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INTEGRATING GIS AND CELLULAR AUTOMATA SPATIAL MODEL IN EVALUATING URBAN GROWTH: PROSPECTS AND CHALLENGES

Narimah Samat
Email: narimah@usm.my

Geography Section, School of Humanities, Universiti Sains Malaysia 11800 Penang, MALAYSIA

ABSTRACT *Malaysia is experiencing rapid urban growth resulted from industrialization and economic policies adopted since 1970s. According to current planning policies and related growth projection, this process is expected to continue at least until the 2020 where Malaysia is planned to be a developed nation. Future urban growth requires a cohesive planning policy in order to ensure this growth does not have negative consequences to economy, environment and society that are experiencing land use transformations. Many studies have shown that an integration of GIS and cellular automata approach is suitable in modelling urban development; however, most of those studies are undertaken in western developed nations which have adequate planners and funds to manage modest population growth. In the context of developing nations like Malaysia, a locally-devised planning and management approach needs to be developed to plan, monitor, and control urban development in order to meet local challenges. This paper evaluates the prospects and challenges of using a GIS-based cellular automata model in planning and monitoring urban spatial growth in Malaysia.*

Keywords: Geographic Information Systems, Cellular Automata and Urban Land Use Planning

Introduction

Malaysia has experience rapid urbanization resulted from industrialization and related residential growth. Urbanization has increased from 27.6% in 1970 to 65.4% in 2000 and it is projected to achieve 75.0% in 2020 (Ghani Salleh, 2000). In 2001, built-up area was approximately 3.3% or 437,100 hectares of the total area of Peninsular Malaysia. However, this built-up area is expected to increase to 5.8% or 768,600 hectares in order to cater for urban population expansion by 2020 (Mohd Atan, 2005). Although the increase of built-up area seems to be small, these changes in land use can have local, regional or global impact because of their influence on biodiversity, landscape or living environment. Thus, a locally-derived planning tool needs to be developed in order to plan and monitor urban spatial growth.

In April 2005, Malaysian government launched National Spatial Plan, a long-term strategic plan which will be used to determine land development, management and conservation for Peninsular Malaysia (Mohd Atan, 2005). It is timely that such plan being introduced in order to ensure a healthy living environment is preserved. In addition, such plan needs to be supplemented by a predictive land use change model in order to understand and derive the information on the complex systems of physical and social factors. Such information can be used in explaining the causes, locations, consequences and trajectories of land use changes (Verburg and Veldkamp, 2005). Furthermore, model can be used to simulate possible future development, which enables planners to anticipate effect of such development on local, regional or global level (Harris and Batty, 2001).

Many studies have shown that the integration of Geographic Information Systems (GIS) and cellular automata (CA) model can be used to understand, simulate and predict urban spatial growth (Batty, Couclelis and Eichen, 1997; Clarke, Hoppen and Gaydos, 1997; Wu and Webster, 1998). At present, however, with the exception of studies undertaken in a few region of China, most of their applications were conducted in the western developed nations that experience modest population growth and have adequate personnel and fund to manage such growth (Samat, 2002). This article intends to evaluate the prospects and challenges in integrating GIS and CA model in understanding urban spatial growth in Malaysia. Modification of earlier model by Samat (2002) was made in order to evaluate the suitability of this approach in modelling urban systems in Malaysia. First, the article will discuss the formulation and implementation of the model in the Seberang Perai region, Penang State, Malaysia. Then, it will discuss the result of the model. Finally, this paper will discuss the prospects and challenges of using such model in the context of urban spatial growth in Malaysia.

Geographic Information Systems and Cellular Automata

Many studies have shown that GIS analytical functions are useful in evaluating the distribution of land use activities, monitoring land use changes, and modelling urban spatial growth (de Bruijn, 1991; Yeh and Li, 2001; Engelen, Geertman, Smits and Wessels, 1999). GIS is a tool to provide and manage information and become a mechanism in implementing planning functions, ranging from daily administrative operations to strategic planning functions, such as evaluating social and economic data in land use allocation task (Clouclelis, 1991, Samat, 2002). Although GIS has the ability to perform various planning functions, at present, its applications in urban planning and management have mainly focussed on automating daily administrative functions (Harris and Batty, 2001; Lee and Tan, 2001). This is probably due to lack of data, limited time and resources or complex and ill-defined planning functions (Verburg and Veldkamp, 2005; Uran and Janssen, 2003). Furthermore, GIS analytical capabilities have been criticized as being limited to manipulating digital map data (Carver, 1991; Samat, 2002). Thus, in using GIS as a decision making tool, this technology needs to be coupled with spatial model in order to enhance its analytical capabilities. Thus it can be used to understand, plan and predict dynamic land use changes (Clarke et al., 1997; Engelen et al., 1999). A simple model such as CA can be used to fit this purpose since it does not required huge amount of data and relatively easy to understand and implement (Couclelis, 1985; Batty et al., 1997).

CA, which is a simple model developed on the basis of cells can easily be coupled with GIS in solving planning problem. CA applications in urban study cover wide variety of urban phenomena ranging from traffic simulation and regional scale urbanization to land use dynamics, polycentricity and historical urbanization. Various models have been developed such as urban sprawl, sociospatial dynamics, segregation and gentrification to simulate urban systems (Torren and O'Sullivan, 2001). This approach has advantage over traditional urban model since it is simple, but has a relationship with complexity theory which can be used to understand the relationship between form, function and urban process (Couclelis, 1985). Furthermore, it is relatively easy to understand and does not require huge amount of socio-economic data (Batty et al., 1997), which is difficult and costly to obtain in the context of urban areas of developing nations like Malaysia (Samat, 2002). In addition, this approach has also been integrated with agent-based model (ABM) in order to capture the behaviour of individual local actors such as individual decision makers in shaping regional land use pattern. Such approach is suitable in capturing both the continuous and leap-frogging types of urban growth (Engelen et al., 1999; Torrens and O'Sullivan, 2001). Therefore, various planning functions or scenarios can be added or simulated in order to find cohesive planning strategy to govern land use development (Wu and Webster, 1998; Yeh, 1999).

Methodology

Formulation of the Model

The proposed model is a modification of earlier work by Samat (2002) where changes had been made on the factors influencing urban growth. This model was be used to simulate the spatial pattern of urban growth for the Seberang Perai region, Penang State, Malaysia using two different planning scenarios. Four basic elements of CA namely cells, states, neighborhood and transition rule were defined on the basis of physical, social and environmental factors. Cell is intrinsically linked with the observed space to represent land parcel or enumeration district. It was aggregated to 90m grid resolution, which is equivalent to an average parcel size in this study area. This size is the best scale to represent urban areas for this study area since it ensures best performance and maintains morphology or urban areas (Samat, *forthcoming*). The states of each cell represented land use activities ($A^t_{i,j}$), which was divided into 5 categories namely urban (residential, industrial, commercial, public facilities and administrative), non-urban (agriculture, vacant land and shrub), village, protected land (wetland) and forest reserve). At its present stage, however, the model only dealt with urban and non-urban conversion. Neighborhood ($N^t_{i,j}$) in a CA-based urban model is consists of a window of predefined size and shape used to define the sphere of influence for urban development. Various techniques have been employed to define neighborhood size (Batty et al., 1997; Torrens and O'Sullivan, 2001; Verburg and Veldkemp, 2003). In this study a 3 x 3 neighbor is used. Transition rule was formulated to govern cell evolution, where cell's state at any time step was determined by the state of cells at previous time step and suitability index calculated on the basis of factor influencing urban growth. This model can be expressed using equation (1) below.

$$^{t+1}A_{i,j} = f\,((^{t}A_{i,j})\,(^{t}N_{i,j})\,(^{t}S_{i,j})) \qquad (1)$$

Where *j*: the potential of the cell at row *i* and column *j* at time *t + 1* for urban development; $^{t}A_{i,j}$: the state of the cell at row *i* and column *j* at time *t*; $^{t}N_{i,j}$: the neighborhood index or the number of developed cells within a defined neighborhood of cell at row *i* and column *j* at time *t*; and $^{t}S_{i,j}$: the suitability index of the cell at row *i* and column *j* at time *t*. The neighborhood is calculated as:

$$^{t}N_{i,j} = \Sigma\, ^{t}N_{i,j} / 8 \qquad (2)$$

In equation (2), $^{t}N_{i,j}$ was calculated on the basis of 3x3 cell neighbors. In addition to neighborhood index, cell suitability index was determined based on physical, social and environmental factors, which was determined on the basis of its relative suitability for urban development. These criteria were evaluated using a weighted linear combination approach (Eastman, 1999). This value is calculated using equation (3) below.

$$^{t}S_{ij} = \sum_{m=1}^{M} {^{t}x_{ij}}\, w_m\, c_m \qquad (3)$$

Where $^{t}S_{i,j}$: the suitability index of cell at row *i* and column *j* at time *t* for urban development, $^{t}x_{i,j}$: the value of factor m for cell at row *i* and column *j* at time *t*, w_m: the weight of the relative important of factor *m*, c_m: the Boolean value of the presence of any constraint that hinder new development at the cell at row *i* and column *j* at time *t*; and m: the criteria used in the model. Environmental factors (flood prone area and valuable agriculture area) were used as constraints toward urban development. The function in equation (1) above was combined using IF, THEN and ELSE statements, such that, For ${}^{t}A_{i,j}$ = non_urban; (4)

IF (${}^{t}S_{i,j} \cdot {}^{t}N_{i,j} \geq$ thresh value old);

Then ${}^{t+1}A_{i,j}$ = urban;

Else ${}^{t+1}A_{i,j}$ = urban. -non

In the equation (4) above, a probability of land use change from non-urban to urban is used to update the cells. At each time step, cell will be update on the basis of its suitability and its neighborhood index as shown in Figure 1. These simple rules were relatively easy to understand especially among planners, who potentially would utilize this model (Batty et al., 1997).

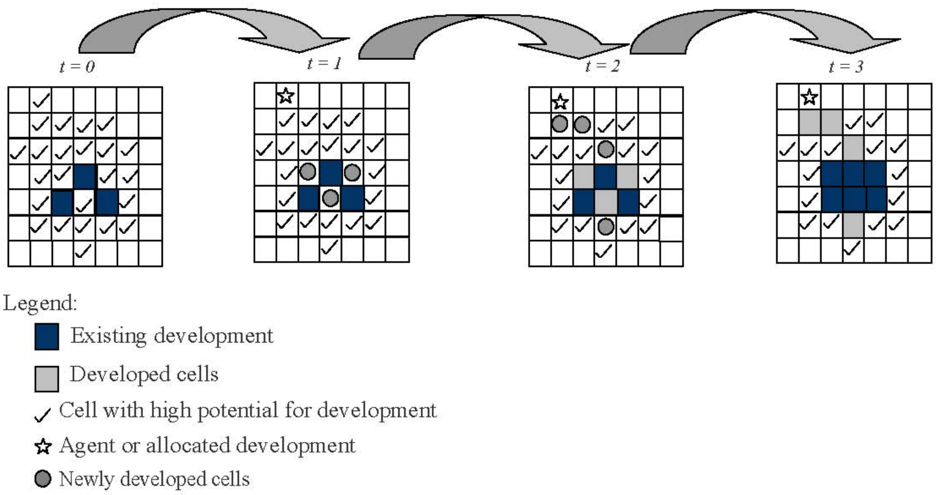


Figure 1: Schematic diagram of the proposed model. (Modified from Chapin et al., 1962)

Study Area and Data

The Seberang Perai region Penang State, Malaysia was chosen to test the proposed model. This area is suitable for testing such model since it has experience significant urbanization resulted mainly from industrialisation and residential growth in the last

30 years. This area has been planned to play a prominent role in attracting economic growth to the Northern Region of Peninsular Malaysia and part of Indonesia-Malaysia-Thailand Growth Triangle (Samat, 2002). Seberang Perai is located in the Northwest of Peninsular Malaysia, centred at 5^{o} 20'N latitude and 100^{o} 25'E longitude, with an area about $738.4km^{2}$ and approximately 27.4 percent urban (SPMC, 1998). Approximately, 92.8 percent of this area has slope of less than 5 percent (with height less than 50m). Only 5.2 percent of the Seberang Perai region has slope of more than 15 percent. This makes the region suitable for many development activities. Figure 2 shows the location of the study area.

Another reason for selecting the Seberang Perai region as the study area is data availability. In Malaysia, like many other developing nations, very few useful spatial modeling datasets exist in a digital format. However, the Geography Section of the Universiti Sains Malaysia, Penang, Malaysia has a collection of digital datasets acquired over prolong period for Seberang Perai. These include digital datasets of roads (at 1:50,000), sub-districts (at 1:75,000), slope (at 1:50,000), and land use (at 1:75,000) of 1990. Other data such as road network and public facilities were digitized from topographic maps (Department of Survey and Mapping, 1986). Land use 1998 data was obtained from Seberang Perai Municipal Council (SPMC, 1998). Soil data was digitized from soil map obtained from Department of Agriculture, Malaysia

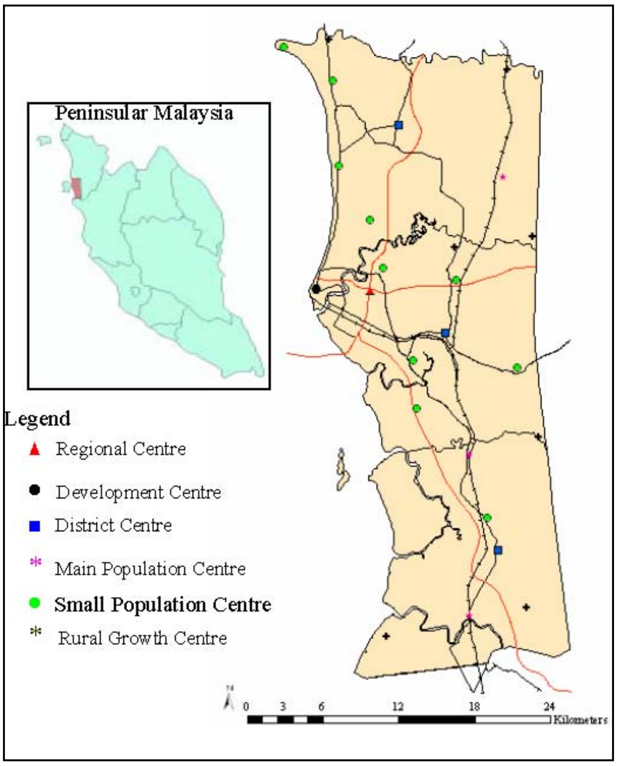


Figure 2: Study area

(Soo and Selvadurai, 1969). Flood-prone area was digitized from the map obtained from Penang GIS. Data from various sources, scale and format, at different temporal scale were converted into ArcInfo format.

Factors Influencing Urban Development

Factors influencing urban land use development can be divided into three categories namely physical, socio-economic and environmental criteria. Four physical factors describing spatial relationship between sites and others facilities located within the study areas were used. Socio-economic factor was limited to the availability of land value data which was interpolated from property evaluation report (Property Evaluation Department, 1999). Finally, environmental factors considered in this model were flood-prone areas and valuable paddy filed agriculture, which were utilized as constraints towards urban development.

These factors were weighted in order to determine their influence on land use development on the basis of interview undertaken with five local planners, who directly involved in land use planning in the study area. Two sets of weights were derived in order to test two different planning scenarios (Table 1). It should be noted that these weights were held constant throughout the simulation, changes in those weights might have significant influence on urban spatial growth (Samat, *forthcoming*). These weights were used to produce suitability index maps as shown in Figure 3.

Table 1: Weights used for each criteria to model two different planning scenarios

Criteria Used	**Scenario 1**	**Scenario 2**
Proximity to employment centers	0.25	0.31
Proximity to major roads	0.10	0.19
Proximity to public facility	0.08	0.07
Proximity to population centers	0.38	0.11
Land Value	0.18	0.32
Consistency Ratio	*0.06*	*0.08*

Scenario 1 or a planned development scenario accounted for the strategy outlined within the structural plan to control urban development from encroach into valuable agriculture land and seeded new development allocated by the government such as newly built industrial estate or new township to act as growth centre for this region. Scenario 2 or uncontrolled growth scenario allowed private developers or agents to develop land without any control imposed on them. This type of development was seeded at the most suitable location during the iteration. The model started with urban area 1990 as initial stage and stopped when the total developed land was equal to developed area 1998. The simulations was then continued to forecast urban spatial pattern until the year 2010. Projected land use demand up to 2010 was used to guide the simulation.

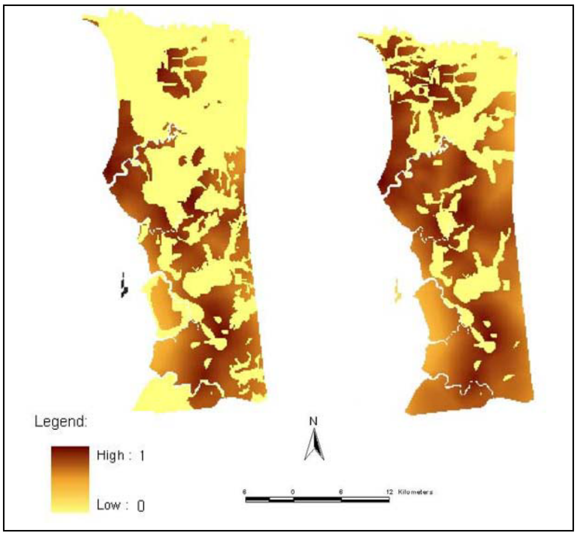


Figure 3: MCE-suitability maps used to determine potential cell for urban development (left) for scenario 1 and (right) for scenario 2.

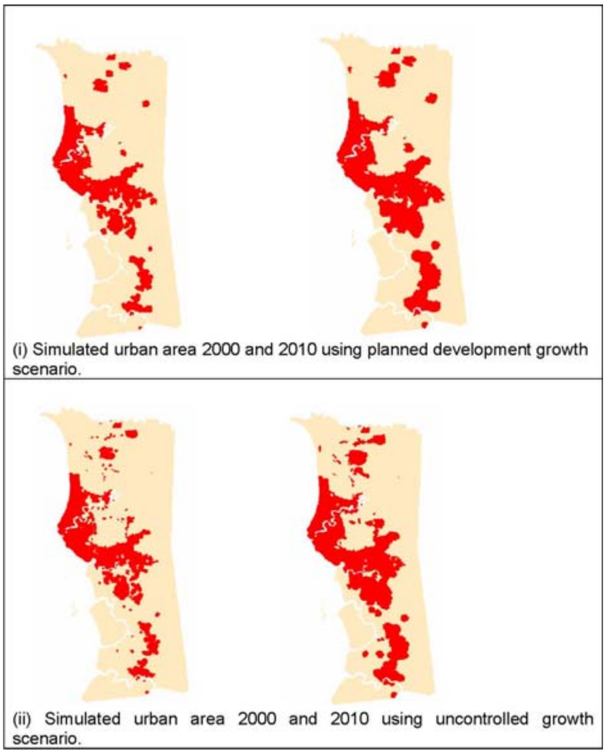
Results

A GIS-based CA model was assessed on its ability to reproduce, from 1990 land use data, urban spatial pattern of 1998. Generally the performance of the model was quite good. Result for the two scenarios modelled is shown in Table 2. Although the model produced high overall accuracy, the accuracy for urban category is quite low. This table shows that a planed development scenario produced better result. This result, however, is not much different (approximately by 2%) from that produced using the other model. This result suggested that between the period of 1990 and 1998, urban development in this region has been the result of an expansion of existing urban areas.

Table 2: Validation result for the simulation of urban development between 1992 and 1998.

Scenario	Accuracy for Urban Area (%)	Overall Accuracy (%)
Scenario 1 – Planned Development	80.1	92.1
Scenario 2 – Uncontrolled Growth	78.3	91.6

The model was used to simulate urban spatial pattern from 1990 to 2000 and 2010 (Figure 4). Interestingly, although for an uncontrolled growth scenario, the restriction from developing agriculture land near existing built-up areas was lifted, not much new development occurred in those areas. Assuming that the transition rules and mce-suitability index calculated were realistic, it seems that urban development tends to move towards the Southern district of Seberang Perai region. Furthermore, current planning practices are likely to result in the expansion of the existing urban areas.



(i) Simulated urban area 2000 and 2010 using planned development growth scenario.

(ii) Simulated urban area 2000 and 2010 using uncontrolled growth scenario.

Figure 4: Simulated urban spatial pattern produced using GIS-based CA model

Discussions

The main concern here is how to implement urban land use model in the context of urban spatial growth in Malaysia. The model that had been tested at a local level could then be used to model urban growth at a national level. At present, although planners know the amount of land needed for various type of development in the future, they have little knowledge over the location of such development or resulted urban pattern if those development took place. Thus, this model can be used to test planning strategy outline in the structural plan or the national spatial plan in order to evaluate whether such development would have negative long-term impact. A GIS-based CA model developed here has ability to forecast the direction, quantity and location of new development. This information is crucial in order to ensure such development does not have negative consequences on biodiversity, landscape and living environment (Uran and Janssen, 2003; Engelen et al., 1999). Various planning scenarios can be tested within computer environment prior to its implementation at specific location in order to avoid mistake in selecting urban planning program, thus reduce its negative impacts (Harris and Batty, 2001).

Although the model developed here has the potential to be used as a planning tool, several challenges needs to be overcome in using model in planning in Malaysia. At its present state, menu-driven function and graphic user interface need to be incorporated into this model in order to make it more user-friendly. Additionally, although the model can be used to simulate and forecast the spatial urban pattern of urban growth, the error in predicting urban areas needs to be reduced. This is a major challenge in using CA modelling approach since calibration issue is still being taken for granted.

Other challenges in using urban model in the context of urban planning in Malaysia include limitation of data, personnel and organizational. Data and its availability in digital format are very important in developing temporal dynamic model (Verburg and Veldkamp, 2003). In Malaysia, very few useful digital datasets is available for such application. Government effort to establish Malaysian Geospatial Data Infrastructure (MyGDI) hopefully help to solve this problem. The intention was to become data provider for the nations. At the state level, Penang GIS (PEGIS) for example, has an established digital data for Penang State; however, at present the cost of digital data is quite high. Other issue related to data is spatial and temporal scale. Data must be available at different time period and should be transformed to uniform spatial scale. It is quite problematic to build such datasets since not many agencies keep record of historical land use data.

Other challenge in using land use model in urban planning is personnel who might be responsible for developing, testing and implementing such model. At present land use allocation is conducted in ad-hoc subjective fashion often on the basis of knowledge and experience of a small group of senior planners and suggestion made by private consultant (Goh, 1991). On the other hand, management of spatial data using GIS is handled by technical staffs. Thus, in many cases GIS has only been used in producing maps or updating land use information (Lee and Tan, 2001). In order to use spatial model in urban planning, planners have to understand and be able to use GIS and translate planning ideas towards a modelling framework. Other problem that is related to personnel is transferred of staffs between department at state and national level (Rainis, 2002). Thus, GIS project is difficult to sustain once the responsible staff move to other place.

Finally, other challenge is using land use model is organization. The implementation of new technology such as in developing a GIS unit requires support from various levels especially top management within the organization. Continuous support from top management ensures sufficient funding or enough resources being allocated toward such project. In many organizations, implementation of GIS failed due to lack of organizational support.

Conclusion

Current planning projection and related planning policies suggest that Malaysia will experience rapid urbanisation at least until 2020. At present, however, land use allocation is still being conducted in rather ad-hoc manner, often on the basis of knowledge of a few decision makers and local planners. Thus, there is no clear policy on land use allocation or resulted urban spatial growth in this region. Although planners are aware that non-urban land especially agriculture land at the urban fringe or linear to major transport network is likely to be converted to urban, this is no planning tool to locate, map or forecast areas that may experience urban pressure. A GIS-based CA model developed here is suitable to be used as a complement to existing strategic plan utilized by planning department in Malaysia. Although this model has potential to become a planning support system, various challenges need to be overcome. These include limitation of data, lack of skilled personnel and organizational support.

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