UNIVERSITI PUTRA MALAYSIA

MULTI-OBJECTIVE BASED CELLULAR AUTOMATA-MARKOV CHAIN MODELING FOR LANDUSE CHANGE ANALYSIS IN KUALA LANGAT, MALAYSIA

RAMIN NOURQOLIPOUR

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By

RAMIN NOURQOLIPOUR

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

March 2013

I would like to dedicate this thesis to

My late mother and my father

My beloved wife and my dear son

My brothers and sisters

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

MULTI-OBJECTIVE BASED CELLULAR AUTOMATA-MARKOV CHAIN MODELING FOR LANDUSE CHANGE ANALYSIS IN KUALA LANGAT, MALAYSIA

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Chair: Associate Professor Abdul Rashid Bin Mohamed Shariff, PhD

Faculty: Engineering

Analysis of land use and land cover change is a complex task on account of tensions between land classes where any land category has a series of specific needs for development. This research addresses resolution of a multi-objective land development problem in Kuala Langat district, Malaysia under an integrated model of Cellular Automata-Markov chain (CA-Markov) towards projecting land development for the year 2020. According to the current land use dynamics, four conflicting objectives are identified including urban and urban related development, oil palm development, agriculture development, and forest development. Four groups of evaluation criteria are developed that define the main driving forces of change in each objective. The Analytical Hierarchy Process (AHP) is adopted to assign a weight to each evaluation criteria based on the expert opinions and judgments. Multi-Criteria Evaluation (MCE) technique is used to conduct four disparate suitability analyses. A Multi-Objective Land Allocation (MOLA) analysis

is then adopted to analyze four different outcomes of MCE. Simultaneously, Markov chain analysis is conducted to compute the quantitative transitions of each land category between 1997 and 2002 to project land change of the year 2008. The projected 2008 is then validated by real map of the year 2008 based on three validation methods. The overall agreements based on three approaches of quantity disagreement and allocation disagreement, &UDPHU¶V,9 and Kappa are 79% (16% allocation disagreement and 5% quantity disagreement), 78%, and 77% (due to location and quantity) respectively. However, the higher accuracy achievement requires model calibration to eliminate the deviations of projection. To increase the agreement of projection, this research initiates a method for calibration of CA-Markov land change projection. The proposed method is based on integration of cross-tabulation analysis and Markov chain analysis of observed and projected land use data. The method is successfully examined in a specific landscape and the time step. Model validation after calibration process reveals a meaningful increase in the agreement of projected versus observed land use data. The quantity disagreement and allocation disagreement approach measures 15% increase in overall agreement, &UDPHU¶V9 measures 13% increase in agreement, and Kappa measures 6% increase in overall agreement due to location and quantity. Finally, the major signals of systematic transition of each land category including net change, swap, gross gain, and gross loss are extracted to compare land transformation process over time. The results demonstrate the high tendency of forest category to systematically lose to µRWKHU¶ODQG FDWHJRry and µRWKH KLJK WHQGHQF\ RI µRWKHU¶FDWHJRU\ WR DYRLG V\VWHPD gain from oil palm category by the year 2020. In the same time, results show the high disinclination of forest category to systematically lose to oil palm category.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PERMODELAN CELLULAR AUTOMATA-MARKOV CHAIN BERASASKAN MULTI-OBJEKTIF UNTUK ANALISIS PERUBAHAN GUNA TANAH DI KUALA LANGAT, MALAYSIA

Oleh

RAMIN NOURQOLIPOUR

Mac 2013

Pengerusi: Professor Madya Abdul Rashid bin Mohamed Shariff, PhD

Fakulti: Kejuruteraan

Analisis penggunaan dan perubahan tanah merupakan satu tugas yang kompleks berikutan penekanan antara jenis kelas-kelas tanah kerana ianya mempunyai siri yang khusus untuk pembangunan. Kajian ini mengkhususkan terhadap resolusi masalah pembangunan tanah pelbagai-objektif di Daerah Kuala Langat, Malaysia menggunakan model integrasi Rantaian Selular Automata-Markov (CA-Markov) dalam pengunjuran pembangunan tanah bagi tahun 2020. Berdasarkan kepada situasi dinamik semasa guna tanah, empat objektif yang berlawanan telah dikenal pasti termasuk pembangunan bandar dan pembangunan berkaitan bandar, pembangunan kelapa sawit, pembangunan pertanian, dan pembangunan hutan. Empat kumpulan penilaian kriteria telah dibangunkan untuk menentukan menentukan daya penggerak perubahan utama dalam setiap objektif. Proses Hierarki Analitikal (AHP) telah diguna pakai untuk menentukan pemberat untuk setiap kriteria penilaian berdasarkan kepada pendapat dan pertimbangan daripada pakar. Teknik Penilaian Multi-Kriteria

(MCE) digunakan untuk menjalankan empat analisis kesesuaian yang berbeza. Analisis Peruntukan Tanah Multi-Objektif (MOLA) kemudiannya digunakan untuk menganalisis empat hasil berbeza daripada MCE. Pada masa yang sama, analisis rantaian Markov dilakukan untuk mengira peralihan kuantitatif untuk setiap kategori tanah diantara tahun 1997 dan 2002 untuk membuat pengunjuran perubahan guna tanah bagi tahun 2008. Hasil pengunjuran guna tanah tahun 2008 ini kemudiannya disahkan berdasarkan kepada peta guna tanah sebenar tahun 2008 menggunakan tiga kaedah pengesahan. Hasil keseluruhan pengesahan iaitu berdasarkan kepada tiga pendekatan; perbezaan kuantiti dan perbezaan peruntukan, &UDPHU¶V dan Kappa adalah 79% (16% perbezaan peruntukan dan 5% perbezaan kuantiti), 78% dan 77% (berdasarkan kepada lokasi dan kuantiti). Namun begitu, untuk mendapatkan ketepatan yang lebih tinggi, model penentukuran perlu menghilangkan sisihan pengunjuran. Untuk menambah baik hasil pengunjuran, kajian ini telah mencadangkan untuk menggunakan kaedah penentukuran perubahan pengunjuran tanah CA-Markov. Kaedah yang dicadangkan ini adalah berdasarkan kepada integrasi analisis penjadualan silang dan analisis rantaian Markov untuk data cerapan dan data pengunjuran guna tanah. Kaedah ini berjaya dilaksanakan dalam persekitaran dan langkah masa yang spesifik. Model pengesahan selepas proses penentukuran telah menunjukkan peningkatan dalam data guna tanah pengunjuran berbanding data guna tanah cerapan. Pendekatan menggunakan perbezaan kuantiti dan perbezaan peruntukan menunjukkan peningkatan 15% secara keseluruhan, &UDPHU¶V 9 menunjukkan peningkatan 13%, dan Kappa menunjukkan peningkatan 6% bergantung kepada kedudukan dan kuantiti. Akhirnya, isyarat utama peralihan sistematik bagi setiap kategori tanah termasuk perubahan bersih, pertukaran, keuntungan kasar dan kehilangan kasar diekstrak untuk membandingkan proses transformasi tanah dari masa ke semasa. Hasil kajian menunjukkan kecenderungan yang tinggi untuk kategori hutan untuk hilang secara sistematik berbanding kategori tanah yang lain, dan kecenderungan yang tinggi untuk kategori-kategori lain mengelak penambahan secara sistematik daripada kategori kelapa sawit bagi tahun 2020. Dalam masa yang sama, hasil akhir juga menunjukkan kecenderungan pertukaran secara sistematik daripada kategori hutan kepada kategori kelapa sawit.

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I certify that a Thesis Examination Committee has met on **14 March 2013** to conduct the final examination of Ramin Nourqolipour on his thesis entitled "**Multi-objective based Cellular Automata-Markov chain modeling for landuse change analysis in Kuala Langat, Malaysia**" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

Members of the Thesis Examination Committee were as follows:

Abdul Rahman Ramli, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Helmi Zulhaidi bin Mohd Shafri, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Biswajeet Pradhan, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Armando A. Apan, PhD
Associate Professor
Faculty of Engineering and Surveying
University of Southern Queensland
Australia
(External Examiner)

SEOW HENG FONG, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Abdul Rashid Bin Mohamed Shariff, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Noordin Bin Ahmad, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Siva Kumar Balasundram, PhD
Associate Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Member)

____

BUJANG BIN KIM HUAT, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

RAMIN NOURQOLIPOUR

Date: 14 March 2013

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LIST OF ABBREVIATIONS

CA-Markov	Cellular Automata-Markov chain
MCE	Multi Criteria Evaluation
MOLA	Multi-objective Land Allocation
AHP	Analytical Hierarchy Process
WLC	Weighted Linear Combination
ESA	Environmental Sensitive Areas
JPBD	Jabatan Perancangan Bandar dan Desa (Department of Town and Urban Planning)

CHAPTER 1

INTRODUCTION

1.1 Background

Land use change dynamic is sequence of coupled human-biophysical environment interactions (Parker et al., 2003; Parker, 2005; Matthews et al., 2007; Robinson et al., 2009; Valbuena et al., 2010). In Malaysia, urban areas have rapidly expanded in the recent years. Meanwhile, the areas under oil palm plantation have increased dramatically since the early 20th century (Basiron, 2007) so that it is considered as the main agricultural land-use of Malaysia (Abdullah and Nakagoshi, 2008). On the other hand, there is a greater pressure on natural forested lands due to urban and oil palm land-use expansions.

The study area is part of Klang-Langat watershed which had been studied before to monitor land-use change over the time period of 1989-1999 (Earth Observation Centre, 2001). The result of land change monitoring in this area shows the largest increase in built up areas associated with urban growth and major reduction in tropical rainforest and the mangrove forest. Agricultural land use shows a steady decline while oil palm is dominant land use. According to Earth Observation Centre (2001) the main trend in land use change occurring in Klang-Langat Watershed can be summarized in three phases. First, the early 60s land use changed from forest to agriculture. Second, the 70s land use changed from rubber to oil palm and third the late 80s and early 90s land use changed from oil palm to urban development. Infrastructure development has further reinforced the major trend towards urbanization. The results reveal that the study area is characterized by multiple conflicting objectives that compete against each other for development.

Generally, the multi-objective approaches have been used to resolve problem of multiple conflicting objectives including one approach which integrates multi-objective trade-off preferences to select the best alternative (Cohon, 2004; Lee, 2012). However, Multi-Criteria Evaluation (MCE) has been implemented in GIS to incorporate trade-off preferences in disparate objectives of land development towards selecting the compromise sites for further development. Integration of MCE with Multi-objective land Allocation (MOLA) model (Eastman, 2009a) under CA-Markov has enabled analysis of multi-objective land change problems towards projecting the future trends of land-use change.

1.2 Problem Statement

The first problem of this research involves projection of a multi-objective land development into the future where different perspectives compete to settle the allocation of a certain resource. There are various approaches to resolve multi-objective land development problems on the basis of; suitability analysis of land classes (Eastman *et al.*, 1993; Cromley and Hanink, 1999; Bergen *et al.*, 2005; Chen *et al.*, 2011), genetic algorithm (Aerts *et al.*, 2003; Matthews *et al.*, 2006; Porta *et al.*, 2012), patch compactness (Aerts *et al.*, 2005; Janssen *et al.*, 2008; Kai *et al.*, 2009) and spatial optimization (Ligmann-Zielinska *et al.*, 2008). However, there is a lack of studies, which clearly examine transitions of entities of multi-objective land development over time, especially multi-objective developments that are analyzed by means of integrated Cellular Automata-Markov chain (CA-Markov) approach. In response to this problem, this research analyzes transitions of a multi-objective land development process over time using CA-Markov (Eastman, 2009a), which projects land-use trajectories into the future based on transitional suitabilities of land change.

CA-Markov has been researched and mainly validated previously using Kappa index of agreement (Pontius and Malanson, 2005; Poska et al., 2008; Kamusoko et al., 2009; Mondal and Southworth, 2010; Mitsova et al., 2011). Kappa indices are based on randomness and ignore a part of transitions from base map to projected one (Pontius and Millones, 2011). This implies a lack of completeness in the current approaches. In response to this problem, the quantity disagreement and allocation disagreement approach (Pontius and Millones, 2011) is implemented that takes into account the entire transitions indicating discriminated spatial and quantitative errors based on summarizing the cross tabulation matrix of projected map vs. real map. In WKLV UHVHDUFK ZH WHVWHG WZR RWKHU YDOLGDWLRQ PHWKRGV &UDPHU¶V 9DO Kappa. However, DOWKRXJK &UDPHU¶V 9 LV EDVHG RQ WKH FURVV-tabulation analysis of two comparisons (Apan and Peterson, 1998; Apan *et al.*, 2002), it indicates association corrected for chance (Ellis and Pontius, 2010) and is not able to discriminate quantitative and spatial errors. Meanwhile, Kappa variations do not take into account issue of the entire transition even though it is able to discriminate quantitative and spatial errors. Thus, to develop a complete approach of validation evaluating the entire transitions from base map to projected one, three methods are tested including quantity disagreement and allocation disagreement approach, .UDPHU¶V 9 DQG .DSSD LQGH[RI DJUHHPHQW

Further, another major problem addressed in this research is calibration of CA-Markov models. The calibration procedure should be able to eliminate the deviation of simulation. Markov chain analysis is one of two major components of a CA-Markov simulation that determines quantity of projected cells in each land class through computing the probability matrix (Pontius and Malanson, 2005; Eastman, 2009a; Kamusoko *et al.*, 2009; Mitsova *et al.*, 2011). Markov chain analysis uses likelihood of change as the baseline and CA-Markov applies this probability to predict the future changes of land-use. The probability based behavior of Markov chain analysis often causes error in the projected data (Bartholomew, 1975), where the error appears in the probability matrix (Logofet and Korotkov, 2002). The error of probability matrix is significant sources of deviation in a CA-Markov simulation. In respond to this problem, a heuristic approach is initiated to calibrate the model based on integration of cross-tabulation analysis with Markovian transition probability of observed and projected map towards eliminating the deviations of simulation. The introduced calibration method is the novel contribution of the study.

1.3 Research Objectives

This research enhances the insights into simulating the change of multiple land categories under conflicting socio-economic and environmental objectives of development by means of CA-Markov model. Moreover, this thesis aims to assess the accuracy of such simulations by implementing three different methods of validation. Further, this research initiates a novel method of calibration to eliminate the deviation of CA-Markov land change simulations. Thus, this research includes three steps of experimentation that meet the requirements of the research problems. The objectives are:

1) Designing a multi-objective based CA-Markov model towards projecting the land development for the targeted year of 2020.

2) Validation of the model quantitatively and spatially based on three measures of accuracy assessment.

3) Calibration of model using a novel method based on integration of Markov chain analysis with cross tabulation analysis.

1.4 The Structure of this Thesis

The thesis is made up of five chapters. Chapter 2 addresses definition of CA-Markov model and its components. This chapter also provides a review on methods of generating the group of suitability image, and model validation and calibration approaches especially on CA-Markov projection. Chapter 3 addresses preparation of spatial datasets, multiple objectives that are involved in research, and the implemented methods to develop a multi-objective CA-Markov projection. Moreover, this chapter explains the implemented methods to validate and then calibrate the model. Chapter 4 shows the results of this research. This chapter indicates the outcomes of Analytical Hierarchy Process (AHP), data standardization, and partial suitability images of each objective. Furthermore, it describes the results of Markov chain analysis and projection of land-use change in 2008 and 2020. This chapter provides the results of model validation and calibration. Finally, chapter 5 concludes the thesis by discussion of implications of multi-objective projection of land development under CA-Markov model, validation, and calibration of developed model by a heuristic novel method, future research, and recommendations.

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