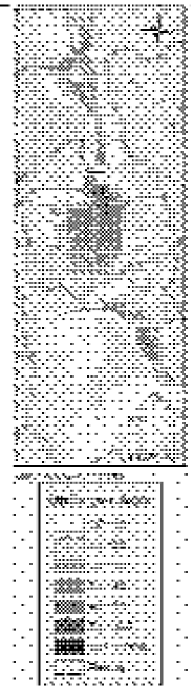
- It is more closely related to the dynamic disequilibrium, It is not self organizing as it deals with various scenarios tend to outcomes which looks like a linear relationship

- It uses large spatial detail, following the discreet-choice (logit multinomial) theory, It is agent-level micro simulation of choice behavior.
- It uses a structure grid-based to represent the spatial information, to facilitate detailed spatial questions and simulation
- It has the potentiality to replace a model with a new one.
- It supports different temporal and spatial steps and scales

However, and according to UrbanSim designers, there are some further works to develop the system. Some if these works are mostly related to urban growth such as:

- Adding some environmental components to simulate land cover change, urban growth and demand of water .... (Waddell, P. et al 2001, 2003).
- Redeveloping the real estate development model to represent the roles of land owners, lenders, investors, ...
- Integrating a macroeconomic model that sends back the local choices macro-effects about major infrastructure and land policies. (bottom – up effects).

Table 14 Outputs of real estate model in 2030 for Wasatch Front Region with five scenarios (Waddell, P. et al. 2001).

The ***Long Range Plan*** scenario, phased in over 1997 to 2030.	A ***No-build*** scenario that holds the transportation system constant from 1997 to 2030, but includes congestion effects.	A ***Highway Alternative*** that removes a major section of Bangerter Highway in southernUtah County.	A ***Transit Alternative*** that removes the proposed Mid-Jordan LRT line (planned for the next 10 years).	A ***Parking Cost Alternative*** that doubles the cost of parking in Salt Lake City.	An ***Urban Growth Boundary Alternative*** that imposes a boundary limiting urban expansion.
					

4-7 Summary

In this chapter, six different urban growth models have been presented, each of them has its technique, inputs and process.

The first model was built upon GIS theory using hierarchical process from logistic to integrated model stage. While, the second model uses a CA approach with some constraints in transition, i.e. the transition is allowed in one way from state to state.

The third and fourth models are two distinctive CA applications widely used in urban growth models, SLEUTH model which has five inputs that are Slope, Land use, Excluded areas, Urban areas, Transportation and Hillshade. It has five coefficients used in implementing model.

RIKS models usually have two hierarchical sub-models; the first (national or regional) is responsible for putting the urban growth constraints while the second is the local sub model where the urban growth pattern appear. This model has a special neighborhood that defined into circular regions, with a radius of 8 cells (196 cells), located in 30 discrete distance zones.

The fifth model could be considered as an agent- based urban growth model that tests the effect of temporal control upon urban growth pattern.

Finally UrbanSim model was presented with its components and its potentiality to modeling urban growth.

Table 15 summarizes the characteristics of each model pre-discussed in this chapter.

Table 16 Outputs of real estate model in 2030 for Wasatch Front Region with five scenarios (Waddell, P. et al. 2001).

	Model (1) Charelston model	Model (2) LUCAM model	Model (3) SLEUTH	Model (4) RIKS	Model (5) Wuhan model	Model (6) UrbanSim
Urban model type	Urban growth model	Urban growth model	Urban growth model	Urban growth model	Urban growth model	Comprehensive urban model
Technique used in model	GIS – rule based	CA approach	CA approach	CA approach	a project-based CA approach	Computer software
Advantages (benefits from the model)	▪Integrating more than one model into one model ▪Experts opinion is clear and obvious	▪Using 5 values for cell state ▪Using irreversible transition rules	▪Using historic data ▪Self modification process ▪Simulating spontaneous growth	▪Reducing semantic gap in determining area of effect ▪Considering the influence of macro level (top – down) ▪Considering government zoning	▪Integrating agents effects with CA model ▪Testing temporal control	▪Considering urban growth model a part from a whole urban system
Disadvantages	▪No limitation for area of effect ▪Variables does not change over time especially according to socio- economic factors	▪No reflection for the nature of lands ▪No flexibility with time	▪No reflection for socio – economic factors	▪No self modification ▪Rule of historic data does not appear	▪Limited usage (designed only for testing temporal control).	▪ Computer application has no theory. (mathematical approach)

Chapter Five

Conclusion and Recommendations

5 Conclusion and Recommendations

This chapter presents the recommendations about the data and techniques needed to building urban growth model for the cities and villages in Egypt.

The first section shows urban growth driving forces and effecting factors in Egypt,

The second section introduces the input data and the database required to build the model.

The third section presents the model components and procedure steps to reach to urban growth map for the urban settlement under study

5-1 Urban growth driving forces and effecting factors in Egypt

As it was introduced in chapter two, the urban growth in Egypt is also shaped according to some macro-scale driving forces and some micro-scale effecting factors.

5-1-1 Urban growth driving forces in Egypt

The main driving force affects the urban growth process in Egypt is the laws and regulations govern urban management, the heights and plot index ratio laws highly influence the total area of urban growth in a certain period. The living standard and national income per capita also affects the urban growth pattern and its temporal pattern, In Build your house by yourself national project which is directed for youth between 21 and 40 years old, each land parcel has an area of 150 m^2 and with allowance to build only 63 m2 (New Urban Communities Authority, 2006). Also the population growth and immigration are forces lead to urban growth.

5-1-2 Urban growth influence factors in Egypt

Beside the factors previously mentioned in chapter two (Accessibility, Suitability, macro location, planning and policy), there are some other factors affects urban growth processes in Egypt, these factors are:

- **Land productivity:** the less the productivity of the agricultural lands the more the potentiality of the land to be converted to urban areas.
- **Land ownership:** the smaller the land parcels, the more the potentiality of the land to be converted to urban areas. Also the land ownerships disputes and problems often lead to prevent its conversion to urban (General Organization for Physical Planning, 2006).
- **Mega and governmental projects:** the governmental projects increase the tendency of neighbor lands to be urban.

The weights of each factor may differ from village to village and from city to city according to its local conditions.

5-2 Input data

The input data in the proposed model are:

5-2-1 Tabular data:

- Population census & prediction.
- Any other economic studies.

5-2-2 Spatial data:

- Land use maps in different previous years.
- Roads networks maps in different previous years.
- Hillshade, productivity and ownership maps.
- New governmental and mega projects.

(Figure 60) presents the proposed GeoDatabase to be used in the model with the attributes of each element (feature class)

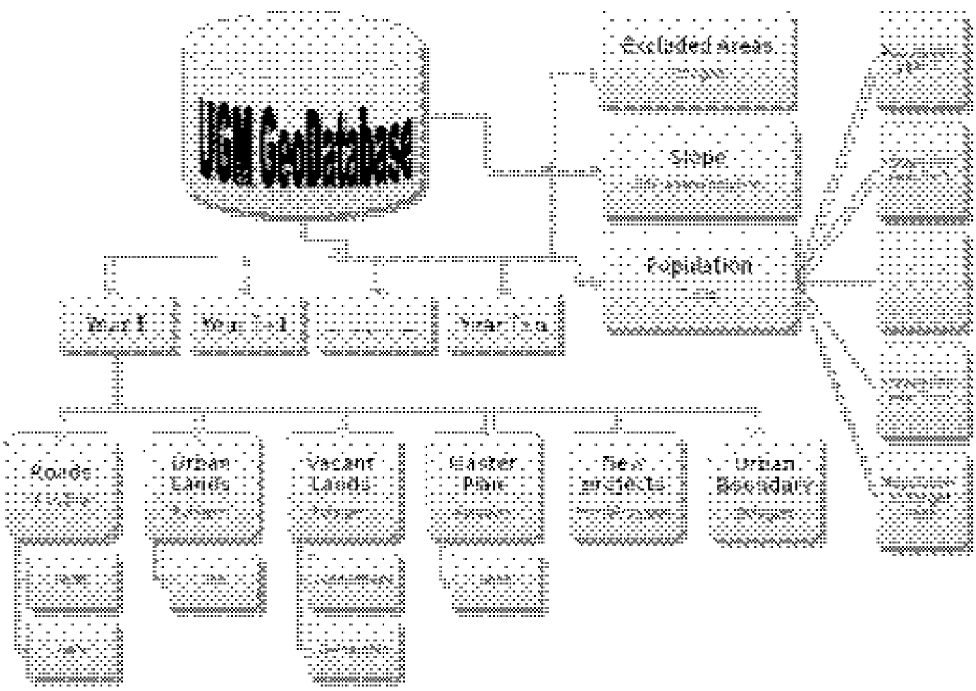


Figure 60 Proposed Urban Growth Model GeoDatabase, (by the researcher)

5-3 Model components

The proposed model is composed of two successive sub models.

5-3-1 Statistical urban growth sub model:

This sub model is responsible for defining the different urban growth scenarios and is mainly dependent on spread sheeting and statistical applications. Each urban growth scenario takes into account:

- Regional relationships and macro location.
- Climatic aspects.
- Population and immigration.
- Urban growth amount in previous periods.

The output of this sub model is the count of urban cells wanted to cover each urban growth scenario.

5-3-2 Spatial urban growth sub model:

This sub model uses the input data to result finally in urban growth map. Firstly all data input have to be converted into raster with a cell size equals the minimum road width on the case study, then the model pass the following three phases:

- **Phase 1 (determining coefficients values):**

  In this phase, the model would make artificial neural networks to approximately determine the effect of each coefficient (factor) and assign a value for it by using the data available from previous years. Also in this phase, the ranking (minimum and maximum) value for each factor

•**Phase 2 (Measuring new and mega projects effects):**

This phase in responsible for presenting the area (and form) of effect by building a multi-agent system model. This model could be built by the help of experts and urban scholars according to the nature of the project.

•**Phase 3 (Mapping the potentiality of conversion from vacant to urban):**

It is the most important phase in the model. A cellular automata model has to be built in order to measure the potentiality of each vacant cell (after excluding unsuitable lands) to convert to urban cell by using transition rules and values of coefficients conducted from phase one, and by putting into account the effect of projects resulting from phase two.(Figure 61)

•**Phase 4 Mapping Urban growth:**

This phase draws the final urban growth according to different scenarios built upon different population growth urban growth ratios by selecting cells with the highest values in potentiality to convert to urban in phase three equals to the cells needed for each urban growth scenario (coming from the statistical urban growth sub model).

In this phase, the model would make artificial neural networks to approximately determine the effect of each coefficient (factor) and assign a value for it by using the data available from previous years.

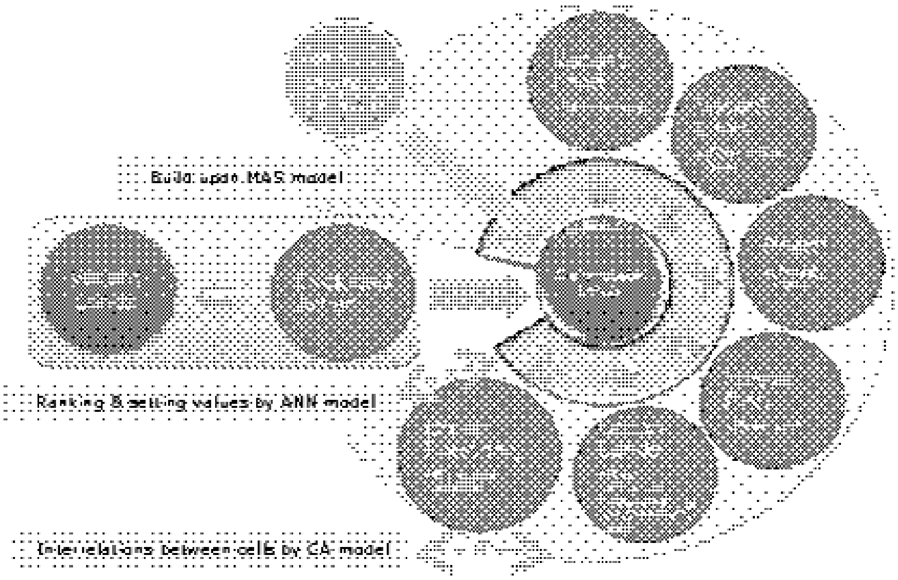


Figure 61 Phase three of the Spatial urban growth sub model, (by the researcher)

5-4 Conclusion

Although there are some attempts to measure and predict urban growth, the results are often disappointing as there are usually external factors.(Clarke et al 1997, Torrens 2000, Torrens 2003, Cheng et al 2003, Sun 2003,). From these factors in Egypt – for example - the laws, which permit the governor to make exception in applying some buildings regulations. The above-proposed model has some limitations such as considering the urban growth is equal in the whole case study and not putting into account the difference in owners' desires in construction time.

From previous experiences (such that mentioned in chapter five), a mega structured mental urban growth model is needed to be built that is capable of understanding the human stochasticity with the help of socioeconomic, industrial, agricultural and urban planners. To reach such model, the efforts have to be achieved in trying to build these types of models so that we can reach to the model that can express the urban growth in Egypt.

5-5 Recommendations

In the future new analytical and research efforts would have to be made in the following fields:

- Designing models represent other urban phenomena such as urban polarization, suburbanization and land value inflation ...
- Digitizing spatial and non-spatial historic data in appropriate formats so that it could be used in studying and interpreting urban growth. As historic data is the raw material for applying methods and models.
- Trying to design a model concerning with the form of urban growth rather than conversion from vacant to urban.
- Making the best use from GIS. It is not only a tool for storing data, it also has a great capability in analyzing urban phenomena.
- Using agents on a CA space to add some levels of randomness to the temporal space of the CA, or dealing with transition processes so that they are only partly sequential, fashioned in dependence of exogenous constraints.
- Reducing the semantic gap between models and real world either by considering the third dimension of the environment of model, or with determining best cell size, shape and real area of effects of model elements.
- Linkage of theory- based models – such as MA, CA or ANN models) with comprehensive radical models such as UrbanSim model.
- Concerning time while designing models. Urban growth system is a dynamic complex system rather than a static one.

Appendix

Appendix (1) Maps used for the Isleta quadrangle, New Mexico in the United States from 1935 to 1996 used in building the SLEUTH model **(Hester, D. 2000)**

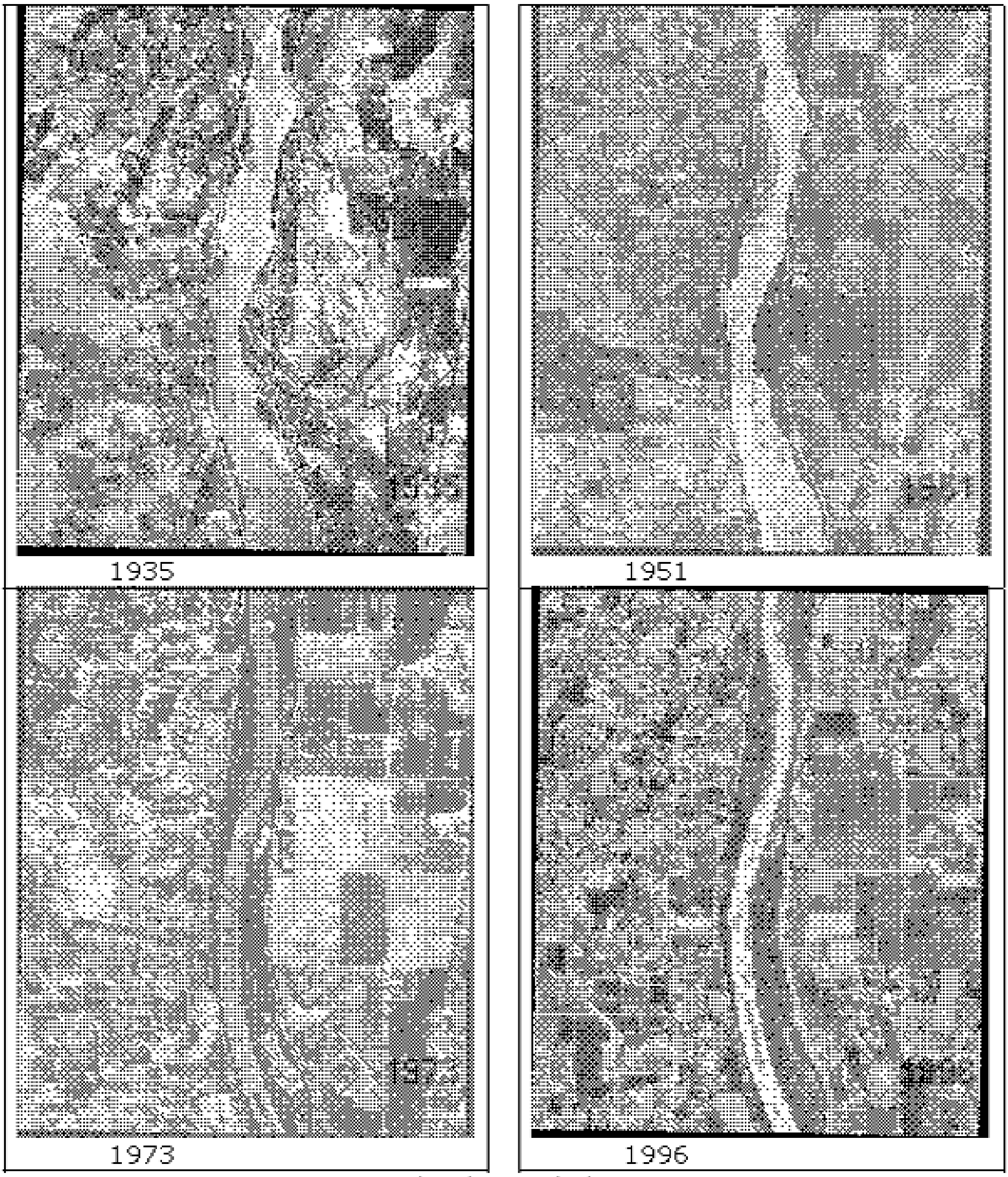


Figure (i- 1) Aerial photos

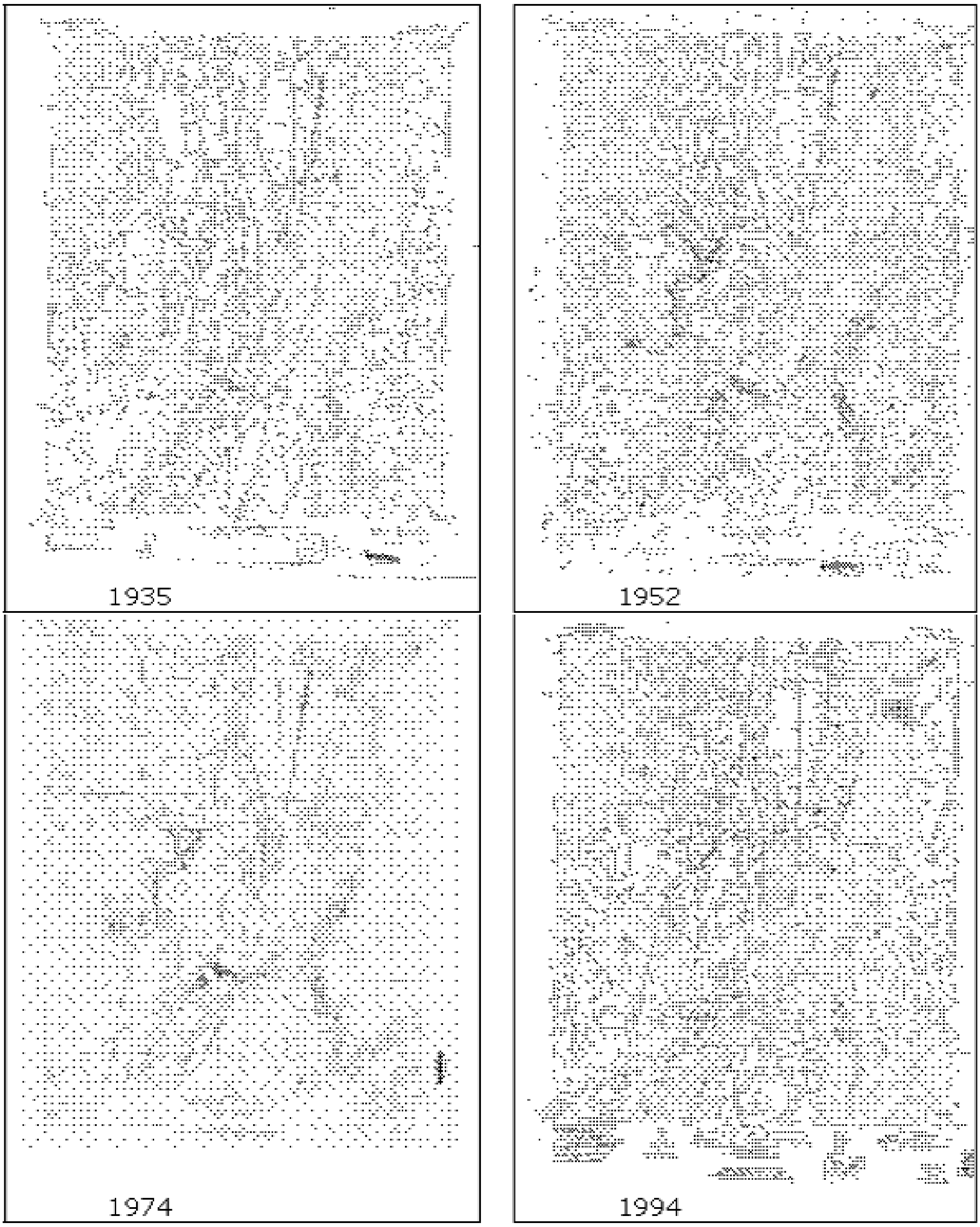


Figure (i -2) Survey maps

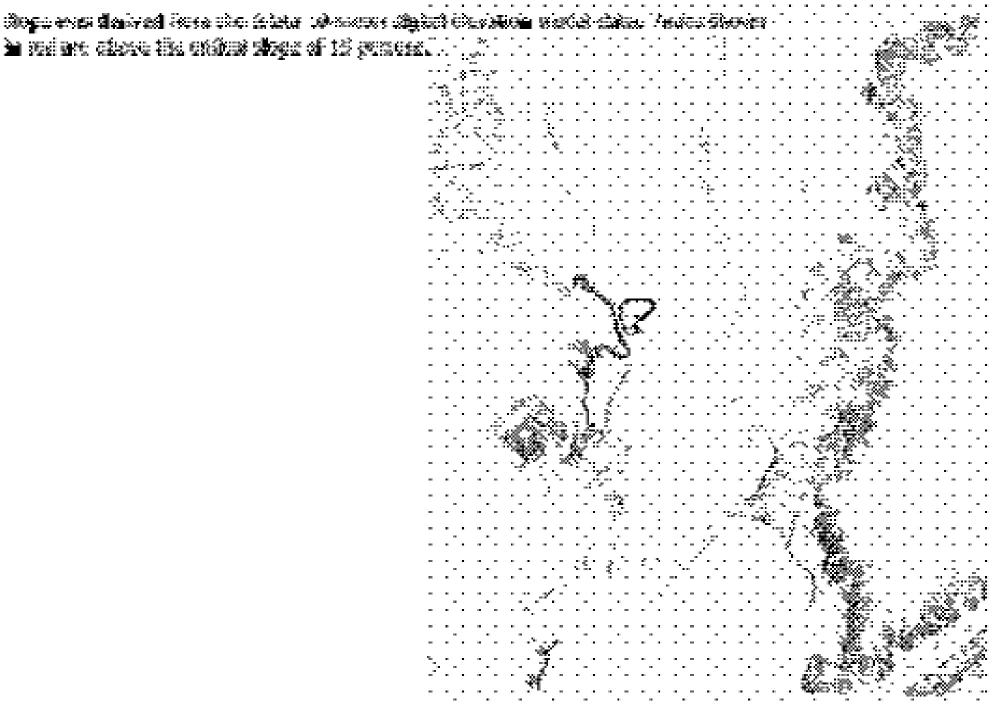


Figure (i-3) Slope map

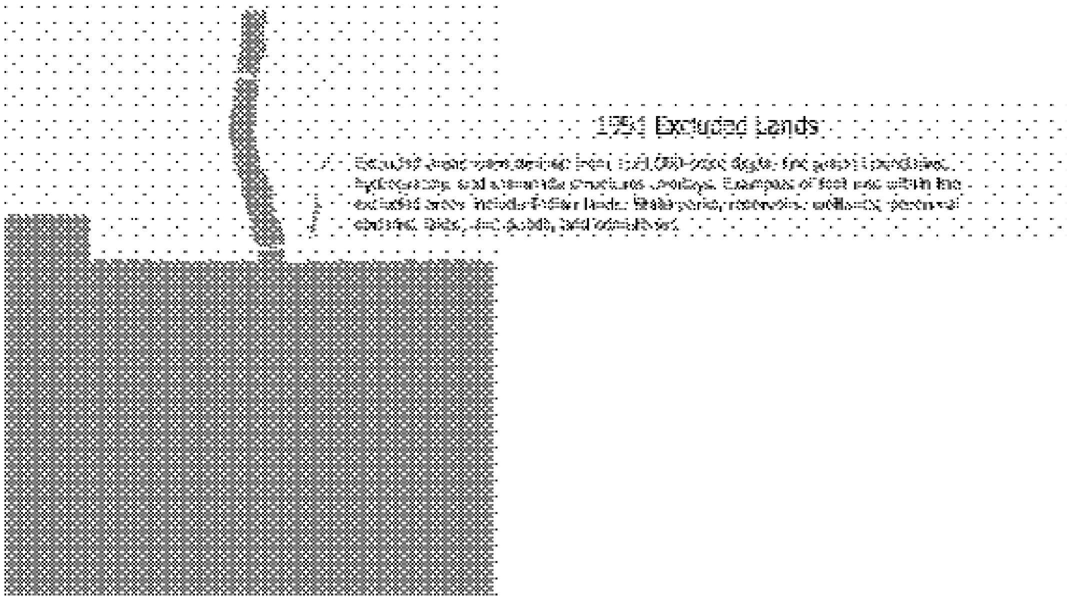


Figure (i-4) Excluded areas from urbanization

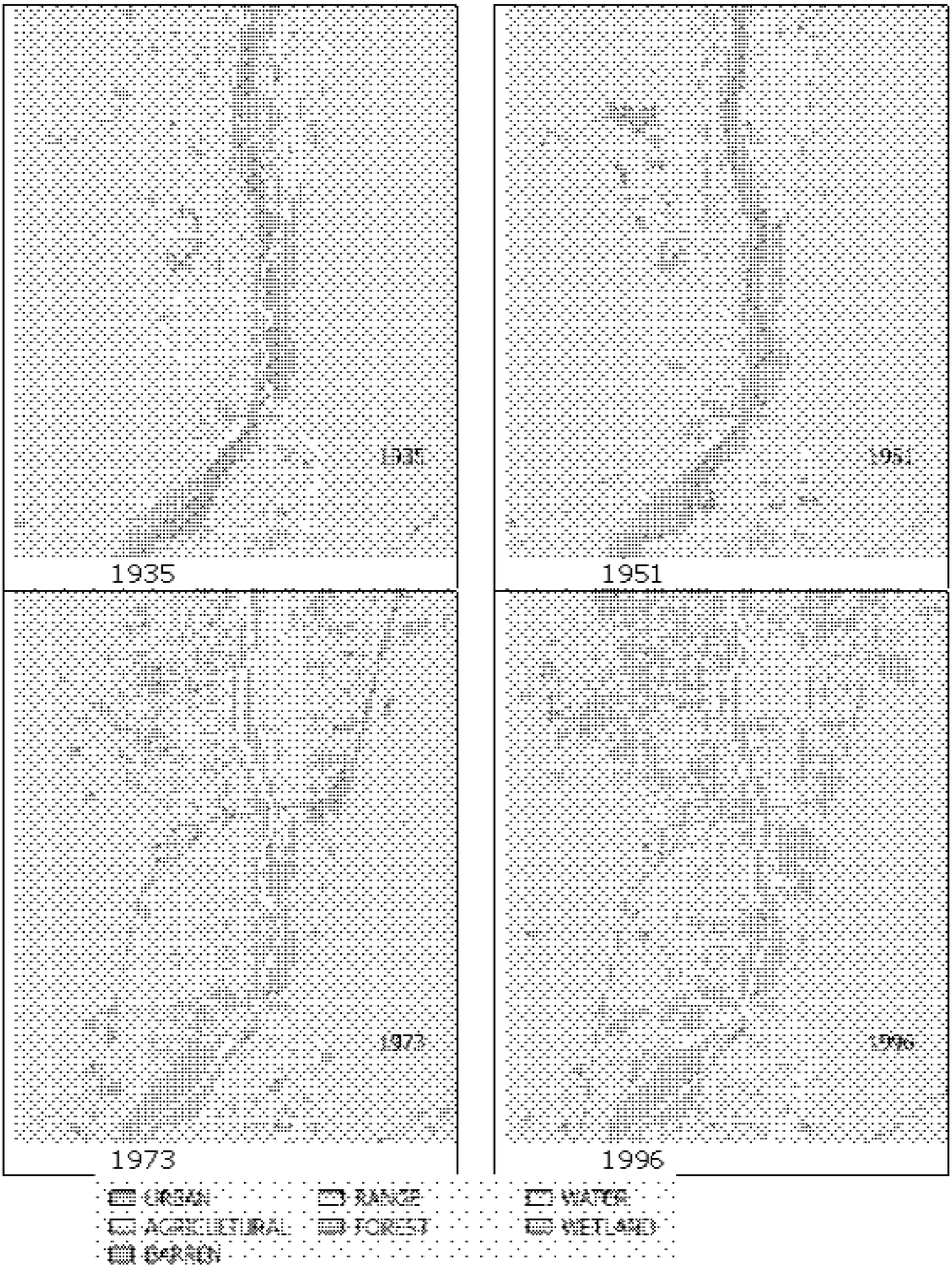
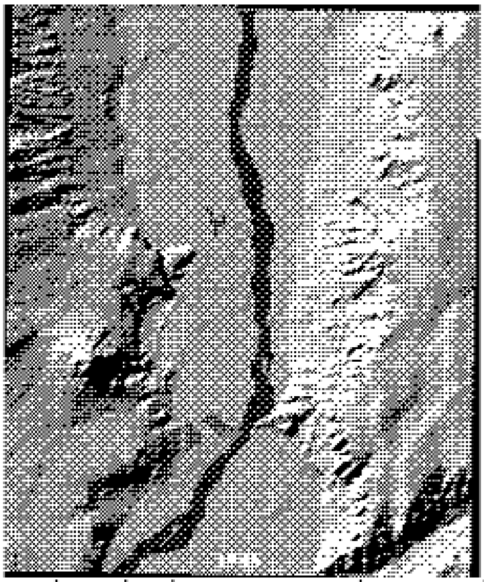
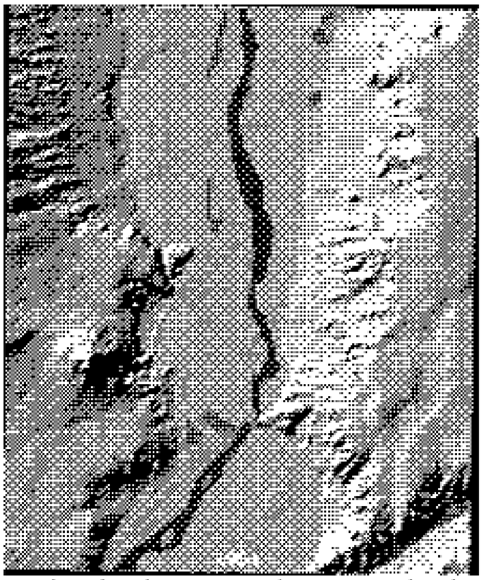


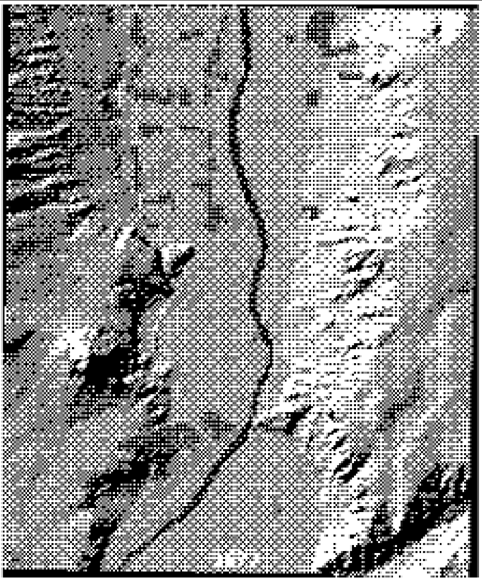
Figure (i-5) Land uses maps



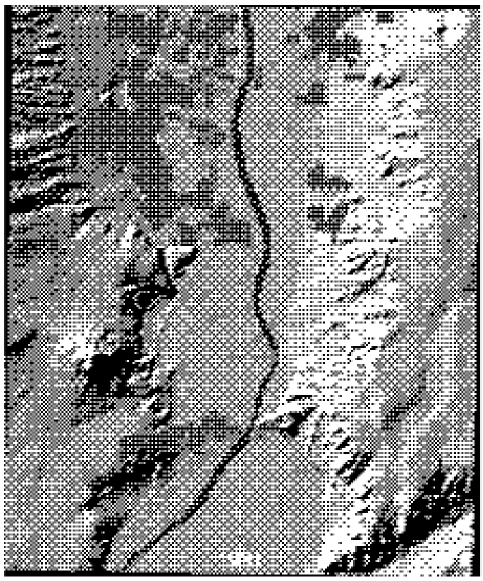
Urban land concentrated west of Rio Grande around I-25/NM 314 and NM314/147 intersections.



Urbanization started to occur in the northern portion of Isleta quadrangle.
Development around community of Mountainview and along Isleta Boulevard.



Expansion around existing urban centers: Mountainview and Isleta. Extension south along Coors Boulevard (NM 45) and Isleta Boulevard (NM 314). Urban growth westward along NM 317 towards I-25 interchange.



Urbanized area expanding west of Coors Boulevard
Infill development occurring between Coors Boulevard and Isleta Boulevard
Extension north from I-25 & NM 47 (Broadway) towards Mountainview

Figure (i-6) the growth of urban land

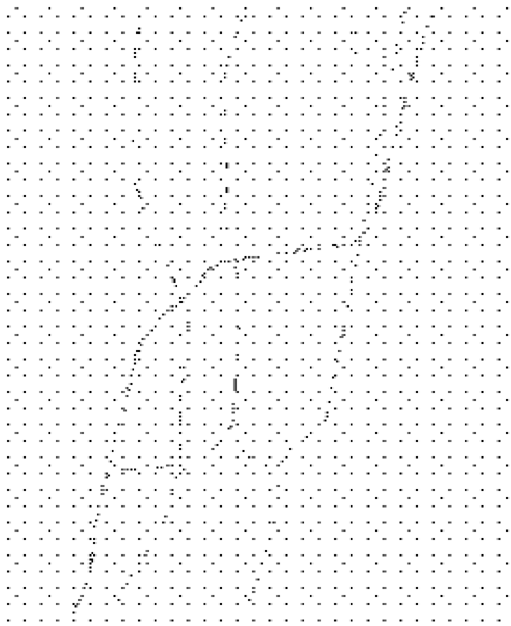


Figure (i-7) Road network

Appendix (2) The Basics of Monte Carlo Simulations (Woller, J. 1996)

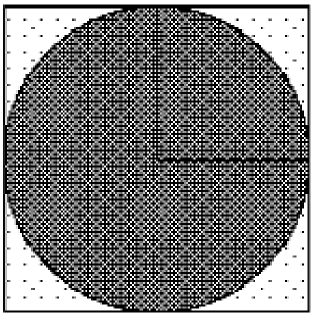
Introduction to Monte Carlo Methods

The expression "Monte Carlo method" is actually very general. Monte Carlo (MC) methods are stochastic techniques--meaning they are based on the use of random numbers and probability statistics to investigate problems. You can find MC methods used in everything from economics to nuclear physics to regulating the flow of traffic. Of course the way they are applied varies widely from field to field, and there are dozens of subsets of MC even within chemistry. But, strictly speaking, to call something a "Monte Carlo" experiment, all you need to do is use random numbers to examine some problem.

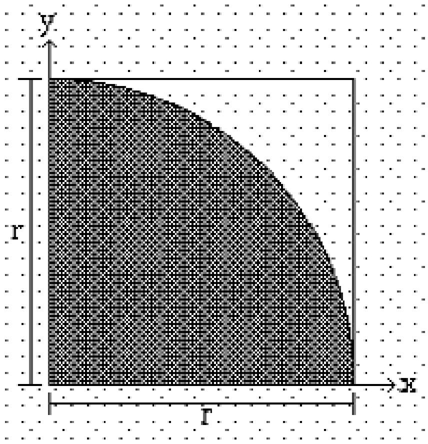
The use of MC methods to model physical problems allows us to examine more complex systems than we otherwise can. Solving equations, which describe the interactions between two atoms, is fairly simple; solving the same equations for hundreds or thousands of atoms is impossible. With MC methods, a large system can be sampled in a number of random configurations, and that data can be used to describe the system as a whole.

"Hit and miss" integration is the simplest type of MC method to understand, and it is the type of experiment used in this lab to determine the HCl/DCl energy level population distribution. Before discussing the lab, however, we will begin with a simple geometric MC experiment that calculates the value of pi based on a "hit and miss" integration.

•**Monte Carlo Calculation of Pi**



The first figure is simply a unit circle circumscribed by a square. We could examine this problem in terms of the full circle and square, but it is easier to examine just one quadrant of



the circle, as in the figure above.

If you are a very poor dart player, it is easy to imagine throwing darts randomly at Figure 2, and it should be apparent that of the total number of darts that hit within the square, the number of darts that hit the shaded part (circle quadrant) is proportional to the area of that part.

In other words, $\frac{\text{\# darts hitting shaded area}}{\text{\# darts hitting inside square}} = \frac{\text{area of shaded area}}{\text{area of square}}$

If you remember your geometry, it's easy to show that

$$\frac{\text{\# darts hitting shaded area}}{\text{\# darts hitting inside square}} = \frac{\frac{1}{4}\pi r^2}{r^2} = \frac{1}{4}\pi$$

or

$$\pi = 4\,\frac{\text{\# darts hitting shaded area}}{\text{\# darts hitting inside square}}$$

If each dart thrown lands somewhere inside the square, the ratio of "hits" (in the shaded area) to "throws" will be one-fourth the value of pi. If you actually do this experiment, you'll soon realize that it takes a very large number of throws to get a decent value of pi...well over 1,000. To make things easy on ourselves, we can have computers generate random* numbers.

If we say our circle's radius is 1.0, for each throw we can generate two random numbers, an x and a y coordinate, which we can then use to calculate the distance from the origin (0,0) using the Pythagorean theorem. If the distance from the origin is less than or equal to 1.0, it is within the shaded area and counts as a hit. Do this thousands (or millions) of times, and you will wind up with an estimate of the value of pi. How good it is depends on how many iterations (throws) are done, and to a lesser extent on the quality of the random number generator. Simple computer code for a single iteration, or throw, might be:

```
x=(random#)
y=(random#)
dist=sqrt(x^2 + y^2)
if dist.from.origin (less.than.or.equal.to) 1.0
let hits=hits+1.0
```

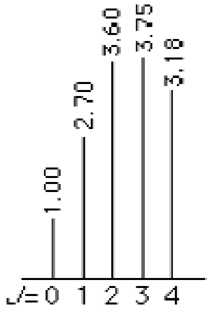
•Monte Carlo Computation of Population Distribution

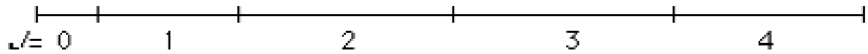
The actual Monte Carlo method used in this lab to determine the population distribution among rotational energy levels is simpler than the two-dimensional example of the estimation of pi, as only one random number is generated for each "throw." This will be apparent shortly.

For this lab, the Boltzmann distribution can be solved analytically, and it is in fact used in determining the Monte Carlo distribution. As such, this is not a particularly informative simulation (you could just solve the Boltzmann equation for however many energy levels you wished and look at those numbers). However, this lab allows you to watch how changing the number of throws affects the results, and it automates the examination of the effects of temperature and isotope on population of energy levels.

The process used by the computer program for this lab is quite simple.

- The input information is used to solve the Boltzmann equation for some number of energy levels. For a maximum of J=4, the relative populations might look like the figure to the right.
- The rest of the simulation is easier to understand if you imagine laying the peaks in the "spectrum" side-by-side, as shown below. If we generate random numbers along that line, whenever a number falls within the range of a particular J value, it counts as a "hit" for that energy level. Obviously, for shorter lengths (J=0) the number of "hits" will be smaller than for longer lengths (J=2).





- Since random number generators typically produce numbers on the range of zero to one, the population distribution is normalized so that the total "length" is equal to 1.0.
- For each "throw," or random number produced, the computer determines which energy level range it belongs to, and calls it a "hit" for that J value. After the computer completes all throws, the number of hits (or relative number of hits) for each energy level are given. It is up to you to compare this output to the theoretical distribution produced by the Boltzmann equation, as described in the Lab Report Instructions.

Appendix (3) Regression analysis (Wikipedia, 2006-b)

In statistics, regression analysis is the process used to estimate the parameter values of a function, in which the function predicts the value of a response variable in terms of the values of other variables. There are many methods developed to fit functions and these methods typically depend on the type of function being used. For example: linear regression, nonlinear regression, and logistic regression.

- **Introduction**

Regression analysis estimates the relationships of a model relationship between one or more response variables (also called dependent variables, explained variables, predicted variables, or regressands) (usually named Y), and the predictors (also called independent variables, explanatory variables, control variables, or regressors, usually named X1,...,Xp). Multivariate regression describes models that have more than one response variable. In the model parameters are the constants that measure the magnitude of a relationship between variables. Regression analysis estimates the values of the parameters. The parameters are commonly designated by Greek letters (such as the θ's of the Example below). The estimated value of a parameter from regression analysis is denoted by a Roman letter or "hatted" Greek letter. These estimates can be used in calculations to test for statistical significance of estimated parameters and to measure goodness of fit of individual equations in a model.

- **Types of regression**
  - **Simple and multiple linear regression**

Simple linear regression and multiple linear regression are related statistical methods for modeling the relationship between two or more random variables using a linear equation. Simple linear regression refers to a regression on two variables while multiple regression refers to a regression on more than two variables. Use of linear regression may assume that the best estimate of the response is a linear function of some variables. If a model has only one equation but more than one predictor, it does not employ multivariate regression.

- **Nonlinear regression models**

If the relationship between the variables being analyzed is not linear in parameters, a number of nonlinear regression techniques may be used to obtain a more accurate regression.

- **Non-continuous variables**

If the variable is not continuous, specific techniques are available. For binary variables, there are the probit and logit model. The multivariate probit model makes it possible to estimate jointly the relationship between several binary dependent variables and some independent variables. For categorical variables with more than two values there is the multinomial logit. For ordinal variables with more than two values, there are the ordered logit and ordered probit models. If the variable is positive with low values and represents the repetition of the occurence of an event, the best models to use are count models like the Poisson regression or the negative binomial model. All these models are estimated by maximum likelihood.

- **Other models**

Although these three types are the most common, there also exist supervised learning and unit-weighted regression.

- **Nonparametric regression**

Several non-parametric techniques may be used to estimate the impact of an explaining variable on a dependent variable. Nonparametric regressions, like kernel regression, require a high number of observations and are computationally intensive.

- **Linear models**

Predictor variables may be defined quantitatively (i.e., continuous) or qualitatively (i.e., categorical). Categorical predictors are sometimes called factors. Although the method of estimating the model is the same for each case, different situations are sometimes known by different names for historical reasons:

- If the predictors are all quantitative, we speak of multiple regression.
- If the predictors are all qualitative, one performs analysis of variance.
- If some predictors are quantitative and some qualitative, one performs an analysis of covariance.

The linear model usually assumes that the dependent variable is continuous. If least squares estimation is used, then if it is assumed that the error component is normally distributed, the model is fully parametric. If it is not assumed that the data are normally distributed, the model is semi-parametric. If the data are not normally distributed, there are often better approaches to fitting than least squares. In particular, if the data contain outliers, robust regression might be preferred.

If two or more independent variables are correlated, we say that the variables are multicollinear. Multicollinearity results in parameter estimates that are unbiased, consistent, and efficient. However, the variance of the estimated coefficients is larger than it would be if the independent variables were uncorrelated.

If the regression error is not normally distributed but is assumed to come from an exponential family, generalized linear models should be used. For example, if the response variable can take only binary values (for example, a Boolean or Yes/No variable), logistic regression is preferred. The outcome of this type of regression is a function which describes how the probability of a given event (e.g. probability of getting "yes") varies with the predictors.

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