A DYNAMIC AGENT-BASED MODEL FOR SIMULATING AND PREDICTING URBAN GROWTH

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A DYNAMIC AGENT-BASED MODEL FOR SIMULATING AND PREDICTING URBAN GROWTH

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In memory of my father-in-law, Salim Sani and my son,

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LIST OF SYMBOLS

°	Degrees
´	Minutes of Ark
ha	Hectares
km	Kilometres
km^2	Square Kilometres
m	Metres
m^2	Square Metres

LIST OF ABBREVIATIONS

ABM	Agent-Based Model
AHP	Analytic Hierarchy Process
CA	Cellular Automata
CI	Commercial or Industrial
E	East
EI	Education Institution
GIS	Geographical Information System
HF	Health Facility
MCE	Multi-Criteria Evaluation
N	North
NPP	National Physical Plan
ODD	Overview, Design, and Detail
PSP	Penang Structural Plan
RSO	Rectified Skew Orthomorphic
SPS	Seberang Perai Selatan
SPSS	Statistical Package for Social Studies
SPT	Seberang Perai Tengah
SPU	Seberang Perai Utara
WGS84	World Geodetic System 1984

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MODEL DINAMIK BERASASKAN AGEN DALAM MENSIMULASIKAN DAN MERAMALKAN PERKEMBANGAN BANDAR

ABSTRAK

Pembandaran yang pesat telah menjadi fenomena penting yang membimbangkan semua negara ketika dunia beralih ke era globalisasi. Walaupun negara-negara maju telah menghadapi pembandaran yang pesat ini sejak akhir abad ke-19, negara-negara membangun berjuang untuk menguruskan fenomena ini setelah tahun 1950-an. Memahami sistem pertumbuhan bandar adalah langkah pertama ke arah mencapai urbanisasi lestari di masa depan. Model pertumbuhan bandar yang dinamik secara spasial dapat memberikan simulasi berharga yang mengandungi pengetahuan penting dalam perancangan dan pembuatan dasar. Sebilangan besar model pertumbuhan bandar yang maju menerapkan kadar pertumbuhan bandar yang seragam untuk meramalkan hasil pertumbuhan bandar masa depan yang berpotensi, yang berbeza dengan dunia nyata. Oleh itu, tesis ini bertujuan untuk mengembangkan model pertumbuhan bandar berasaskan ejen yang membolehkan ketidakseragaman dalam kadar pertumbuhan bandar. Kadar pertumbuhan bandar berbeza di kawasan bergantung pada lokasinya, seperti dekat dengan pusat bandar dan ketersediaan kemudahan awam. Untuk tujuan ini, Sistem Maklumat Geografi (GIS) telah digunakan untuk menyiapkan data Seberang Perai Tengah, Pulau Pinang, Malaysia, yang memiliki atribut tanah, pertumbuhan bandar, dan kesesuaian tanah di kawasan kajian. Model berasaskan ejen (ABM) dikembangkan untuk mensimulasikan dan meramalkan pertumbuhan bandar di kawasan kajian. Ejen yang diwakili oleh pemaju bandar swasta membuat keputusan untuk memajukan kawasan yang dipengaruhi oleh atribut tanah

di kawasan kajian. Dalam kajian ini, empat senario yang berbeza telah dinilai ketepatannya. Senario yang digabungkan dengan kadar pertumbuhan bandar yang berbeza secara beransur-ansur meningkatkan ketepatannya berbanding dengan senario yang digabungkan dengan kadar pertumbuhan bandar yang seragam. Ketepatan model berada antara 86.2 peratus hingga 87.2 peratus dengan pekali KAPPA antara 0.7986 hingga 0.8189. Senario dengan ketepatan tertinggi dianalisis lebih lanjut dengan menerapkan dengan dasar perbandaran yang tersedia seperti sempadan koridor pembangunan dan pembangunan tersedia. Dengan cara ini, model yang dikembangkan juga dapat mengkaji bagaimana dasar perbandaran yang ada mempengaruhi pemaju bandar swasta dan membentuk pertumbuhan bandar di dalam kawasan kajian. Ringkasnya, kajian ini memberikan kepentingan mempertimbangkan kadar pertumbuhan bandar yang berbeza dalam model bandar (87.2% lebih tinggi daripada model yang memggunakan kadar pertumbuhan yang sama iaitu 86.2%) yang mempengaruhi pertumbuhan bandar di suatu wilayah. Ini membantu perancang bandar untuk merangka dasar perencanaan yang merangkumi pelbagai kadar pertumbuhan bandar di seluruh wilayah. Model-model ini juga membantu menjelaskan mengapa corak bentuk bandar tertentu muncul di lokasi tertentu kerana kesesuaian tanah yang berbeza dipengaruhi oleh kadar pertumbuhan bandar yang berbeza.

A DYNAMIC AGENT-BASED MODEL FOR SIMULATING AND PREDICTING URBAN GROWTH

ABSTRACT

Rapid urbanisation has become a significant phenomenon that concerns all nations as the world shifted into a globalisation era. While developed countries have faced this rapid urbanisation since the late 19th centuries, developing countries are struggling to manage this phenomenon after the 1950s. Understanding the urban growth system is the first step towards achieving future sustainable urbanisation. Spatially dynamic urban growth models can provide valuable simulations that contain essential knowledge in planning and policy-making. Most developed urban growth models implemented a uniform rate of urban growth to predict potential future urban growth outcomes, which is different from the real world. Thus, this thesis aims to develop an agent-based urban growth model that allows non-uniformity in urban growth rate. Urban growth rate differs within a region depending on its location, such as close to the city centre and public amenities availability. For this purpose, Geographical Information System (GIS) has been used to prepare Seberang Perai Tengah, Penang, Malaysia, data which possesses land attributes, urban growth rates, and land suitability of the study area. An agent-based model (ABM) was developed to simulate and predict urban growth of the study area. Agents represented by private urban developers making decisions to develop area influenced by land attributes in the study area. In this study, four different scenarios have been assessed its accuracy. Scenarios incorporated with different urban growth rates have gradually increased its accuracy compared to the scenarios incorporated with a uniform urban growth rate.

The model's accuracy ranges from 86.2 per cent to 87.2 per cent with KAPPA coefficient ranging from 0.7986 to 0.8189. Scenario with the highest accuracy was analysed further by implementing with the available planning policies such as development corridor boundaries and readiness development. In this way, the developed model can also examine how existing planning policies influenced private urban developers and shaped urban growth within the study area. In summary, this study provides the importance of considering the different urban growth rate in the urban model (87.2% higher than a model with uniform urban growth rate 86.2%) that influenced urban growth in a region. It helps urban planners to devise planning policies that encapsulate various urban growth rate across regions. The models also help to explain why particular patterns of urban form emerge in specific locations due to different land suitability influenced by the different rate of urban growth.

CHAPTER 1

INTRODUCTION

1.1 Preliminary

This chapter introduces the research background, problem statement and research objectives of the study. This chapter then concludes with the contribution of the research and the structure of the thesis.

1.2 Research Background

Most of the countries in the developing nations are facing rapid urbanisation. This phenomenon is inevitable as the world has shifted into the globalisation era. Historically, rapid urbanisation took place in the developed countries in the 19th and early 20th centuries. After 1950, however, this phenomenon has occurred tremendously in developing countries (Henderson, 2002). In 1970, the urban population in less developed regions had more than 680 million compared to 674 million in more developed regions (United Nations, 2019). The increasing number of the urban population in developing countries is due to the policies adopted in these countries. They have been shifted from agricultural to industrial activities to compete with developed countries. This phenomenon has caused major cities in those countries to grow into a mega-urban region where infrastructure was developed to support industrial activities and accommodate the influx of migrants.

United Nations (2019) has also projected that urban population would rise to approximately 2.77 billion in the year 2050, where more than 82 per cent were anticipated to emerge in the developing countries (refer to Figure 1.1). As stated in Figure 1.1, the high increase of urban population in the less developed region is mainly due to the belief that cities can provide a better quality of life by providing job opportunities and healthful social lifestyles that promote migration from rural into an urban area. (Deng, Wang, Hong and Qi, 2009; Tan, Liu, Zhou, Jiao and Tang, 2015).

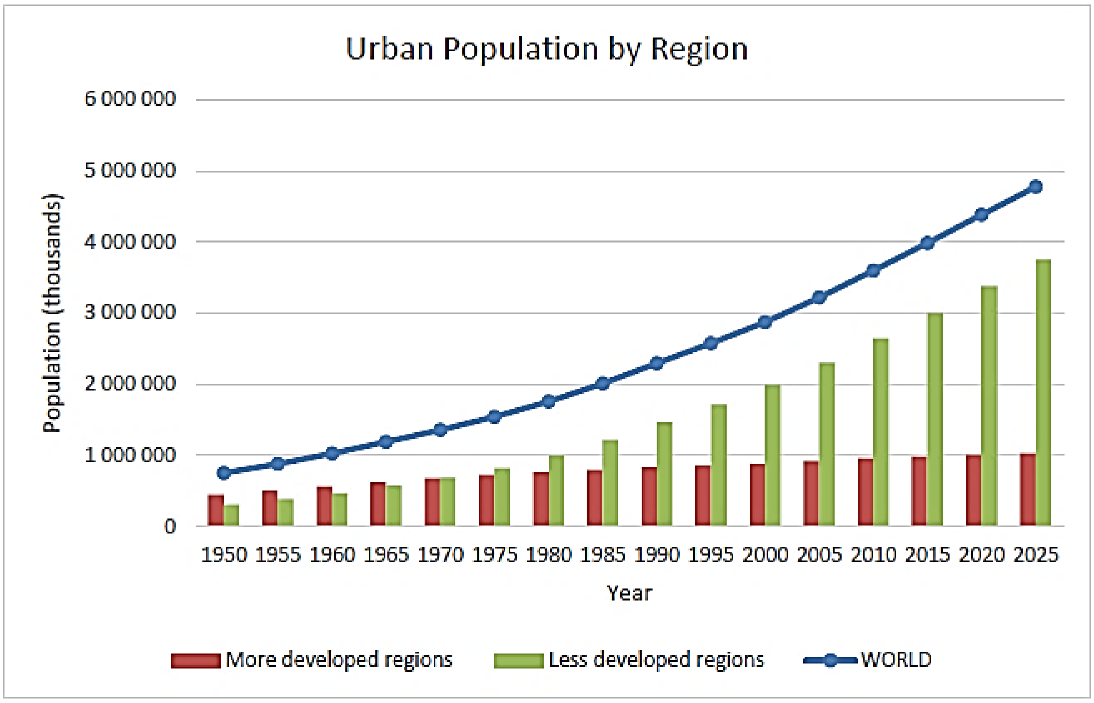


Figure 1.1: Urban population by regions from 1950 – 2025 [1] . (Source: United Nations, 2019)

[1] Notes:

(1) More developed regions comprise Europe, Northern America, Australia/New Zealand and Japan.

(2) Less developed regions comprise all regions of Africa, Asia (excluding Japan), Latin America and the Caribbean plus Melanesia, Micronesia and Polynesia.

An increasing number of urban populations can benefit the city and foster economic development, especially in boosting business, commercial, and industrial activities (Liu, Wang and Long, 2008; Lu, Wu, Shen and Wang, 2013). These activities can create higher demand from the population and utilise the full range of labour skills for their activities. Furthermore, this economic growth can be exploited by improving public infrastructure and providing a conducive environment that would attract more foreign investment to the region (Su, Jiang, Zhang and Zhang, 2011). Although urbanisation brought positive impact economically, over-population in urban areas would contribute various problems such as social, economic and environmental problems, namely pollution, traffic congestion and rise of housing prices (Tan and Li, 2013). In dealing with overpopulation, cities will expand vertically or horizontally (Su *et al.*, 2011) and eventually encroach into agricultural land and natural vegetation causing the transformation of land-use and land cover (Kumar, Arya, and Vojinovic, 2013). Therefore, a more profound understanding of the concepts or mechanisms underlying urban growth is needed to help urban planners reduce the negative impact of urbanisation and subsequently plan for the benefits from this phenomenon (Aguayo, Wiegand, Azócar, Wiegand, and Vega, 2007; Turok, and McGranahan, 2013; Romero-Lankao, Gnatz, Wilhelmi, and Hayden, 2016).

Various studies were shown that better strategies and plans can be developed to manage such growth (Aguayo *et al.*, 2007; Lu *et al.*, 2013). Potentially, the urban spatial model can be used. For instance, studies have been demonstrated that urban spatial growth model can potentially be implemented in simulating the future scenario of urban growth (Deng *et al.*, 2009; Yuan, 2010; Al-shalabi, Billa, Pradhan, Mansor, and Al-sharif, 2013; Rui, 2013). The model allows an understanding of an urban system's complexity, which functions as a centre of various human activities. Furthermore, those activities have been shaped a city's development through sets of interactions among the urban population.

Consequently, the impact of such development has formed a dynamic process that affects other activities and generates a system within the city (Batty, 2008). The complexities underlying urban dynamic system are intricate to understand without appropriate methods and approaches. Thus, modelling urban spatial growth has become a popular technique since its ability to simulate and predict future urban growth. This technique provides a clearer view to formulating the necessary plan to control and manage urban expansion.

At present, numerous complex models have been utilised to understand the dynamic urban system (Rui, 2013). The model developed should account for simulating complex processes that affect and shape urban structure (Batty, 1971; de Bruijn, 1991; Briassoulis, 2008; Simmonds, Waddell and Wegener, 2011). The fundamental concepts underlying urban spatial growth models have been initiated in North America for five decades ago (Batty, 1971) and widely developed in Europe, East Asia and West Asia countries. Those urban growth model have been used to comprehend the dynamic processes of urban system (Zhiyong and Lo, 2007).

Urban spatial growth models have been extensively applied to illustrate the future growth of a city where one can clearly understand the process of urbanisation (Verburg, Schot, Dijst and Veldkamp, 2004). These models can simulate the spatial changes of land-use and land cover within the city and forecast the possible urban growth according to the data (Wahyudi and Liu, 2014). Al-shalabi *et al.* (2013), for example, had demonstrated modelling the pattern and processes of the urban system would be a useful tool for planning urban system. Although various studies have been shown that urban spatial models could simulate urban systems, not many studies were undertaken in developing countries like Malaysia. This situation is due to difficulties in deriving factors or driving forces of urban growth.

Factors or driving forces that influence urban spatial growth are essential to simulate urban changes in a very complicated way (Entwisle, Rindfuss, Walsh, and Page, 2007). Bürgi, Hersperger and Schneeberger (2004), for example, have classified five significant classes of driving forces, namely cultural, natural, political, socioeconomic, and technological factors. As far as urban growth's complexity is concerned, driving factors should also be involved human interactions such as socio-demographic components, demographics, location choices of households and firms, economic variables, transportation and effects on land-use and environment (Miller, Hunt, Abraham and Salvini, 2004). Thus, those driving factors are essential to model complex urban systems, which could help planning support in growth management (Entwisle *et al.*, 2007; Tayyebi, Pijanowskia and Tayyebi, 2011; Al-shalabi *et al.*, 2013; Wahyudi and Liu, 2014).

1.3 Problem Statement

Various studies have been demonstrated that urban spatial model could potentially be used in assisting urban planning. These models can function as a decision support system. For example, most developed countries and some developing countries like

China and middle-eastern countries have developed and implemented these models to help urban planners manage urban growth (Liu *et al.*, 2008; Tayyebi *et al.*, 2011; Al-shalabi *et al.*, 2013; Tan *et al.*, 2015). There are three major classes of urban spatial models utilised to explain urban growth's spatial system: classical urban model, mathematical urban model, and dynamic urban model (Batty, 2008). The classical urban model was the early effort taken by urban scholars and urban planners to understand the urban system. The model focused on factors that influenced urban areas to illustrate urban growth (Alonso, 1960; Sinclair, 1967; Ullman, 1941). Then, in the early 1960s, the urban model infused with mathematical expression has been explored to explain the relationship between elements in urban systems (Altmann, 1981). The introduction of the urban spatial model with mathematical operation has drawn Britain’s researchers' attention and thus acknowledges the importance of modelling in studying urban phenomena (Harris, 1966; Batty, 1976). Furthermore, these models attempt to achieve specific goals or constraints defined when projecting future urban growth (Gilbert and Terna, 2000).

Although various models have been developed, Cellular Automata (CA) and Agent-Based Model (ABM) are two popular techniques in modelling and simulating the dynamics of urban systems (Arsanjani, Kainz, and Mousivand, 2011; Wahyudi and Liu, 2014). CA is a discrete dynamic system where space was categorised into regular spatial units known as cells and time progress in discrete steps (Abubakr and Pradhan, 2015). CA is considered a simple model that can be easily simulated, gives intuitive simulation results and delivers strong messages to its users (Wu and Silva, 2009). Various studies have demonstrated its effectiveness in modelling urban spatial growth. For instances, Onsted and Clarke (2012) used CA to model urban system in the United

States of America to understand the role of differentially assessed lands in influencing urban growth. Similarly, Rienow and Goetzke (2015) have combined CA's simulation skills with the machine learning approach in their study conducted in Germany.

In Southeast Asia, for example, the study by Ongsomwang and Saravisutra (2011) established a framework to identify an optimum predictive model for simulation of urban dynamics in Nakhon Ratchasima province, Thailand. That study focused on two different stochastic algorithms, including the CA-Markov and logistic regression models. In Malaysia, the study by Samat (2002) and Samat, Hasni and Elhadary (2011) had integrated GIS and CA to evaluate land-use changes and forecast land-use pattern in Seberang Perai, Penang. Similarly, Sangavongse, Sun and Tsai (2005) applied the SLEUTH Cellular Automata Model to explore land-use dynamics of the two Asian cities (Chiang Mai and Taipei) over several decades.

Although those studies had demonstrated CA's ability to be used as a tool in understanding urban spatial growth, this modelling framework has several limitations that need to be addressed before its implementation. CA cannot relate one driving force or factor with another, provide the system's reaction and consider the socio-economic influence on decision making. For instances, Samat *et al.* (2011), and Ongsomwang and Saravisutra (2011) have incorporated a series of suitability maps comprising factors influencing urban growth into the CA model. However, it could not update the reaction between those maps after one cycle and affect the next urban growth prediction process. Furthermore, the CA model cannot incorporate different urban driving forces and quantitative understanding between land-use and driving factors (Arsanjani *et al.*, 2011; Abubakr and Pradhan, 2015).

Due to these limitations within CA, Matthews, Gilbert, Roach, Polhill, and Gotts (2007) emphasised that ABM's shows definite advantages over CA especially in their ability to represent individual decision-makers and their interactions. It is seen that each individual possesses their unique characteristics to influence the systems' dynamics rather than taking the average to represent the society (Matthews *et al.*, 2007). These facts have also been emphasized by Weisbuch and Boudjema (1999), and Evans and Kelley (2004) where average information was unable to project the systems due to heterogeneity characteristics possess in each factor when simulates the reality. Matthews *et al.* (2007) also highlighted the other advantages of ABM over CA: the ability to link social and environmental processes dynamically. There are cases where the environment is affected by human actions, impacting the environment and leading to complex systems. Similarly, Scheffer and Carpenter (2003) added that it is essential to know which conditions of a dynamics land-use system become unpredictable due to different human responses in the environment.

Another concern that arose when modelling urban spatial growth is the uniqueness of urban growth rate in each area. The urban growth rate was believed to influence predicting future urban growth as in one large area will have its characteristics when considering forecasting urban growth. The previous developed urban spatial model that used CA is likely to monitor changes between two different periods of land-use activities. Together with incorporated suitability maps, each cell will be calculated its probability to change into future land-use pattern. However, if land-use activities used to monitor changes have two different massive gap periods, CA has lost its ability to capture any unpredictable activities or planning policies that occur between that period in which can be impacted to change the land-use pattern area. Thus, it is essential to develop a model that can account for unique behaviour in a different location to provide a coherent understanding of a sophisticated urban system for development.

ABM has been widely used and relatively widespread in many disciplines such as natural sciences, formal sciences and social sciences (Bonabeau, 2002; Gilbert and Terna, 2000). It is a powerful, computational simulation technique for modelling phenomenon as dynamic complex systems of agents living in an environment (Useya, 2011). ABM is a research technique to model a complex adaptive system comprised of autonomous, interacting agents (North and Macal, 2009). In other words, ABM allows us to generate, analyse, and experiment with models consists of agents that interact within a system. ABM models are less applied in complex socio-economic systems; however, these approaches have been incorporated into wide-scale urban planning models (Batty, 2003). As a result, urban growth models can account for several urban-driving factors, and these driving forces can complement each other to optimise urban growth simulations. Furthermore, ABM can consider each behaviour into a vital model when modelling urban spatial model. Such characteristics allow the model to incorporate dynamics process on the ground, including population dynamic.

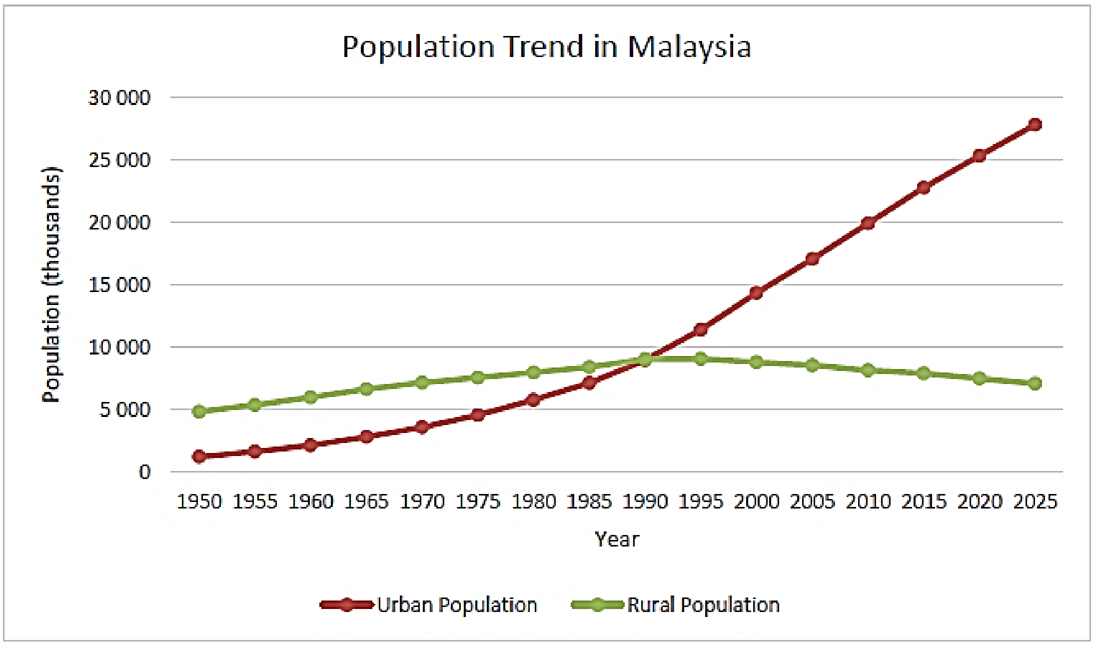


Figure 1.2: Urban population and rural population in Malaysia. (Source: Department of Statistics Malaysia, 2019)

The World Bank (2015) has reported that the number of the urban population in Malaysia is increasing rapidly and claims Malaysia among the most urbanised countries in East Asia. Its urban population is from 10.2 million in the year 2000 to 15 million in the year 2010. Figure 1.2 shows that since 1970 people have started to migrate from rural into urban areas, and the majority of Malaysia's population have resided in the urban area starting 1990. About 71 per cent of the urban population resides within 4,600 square kilometres of urban land in 2010. Although Malaysia is among the least dense in terms of urban population density, the spillover of the rapid development of a city into an urban fringe has made urban area expanded together with the demand to accommodate the urban population's growth. Thus, the new urban area started to encroach into the fringe area causing urban sprawl, congestion and unplanned development. These issues post challenges to urban planners and local authorities (Salleh, 2000; Samat, 2002). Therefore, there is a need to develop a predictive urban growth model using ABM urban spatial model in Malaysia context, which can be used to plan and understand better urban growth. The model should address the diversity of urban growth rate, which can increase the prediction accuracy.

1.4 Research Objective

This research aims to develop a computational model using an ABM urban spatial model to be used as a predictive model to plan and manage urban growth in Malaysia. Potentially, this model can be used to map, locate and forecast urban spatial growth and consequently to assist urban planners in formulating planning policy in managing urban growth in this area.

There are three specific objectives to be studied concerning this aim.

i. To distinguish the factors/parameters that influenced the urban growth and urban growth rate in the Seberang Perai Tengah, Penang State, Malaysia.
ii. To build a dynamic urban growth spatial model using ABM in GIS platform that can cater to different urban growth rate.
iii. To evaluate the developed ABM urban spatial model in simulating the future urban growth in the Seberang Perai Tengah, Penang State, Malaysia.

1.5 Scope of the Study

The study area was conducted in Seberang Perai Tengah (SPT) district at Pulau Pinang, Malaysia. The study was based on land-use data provided by Pulau Pinang Town and Country Planning Department - PLANMalaysia @ Pulau Pinang (2018). Three different land-use data (land-use 2010, 2015, and 2018) have been obtained from the PLANMalaysia and were used as input of the developing model. The study has used ArcGIS 10.4 proprietary software for data preparation, database development and accuracy assessment. The study has also gathered urban driving factors that influenced urban growth in Malaysia context using an online survey distributed to urban planners from PLANMalaysia, academicians, and public universities in Malaysia, private urban modellers and developers. The identified related urban driving factors in the survey were developed based on the past study of urban driving factors.

Simultaneously, NetLogo 6.0 open-source software was used to develop an urban spatial growth model that applied the ABM concept to simulate and predict future urban growth in Seberang Perai Tengah. The ABM concept implemented several agents that have a significant role in developing urban growth. These agents have been set its characteristics to replicate the real agents. Rules of converting other land-use into built-up were also incorporated in the model to simulate a real urban system. The loose-coupling approach has been used to develop the ABM and GIS model.

1.6 Significant of the Study

The Eleventh Malaysia Plan (2018) anticipates the city to be significant for its economic growth, especially in the Central Region, Southern Region and Northern Region. Therefore, many strategies have been carried out mainly in improving facilities and infrastructures that drive cities' rapid growth. It raises the usage of natural spaces and inefficient use of the region. Cities are a dynamic and complex system where it continuously changes and its development driven by numerous complex factors; formulating good plans and strategies would be complicated without predicting its growth and development. On the other hand, many new decisions were made based on the local plan devised at the micro-level. At present in most cases, local plan was developed by a consultant and in the form of development plan. It has not been tested, so the impact of such a plan on future growth was not known.

Thus, ABM provides a mechanism that allows dynamic urban spatial growth to be predicted. The result could be used in formulating appropriate policy to plan and manage urban growth. The model develops in this study would allow planners and decision-makers in understanding the resulted urban growth process based on strategy or policy implemented. Furthermore, ABM also provides a mechanism which will enable various factors to be incorporated into modelling urban spatial growth. Therefore, the approach will increase the rate of success in predicting future spatial of urban growth pattern. Besides, urban growth does not occur uniformly. The proposed model allows non-uniformity in term of growth rate within the study to be addressed. Such an approach would let reality to be capture in understanding the urban growth process.

1.7 Thesis Structure

This thesis consists of seven chapters. Chapter 2 reviews the literature and approaches to dynamic urban spatial modelling. It starts with a brief introduction on early urban growth models, urban driving forces and urban growth rate incorporated into the model, and reviews on Agent-Based Model (ABM) approaches and introduces ABM in developing urban growth spatial model. This chapter justifies the implementation of ABM to model urban growth spatial model of the Seberang Perai Tengah district, Pulau Pinang, Malaysia. Chapter 3 introduces the general methodology used in this study. This chapter discusses Seberang Perai Tengah district, sources and pre-processing performed before modelling. This chapter also outlines the data sets obtained and preparation undertaken for modelling. Chapter 4 describes the conceptual framework applied to develop an ABM urban spatial model. Selected factors and weights derivation were also discussed in Chapter 4. Important agents and environment designed in the model were also explained and presented in Chapter 4. Chapter 5 implements the developed model and run the operation to test four different urban growth scenarios on historical land-use data to evaluate the model performance and its accuracy in predicting and simulating urban growth. Chapter 6 applies the selected model to project the land-use pattern up to the year 2030. The model also predicts the spatial pattern of urban growth influenced by planning policies in Penang Structural Plan 2020. Finally, Chapter 7 presents a discussion of the thesis findings and overall contribution of the research. Furthermore, this chapter presents recommendations and limitations to outline potential future research and improve the dynamic urban spatial model.

CHAPTER 2

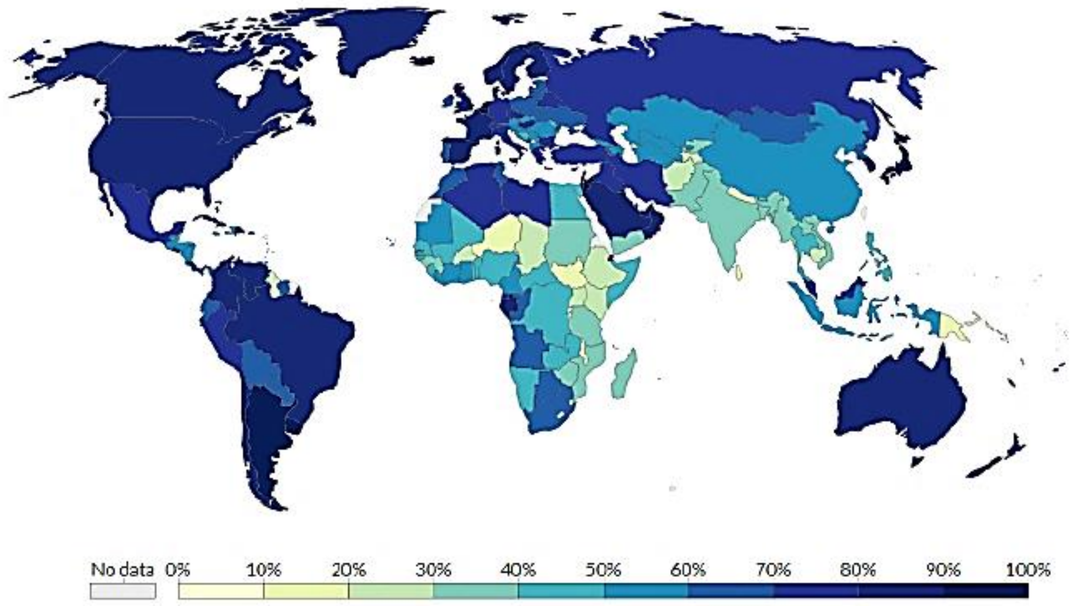
URBAN GROWTH SPATIAL MODELS

2.1 Introduction

The urban spatial model has helped urban planners visualise the future growth of urban areas, analyse urban growth impacts on land-use and land cover, and test different urban plan and policy scenarios. This chapter reviews the existing techniques of modelling urban spatial growth to select the most feasible and suitable approach in modelling the spatial pattern of urban growth in Malaysia. The discussion starts by reviewing urbanisation in Malaysia to overview the phenomenon better and capture the requirements for developing an urban spatial model suitable for the Malaysian context. This is followed by a discussion on urban spatial models proposed by the previous researchers, which is applicable to simulate the real urban system. In Section 2.4 and Section 2.5, urban factors and urban growth rates are discussed further where these two items are fundamental criteria in the study. After that, Section 2.6 concludes justification of technique used in the remaining chapter of this thesis.

2.2 Urban growth

Urban growth or urbanisation can be interpreted as transforming rural areas to urban areas to accommodate people and activities concentrated on land-use development (Weber and Puissant, 2003). According to Satterthwaite, McGranahan, and Tacoli (2010), urbanisation can precisely be defined as the increasing share of the country’s population living in urban areas compared to living in rural areas. Map 2.1 shows the share of people living in urban areas across the world in the year 2017. Most developed countries such as Western Europe, the United States of America, Australia, and Japan have more than 80% of the population live in urban areas. In the past 20 years, many developing countries are experiencing rapid urbanisation, and today have contributed to most urbanisation in the world (United Nations, 2018). The statistics published by the United Nations (2019) reported that more than 76 per cent (3.226 billion out of 4.220 billion) of the urban population lives in developing nation.



Map 2.1: Share of people living in urban areas, 2017. (Source: United Nations, 2018)

Urbanisation will bring significant impact to the surrounding environment. Among the positive impacts of urbanisation are creating more economic and employment opportunities (Liu et al., 2008; Su et al., 2011; Lu et al., 2013). Sitharam and Dindaw (2016) added that urbanisation could create employment opportunities in urban centres, foster economic growth, and increase trade and tourism. This view is enforced by Mathur (2013) that urbanisation forms a strong link with the increasing Gross

Domestic Product (GDP) on a nation (Browne, 2014). Similarly, Sridhar (2016) states that the urbanisation rate and GDP per capita are positively related to most countries at the global level.

Economic growth will bring more benefits to urbanisation and result in development, leading to efficiency in land utilisation and service delivery functions, access to amenities, resources and facilities not easily available in rural areas, access to transit, and transport networks at reduced costs. This leads to cities being able to act as knowledge hubs, environments for social integration. All these benefits will ultimately lead to an increase in the standard of living and poverty reduction (Hildebrand, Kanaley, and Roberts, 2013; Samat, Ghazali, Hasni, and Elhadary, 2014; Sitharam and Dindaw, 2016). However, Sitharam and Dindaw (2016) emphasised that all these benefits are only possible within a planned environment with foreseeable results.

Although urbanisation can bring positive impacts, it can also bring negative impacts such as increasing pressure on cities and natural resources (Su et al., 2011; Kumar et al., 2013; Tan and Li, 2013). The view of the increased pressure on cities is shared by McGee (1989) and Ghazali (2011) who stated that the massive migration of people from the rural areas to the urban areas puts high pressure on the existing social services of the urban area, which becomes a challenge to meet the demands of this continuously growing urban population. Sitharam and Dindaw (2016) also state a few challenges of urbanisation in relation to additional pressure on cities such as a deficit in urban infrastructure, poor service delivery, difficulties in meeting the mobility needs of the urban population through the use of mass public transport and coping with health impacting pollution from industries and vehicles.

Table 2.1: Summary of urbanisation's impacts from the previous study.

Positive Impact	Negative Impact
More job opportunities created in urban areas	High pressure in meeting urban population social service demands
Foster trade and tourism of a nation	Deficit in urban infrastructure
Increase Gross Domestic Product (GDP) and elevate economy growth of a country	Poor service delivery to the massive urban population
Efficiency development in land utilisation and service delivery functions	Challenges in handling mass public transport
Easy access to amenities, resources and facilities	Difficulties in coping health due to pollution from industries and vehicles
Availability of transit and transport at a cheaper cost	Decreasing of food and crop production due to farmland conversion
Increase the standard of living and reduce poverty	

The view that urbanisation will tax natural resources was shared by Raddad, Salleh, and Samat (2010). They state that the conversion of farmland and vegetation land cover into developed urban areas reduces the number of lands available for food and crop production (Ghazali et al., 2014). This is especially worrying as the long-term impacts of the lack of sufficient food production could be devastating. According to the World Hunger, a principal problem of world hunger is that many people still do not have sufficient income to purchase or land to grow enough food or access to nutritious food (World Hunger, 2018).

With all the impacts that urbanisation brings, as shown in Table 2.1, it further emphasises the importance of proper city planning. Urban spatial models have been used to understand complex urban systems. Model builders should account for simulating the many complex processes that affect the urban systems' structure (Batty, 1971; Rui, 2013; Simmonds et al., 2011). The advancements of Geographic Information System (GIS) and Remote Sensing (RS) enable urban expansion patterns and their dynamics to be studied, monitored and predicted (Masser, 2001). At present, various modelling approaches and techniques have been generated to predict and simulate spatial urban growth or expansion (Luo, Yu, and Xin, 2008; Bhatta, 2010).

2.3 Spatial Model of Urban Growth

Urban spatial models are tools that are usually used to study the trends and behaviour of land-use changes and have become very essential in exploring the interactions between land-use changes and factors of changes (Sefidi and Ghalehnoee, 2016). In understanding urban growth and development, the spatial model of urban growth has been developed and implemented in the urban system (Batty, 1971; de Bruijn, 1991; Briassoulis, 2008).

Urban spatial growth models have been extensively applied to illustrate the future growth of a city where one can clearly understand the process of urbanisation (Verburg et al., 2004). These models have the ability to simulate the spatial changes of land-use and land cover of a city and forecast the possible urban growth according to data that the model received (Wahyudi and Liu, 2014). The fundamental concepts underlying urban spatial growth models have been initiated in North America since five decades ago and widely developed in Europe, East Asia and West Asia countries (Batty, 1971). Models are needed as various factors or driving forces that stimulate urban change in a very complex way (Entwisle et al., 2007). Al-shalabi et al. (2013) have demonstrated the effectiveness of planning an urban spatial growth by modelling the urban system's pattern and processes. Therefore, modelling and simulation are believed to be essential approaches to research urban systems' mechanisms and contribute to planning support in growth management (Tayyebi et al., 2011; Entwisle et al., 2007, Al-shalabi et al., 2013; Wahyudi and Liu, 2014).

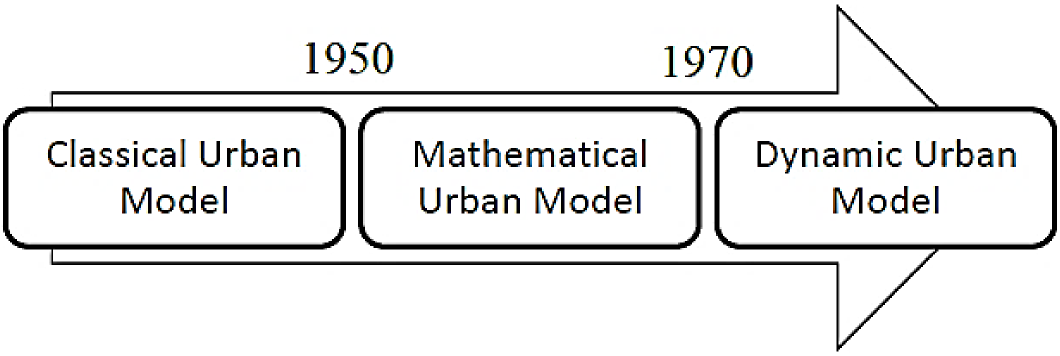


Figure 2.1: Trends of the urban spatial model (Batty, 2008).

Urban growth modelling aims to comprehend dynamic processes, and thus interpretability of models is becoming very important (Zhiyong and Lo, 2007). Urban growth models have been proven to be effective in simulating and representing the complexity of the dynamic urban system, and these models are very beneficial in planning and decision support for urban environmental management (Wu and Silva, 2009). As computer technology advanced, urban growth modelling methods also diverse to improve the efficiency of urban spatial growth model (Kim, 2012). Kim (2012) added that urban growth models vary based on data, methods, and theories. They can be classed into the classical urban spatial model, mathematical urban spatial model, and dynamic urban spatial model (refer to Figure 2.1). These modelling approaches may not cover all types of the urban growth model, but it can be presented as to how the urban growth model trend was used from time to time.

2.3.1 Classical Urban Spatial Model

In the early effort to understand urban systems, urban scholars and planners introduce the classical urban spatial model to illustrate and explain the existing urban growth (Alonso, 1960; Ullman, 1941). Factors that influence urban areas' shape are focused on developing the classical urban spatial model (Sinclair, 1967; Batty, 2008). Location and distance have been identified to give strong influences in shaping urban areas. Three major early urban spatial models that have been used to describe urban phenomenon are concentric zone urban model (Burgess, 1925), sectoral urban model (Hoyt, 1939), and multiple nuclei urban model (Harris and Ullman, 1945). These urban spatial models are developed based on urban structures identified in the western developed nations.

Urban areas are developed to be transformed from other land-use activities (Chapin and Kaiser, 1979). Land-use that converted into built-up was presumed to expand outward around its centre (Burgess, 1925; Hoyt, 1939; Harris and Ullman, 1945). This idea has become the foundations of classical urban spatial models such as concentric zone urban model, sectoral urban model, and multiple nuclei urban model. Figure 2.2 shows the earlier classical urban spatial model foundations.

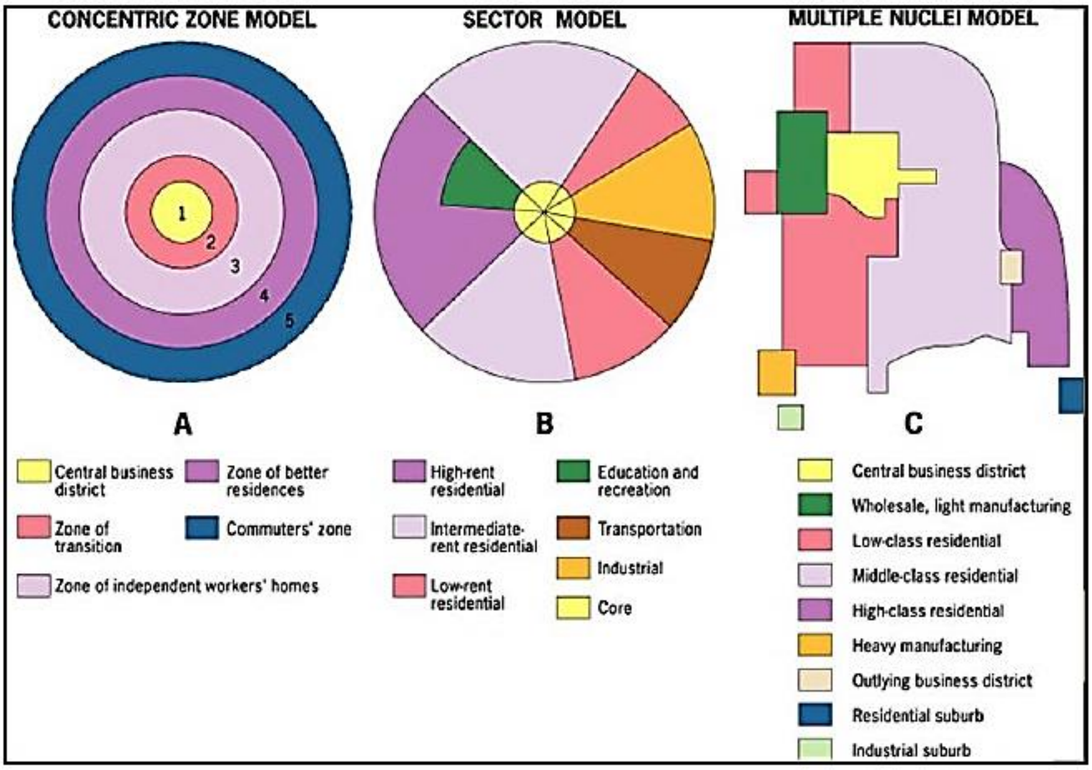


Figure 2.2: Earlier classical urban spatial models. (Source: Schlesinger, 2013)

The concentric zone urban model was developed based on real situations of Chicago city, where Burgess (1925) observed that the city expanded outward, creating a series of rings from a single centre. This model was among the first attempts to analyse land-use pattern at the urban level (Burgess, 1925). Burgess (1925) emphasises there are five series of zones that represent the different socio-economic urban landscape. Transportation and mobility were recognised as important factors for residents to live and stay in a certain zone (Burgess, 1925). For instance, residents can afford to stay further away from the urban centre if the cheap cost and good transportation quality are available. This model was simple to understand, describe, and show that the urban pattern and land-use landscape were based on population and economic growth (Chapin and Kaiser, 1979).

Another model that attempts to analyse urban landscapes is the sectoral urban model proposed by Hoyt (1939) where a city grows in sectors instead of rings. This model also emphasises that socio-economic status influence urban shape same as concentric zone urban model; however, it also based on their geographical or environmental characteristics, which have been overlooked by the concentric zone urban model (Hoyt, 1939). As a result, Hoyt (1939) emphasised that the urban pattern was more to sector shape, depending on its location. Residential areas that have been set up in a good environment with high housing prices will expand with a new development from the outer edge.

The multiple nuclei urban model was developed by Harris and Ullman (1945) that introduced a more effective illustration of urban landscapes. They proposed that urban areas' spatial structure is more dispersed and formed by a number of separate nuclei where more than one single centre is developed with different major activities involved. Harris and Ullman (1945) emphasised land-use compatibility together with location suitability and accessibility has contributed to urban pattern processes. For instance, heavy industrial areas repelled high-quality residential areas which prefer quiet surroundings and a healthy environment. Institutions, health facilities, stores and banks were attracted to each other where they share common economic interactions among them.

2.3.2 Mathematical Urban Spatial Model

In the early 1960s, an urban spatial model with a mathematical expression has been used to explain the relationship between elements in urban systems (Altmann, 1981). The infusion of building a mathematical model into urban systems has drawn researchers' attention in Britain, which has become a trend in designing and operating models of city development based on the mathematical operation (Batty, 1976). Harris (1966) defines an urban spatial model as 'an experimental design based on a theory', thus acknowledging the role of modelling in searching for a relevant understanding of urban phenomena.

Mathematical urban modelling firstly assumed that housing production, housing demand, and transportation costs are acting together, forming a constant correlation among them in the urban systems (Altmann, 1981). This type of modelling has become more explicit than classical urban modelling as the relationship between factors and the possibility of land-use change has been infused in the model. The mathematical urban spatial model has rendered clearer explanation and better predictive capability than the classical urban spatial model (i.e. Markov-chain change probability and logistic regression).

Mathematical urban modelling requires all factors or elements to be converted into weights that represent the contribution scale measurement of a factor in urban growth. Various techniques can be explored, such as multi-criteria decision analysis, or Analytical Hierarchical Process (AHP) to derive weights in urban mathematical modelling (Park, Jeon, Kim and Choi, 2011). There were two steps in implementing