Urban Growth and Land Cover Change In Chiang Mai and Taipei: Results From The SLEUTH Model

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EXTENDED ABSTRACT

SLEUTH is a modified cellular automata (CA) model which consists of an urban growth sub model and a land cover change transition sub model. The urban growth model is the main component of SLEUTH, which is tightly coupled with the land cover change transition model. This model was chosen to calibrate urban growth in two Asian cities, Chiang Mai (Thailand) and Taipei (Taiwan). These cities are undergoing rapid land use/land cover change as a result of robust economic and population growth. SLEUTH cellular automata model contains characteristics that offer advantages for modelling physical dynamics. Because of its cellular data structure, it can be integrated with raster-based remote sensing data. Calibration of the SLEUTH model requires gridded inputs of topographic slope, land use, zones excluded from growth, urban spatial extents, transportation networks and terrain hillshading. These data were developed from remote sensing and from topographic maps using GIS, and were prepared at three different resolutions.

This research applied the SLEUTH cellular automata model to explore land use dynamics of the two Asian cities over several decades. Three phases of calibration were used, corresponding to progressively higher spatial resolutions whilst the ranges of SLEUTH parameters were narrowed. The result yielded five key parameters characterizing historical urban growth patterns and suggesting a basis for exploring future scenarios of land-use change. We discuss the lessons learned from applying SLEUTH model to Chiang Mai and Taipei compared to other SLEUTH applications. The study reveals that: (1) urban development in Chiang Mai is best captured by Xmean and edge growth regression scores, whereas Taipei is best simulated by fitting using the Lee Sallee shape correspondence index; (2) the SLEUTH model can be applied to study urban land use dynamics in both countries, when some adaptations for spatial accuracy and scale sensitivity are made.

With a suitably calibrated model, the next phase of research is to use it to explore alternative futures by adjusting some of the key parameters. It is also intended to use the urban extents from other years in the calibration to observe the model sensitivity to temporal data sets. At this stage the model moves from a descriptive tool to one that could help facilitate deliberation about alternative futures about the urban growth patterns for Chiang Mai and Taipei. The historical understanding provided by the model would need to be communicated in graphics, but with care many of the cellular automata ideas are intuitive and visually exciting for researchers to explore (Lebel, et. al., 2005). In conclusion, applying the SLEUTH model to Taiwan and Thailand can increase the potential use of remote sensing and GIS data for the land cover change modeling. The result will be very useful to city planners, resource managers, policy makers and others in the related fields.

1. INTRODUCTION

The modeling approach has become recognized among modelers in many developed countries as the efficient tool for mapping spatial dynamics such as land use/land cover change (Wagner, 1997). In Asian countries like Thailand and Taiwan, only a few models were used for such purposes due to limitation of experts. However, there is a need for researchers in these countries to apply the land cover modeling in their studies. From our review, we found that the SLEUTH is one of the urban growth and land cover change models, that projects urban growth and examines how new urban areas consume surrounding land and impact the natural environment (United States Environmental Protection Agency, 2000). The model has been applied to simulate and forecast urban growth and land use change in several developed country settings. The present study is apparently the first SLEUTH model application in Asian countries. SLEUTH cellular automata model contains characteristics that offer advantages for modelling land use change and other physical dynamics. In this paper, section two provides a general background of the land use/land cover dynamics of the two Asian cities – Chiang Mai and Taipei. Section three gives a technical and application review of SLEUTH model. Section four describes the preparation of input data and calibration of the model. Research results and discussion are provided in section five.

2. LAND USE/LAND COVER DYNAMICS IN THE STUDY AREA

The Chiang Mai study area lies north of Thailand or approximately between 18° 40′ and 19° 00′ N latitude and between 98 $^\circ$ 55′ and 99 $^\circ$ 10′ E longitude (Figure 1). The size of the study area accounts for about 2,415 km^2. It encompasses the administrative districts in the integrated town and city planning scheme which are greatly influenced by urban sprawl. The Chiang Mai city was found in 1296 as the administrative capital of northern Thailand. It is characterized by rectangular walls surrounded by moats. At present, it is the center of culture, economics and education of northern Thailand.

The Taipei study area lies north of Taiwan Island, which is located approximately between 25° 00′ N and 25° 30′ N latitude and between 121° 30′ and 121° 50′ E longitude (Figure 2). The total size of the study area accounts for about 270 km^2. Taipei city falls within the Tansui River Basin, which is considered as the heartland of Taiwan in terms of economics, politics and culture (Lay and Liu, 2002).

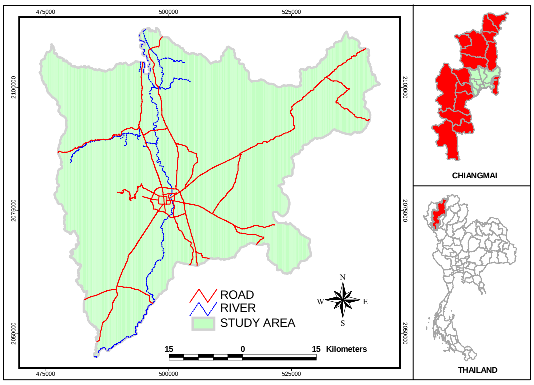

Figure 1. Chiang Mai Study Area (2, 415 km^2)

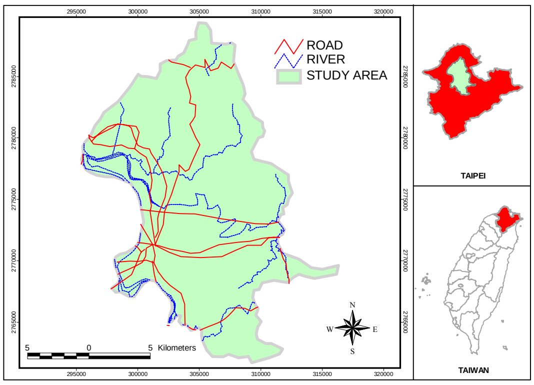

Figure 2. Taipei, Taiwan Study Area (270 km^2)

Chiang Mai and Taipei cities and their surroundings have undergone rapid land cover and land use changes, especially during the periods of economic and population growths. Due to the increase in population and the expansion of commerce and industry, the amount of urban and suburban/industrial land is sharply increasing. The expansion of city has greatly affected the surroundings. In Thailand for instance, it was found that agriculturally productive land and forestlands have been converted into residential and other uses. (Navanugraha, 1997; Sangawongse and Peterson, 1997, Wara-aswapati, 1991).

Based on the change detection analysis from the existing land cover data, the urban area of Chiang Mai increased from 15 km^2 in 1952 to 339 km^2 in 2000, with a tendency to increase over time (Figure 3). The significant changes can be found from agriculture to urban land. Similarly, large areas of agricultural fields in Taiwan have been converted to urban and industrial uses; more agriculture has moved to slope land and accelerated the removal of forest cover on the slopes.

Figure 3. Urban growth in Chiang Mai study area between 1952-1989-2000

Land use/land cover change in Taiwan between 1956 and 1994 was reported by Chang and Tsai (2001) that agricultural land increased by 10.7% between 1956 and 1977, and decreased by 28% between 1977 and 1994. Forest area decreased by 7.6 % from 1956 to 1977, and increased by 15.6 % from 1977 to 1994. Urban and industrial areas increased by 3.25 % between 1956 and 1994**.** Lay and Liu (2002) studied land use change in the Tansui River Basin of northern Taiwan using a GIS as a tool for mapping land use change from five data sets, 1904, 1926, 1971, 1977 and 1995. They found that change from agriculture to settlement area was significant**.** A cellular automata concept was firstly introduced in this study as well. Based on our analysis of data between 1924 and 2003, urban area of Taipei increased from 61 km^2 to about 113 km^2 in 2003. All of these findings confirm the rapid urbanization in Taipei city. There is a high probability of Taipei city to urbanize into the surroundings as a result of an increase industrialization and construction of buildings elsewhere. The emigration of rural people into Taipei city for seeking better job opportunities has brought about many social and environmental problems that relate to the land cover change inside the city (Kuo, 2003).

3. SLEUTH URBAN GROWTH MODEL – A REVIEW OF APPLICATION

The SLEUTH urban growth sub model is characterized by grids of homogeneous pixels, with a neighborhood of eight cells of two cell states (urban/non urban), and five transition rules that act in sequential time steps (Silva and Clarke, 2002). SLEUTH simulates four types of urban land use dynamics: spontaneous growth, new spreading center growth, edge growth, and road influenced growth (Clarke, Hoppen and Gaydos, 1997), as shown in Figure 4. The growth rules are applied sequentially during each cycle, and are controlled by five coefficients, namely: Diffusion, Breed, Spread, Slope Resistance, and Road Gravity. Spontaneous growth simulates urbanized pixels by random and it is controlled by diffusion coefficient. New spreading center growth determines whether any of the new spontaneously urbanized cells will become new urban spreading centers by the breed coefficient. Edge-growth simulates growth that stems from existing urban centers. It is controlled by the spread coefficient, which influences the probability that a non-urban cell with at least three neighbors will become urbanized. Road-influenced growth simulates the influence of transportation network on growth patterns and it is controlled by the breed coefficient.

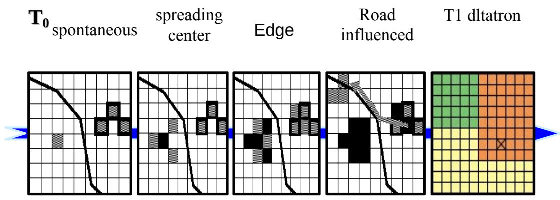

Figure 4. The Behavior Rules

Source: http://www.ncgia.ucsb.edu/projects/gig)

Silva and Clarke applied the model to Porto and Lisbon Metropolitan areas in Europe which are characterized by different spatial objects (Silva & Clarke 2002). Calibration result showed that the model adapted well to the European context as indicated by high regression scores which are close to the local characteristics. Candau applied the model to Santa Barbara in California as example to study urban growth (Candau, 2002). It was found that SLEUTH calibration was not scalable across image resolutions and data from the last 40 years proved more effective for calibration than including the entire historical profile available. Jantz and colleagues applied the SLEUTH model in Baltimore-Washington metropolitan area (23, 700 km^2) in the United States using a historic time series remote sensing imagery for assessing the impacts of alternative policy scenarios on declining of water quality in the Chesapeake Bay estuary (Jantz et al. 2003). In this application, future growth was projected to 2030 under three different policy scenarios (current trends, managed growth, ecologically sustainable growth). Result showed that SLEUTH has an ability to address many regional planning issues, but spatial accuracy and scale sensitivity must be considered for practical applications.

Applying this model to the rapid urbanization cities like Chiang Mai and Taipei are a challenging task and some insights from applying SLEUTH model may be obtained from non-western countries.

4. METHODS

4.1. Data Preparation for SLEUTH

This study utilized data from various sources, including GIS digital data, satellite images and topographic maps. The digital land cover data of Taiwan was available from 1924 to 2003. The 1924 data was digitized from topographic maps at 1:24,000 scale. The 1977 data and those recorded between 1982 and 1988 were derived from aerial photos interpretation (Chang and Tsai, 2001). The 2003 data was obtained from classifying SPOT February image into five land cover types (Urban, Agriculture, Forest, Water and Miscellaneous).

The Chiang Mai spatiotemporal data consisted of 1952, 1977, 1989, 2000 and 2002. The 1952 and 1997 data were digitized from topographic maps at 1:50,000 and analog land use map at 100,000 scales, respectively. The 1989 and 2000 data were acquired from Landsat-5 TM and Landsat-7 ETM+ at 30 meters resolution, respectively. ASTER image acquired in February 2002 was used for producing the slope data. The satellite data for Chiang Mai study area were mainly supplied by the Center for Global Change and Earth Observation, Tropical Rain Forest Information Center (TRFIC), Michigan State University, USA.

The input data required by the SLEUTH model includes Slope, Land use, Exclusion, Urban extent, Transportation and Hillshade. Data preparation depends greatly on GIS and remote sensing techniques, for example, data conversion, reclassification and data import/export. The software used for preparing the input data included ERDAS Imagine version 8.5, ArcGIS version 6.1.1, ArcView version 3.2, Adobe Photoshop version 5.5 and Geomatica Version 9.1.

A slope map of the Chiang Mai area was created from a Digital Elevation Model (DEM) which was developed from an ASTER image by Geomatica software. The ASTER image contains topographic information derived from the along-track scan of the satellite orbit. The slope layer of the Taipei area was created from a Taiwan DEM at 40 m resolution, which was later resampled into 30, 60 and 120 m resolutions before use in the calibration process. The Hillshade layer for each study area was produced directly from a DEM, which was used as the background for model image output and for visualization purposes.

The land use data from both study areas were developed from GIS and satellite images, which consisted of five major classes: Agriculture, Forest, Urban, Water and Miscellaneous. Land use with consistent classification for two time periods is needed for the model.

Exclusion is defined as areas which are resistant to urbanization. Excluded areas chosen for this analysis are water bodies, public land, forestland, national park and the military area. These areas were mainly extracted from the classified land cover data. Pixel values for excluded areas range from 0-255, but areas available for urban development have a value of zero (http://www.ncgia.ucsb.edu/projects/gig).

The urban extent for this study includes city/towns, institutional land, airport, rural residential land, recreational land and golf course (Dietzel, 2003, Lo and Yang, 2002, Wara-Aswapati, 1991). Four urban time periods were used for calculating best-fit statistics of the model (Jantz et al., 2003, Candau, 2002 and Clarke, 2002). The urban extents for Taiwan included 1924, 1977, 1982 and 1988. For the Chiang Mai area urban extents from 1952, 1977, 1989 and 2000 were chosen as inputs into the model.

Transportation layers for Chiang Mai area were derived from digitizing the historical topographic maps in 1952 and 1977. The transportation layer for Taiwan in 1924 was obtained from historical topographic maps, whereas the 1988 layer was obtained from the road database of Taiwan. All the roads layers were given weight in a GIS based on their 'accessibility'. Highways were treated as the most accessible, with a weight of 100, provincial roads as second most accessible at 50, and neighborhood streets as the least accessible with a weight of 25. Then, the weighted vector coverage was converted to a grid with the same resolution as other input data, giving the background a value of 0.

Input data for the Chiang Mai and Taipei areas were prepared at three resolutions to calibrate the SLEUTH model. The resolutions or cell sizes of 200m, 100m and 50m, which correspond to image rows and columns of 355×346, 670×691 and 1340×1383 were used for Chiang Mai, for Taipei the cell sizes of 120 m, 60m and 30m corresponding to 175×231, 349×461 , and 699×924 image dimensions were selected. (Table 1). The selection of these spatial resolutions was based on Dietzel (2003) and Candau (2002). It is noted that the land use data were not used in the model at this time due to the inconsistencies of some land cover types between different dates.

Table 1: Input gif images at full, fine and coarse resolutions for calibration of the SLEUTH model

Study area	Resolution (meter)		
	Full	Fine	Coarse
Chiang Mai	50	100	200
Taipei	30	60	120

4.2. Calibration of SLEUTH Model

The calibration procedure was based on SLEUTH version 3.0 beta program, which was downloaded from http://www.ncgia.ucsb.edu. The code is written in C programming language, and supports three modes: test, calibration, and prediction. For this study, only test and calibration modes were used. The model was operated by a Linux Redhat version 9.0 on PC microcomputer.

4.2.1. Brute Force Calibration

All input grey scale gif images at different resolutions were verified in the SLEUTH test mode before use in the calibration as suggested by Silva and Clarke (2002).

Brute-force calibration involved fitting the model to historical data on land use, transportation, and urban extent. Three phases of calibration corresponding to progressively higher spatial resolutions were carried out. As calibration proceeded to finer resolution the range of parameters explored was narrowed around the best values obtained at the previous level, and the number of Monte Carlo simulations for coefficient combinations increased from previous to final calibration phases. The process of model fitting (or "calibration") is computationally very intensive so only 4-8 simulations were done for each combination of parameters.

4.2.2. Selection of the goodness of fit statistics

At the end of each calibration run, the model produced 13 least squares regression metrics, such as population (number of urban pixels), cluster (urban cluster edge pixels), edges (urban perimeter), average slope, Xmean (average longitude) and Lee Sallee (a shape index) metric. Each metric represents the comparison between the simulated growth and the actual growth for the control years. To avoid difficulties in isolating and describing the factors that influence a regression score, only a subset of significant metrics were selected to explain the growth characteristics of both cities (Dietzel and Clarke, 2004). These metrics included Compare, Cluster, Cluster Size, Edges, Xmean, and Lee Sallee. Tables 2 and 3 show only six metrics from the sorted top five highest scoring results from Chiang Mai and Taipei data, with their associated growth parameters that control the behavior of the system at a different phase of calibration.

Table 2: Calibration result of Chiang Mai city

Least squares regression metrics	Resolution (meter)		
	200	100	50
1. Compare	0.99	0.99	0.99
2. Cluster	0.91	0.99	0.99
3. Cluster Size	1	0.99	0.99
4. Edges	1	0.97	0.99
5. Lee Sallee	0.16	0.18	0.26
6. Xmean	0.99	1	1
Five growth parameters			
Diffusion	3	10	33
Breed	71	66	46
Spread	16	38	60
Slope	38	50	43
Roads	36	30	47

Table 3: Calibration result of Taipei city

Least squares regression metrics	Resolution (meter)		
	120 m	60 m	30 m
1. Compare	0.72	0.99	0.99
2. Cluster	0.67	1	1
3. Cluster Size	1	1	0.78
4. Edges	1	0.99	0.99
5. Lee Sallee	0.61	0.66	0.66
6. Xmean	0.99	0.99	0.99
Five growth parameters			
Diffusion	4	30	18
Breed	3	50	30
Spread	1	75	54
Slope	30	13	9
Roads	43	26	42

5. RESULTS AND DISCUSSION

Calibration output was explored by using the statistical methods (e.g. sort descending) to select the best fit values for both cities. It was found that Cluster-Size, Edges and Xmean scores were best captured for Chiang Mai as indicated by scores of 1, 1 and 0.99, accordingly. Taipei was best captured by Edges scores (1), Cluster Size (1) and Lee Sallee (0.66). It is observed that Lee Sallee that measures spatial fit by taking the ratio of intersection and the union of the simulated and actual urban growth (Candau, 2002) did not yield a high score for Chiang Mai (around 0.26 in the coarse calibration phase), but for Taipei it yielded a fairly high score (about 0.6 for all calibration phases). A perfect spatial match is 1. It is hard to obtain high values of the shape match for Chiang Mai due to scattered expansion of the city (Lebel et. al., 2005), making it hard for the model to fit the actual shape exactly.

Increased spatial resolution and narrowed down the ranges of parameters have improved the calibration. For example, the initial Diffusion and Spread values of 33 and 60 in Chiang Mai were narrowed down to 3 and 16, and the initial Diffusion value of Taipei was narrowed down from 18 to 4. Figures 5 and 6 reflect the behavior of both cities to the different growth coefficients values.

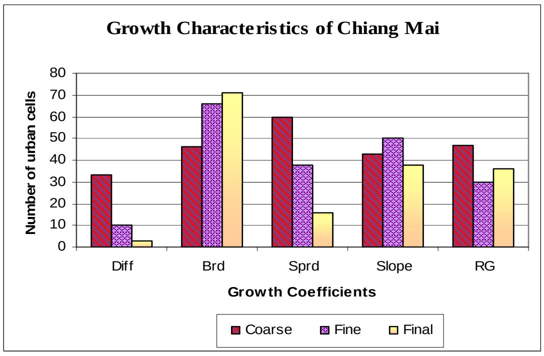

Figure 5. Behavior of Chiang Mai to the growth coefficients

From Figure 5, the high Breed coefficient value derived from final calibration (70) in Chiang Mai may indicate the abundance of vacant land suitable for development, and as a result many new buildings or spreading centers are being developed on such areas. In Taipei, the spread coefficient value is high (about 75) at the fine calibration (Figure 6), because of the development of transportation infrastructure to spread urbanization. The spread value adjusted to the local characteristics at the final calibration.

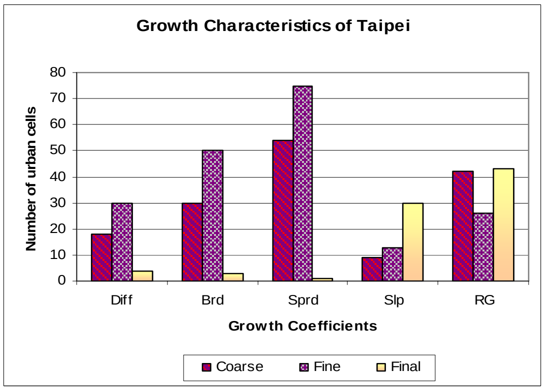

Figure 6. Behavior of Taipei city to the growth coefficients

Different characteristics of both cities were captured in the set of final coefficients that describe the areas under investigation. For Chiang Mai, the starting parameter values in 1952 of: Diffusion = 1, Breed = 1, Spread = 3, Slope = 29, Roads = 40. For Taipei, the equivalent values were: 1, 1,1,100,18. These numbers can be used to predict future growth in the prediction mode of the SLEUTH model.

The quality of the input data and the selection of optimal parameter ranges should be considered carefully to improve the calibration result. Since the calibration of SLEUTH is computer intensive, it should be implemented on a super computer or to be run on a parallel processing and high performance computing methods (e.g. cluster computer) in order to obtain the result in a timely manner. In conclusion, applying the SLEUTH model to Asian countries has just started, there is still a need for modelers to explore in more aspects of using this model. This calibration experience has provided us some insights to SLEUTH model and more understandings on how the CA adapted to the urban environment in Asian countries.

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