MULTIPLE OBJECTIVES HYBRID METAHEURISTIC FOR SPATIAL-BASED REDISTRICTING: THE FRAMEWORK AND ALGORITHMS

BONG CHIN WEI

A thesis submitted
in full fulfillment of the requirements for the degree of PhD in Information Technology

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2006
DECLARATION

No portion of the work referred to in this report has been submitted in support of an application for another degree or qualification of this or any other university or institution of higher learning.

Bong Chin Wei
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2006
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ABSTRACT

Redistricting is a process to divide a land surface into two or more pieces by partitioning geographical zones or districts into territories, subject to some side constraints. Redistricting is an important spatial optimisation problem because it decides the space management of a particular region and is related to location data. In more specific and scientific way, redistricting is multiple objectives combinatorial optimisation problem as it involves optimal arrangement of a group of discrete entities to satisfy various criteria for evaluating of the quality of the given arrangement or solution. Thus, there is a minimisation or maximisation objective related to each of these criteria. However, no single solution optimises simultaneously all the objectives and there is a need to select the best compromise solution. In addition, there are often a variety of competing objectives in real world situations, and perfect solution to achieve any one of the objectives may be impossible. A very obvious knowledge gap exists in the current trend of methods for redistricting problem with existing real world multiple objectives natures. Consequently, this thesis aims to resolve the gap of the current trend of redistricting approaches with a framework of MODM approach. This research has designed and developed a generic multiple objectives decision support framework for redistricting to provide a more realistic perception of redistricting problems. This thesis considers the multiple objectives definition, identifies a wider range of alternatives, and describes the relationship between alternatives. The multiple objectives redistricting approach designed is called Multiple Objectives Spatial Redistricting Framework (MoSReF) and it is supported by redesigning a search strategy from a hybrid metaheuristic, called HMH. The two proposed mechanisms operate closely together to show the realities of the multiple objectives spatial redistricting problem because it considers the relationships between multiple objectives, which may be conflicting as well as complementing. The HMH incorporates the symbiotic methods of tabu search, scatter search, and path relinking that not only has a wide exploration in the search space but also avoid being trapped in a local optimal. The multiple
objectives redistricting decision-making is formulated based on a natural and open extension of simulation
models because it enables the decision-makers to understand a problem by considering it based on their
preferences and to grasp the required tradeoffs in the problem. The integration of the decision-makers’
knowledge with the multiple objectives constitutes the genuine knowledge in the complex decision-
making process. Later, the research has creatively designed and developed a workable prototype of the
proposed MosReF. The prototype developed has defined the procedures for spatial data handling,
dominancy comparison, decision-makers’ preferences, selection of scalarising function, power search with
intensification and diversification, and handling of optimal solutions set. The result and analysis of the
developed prototype has proved the applicability and effectiveness of the multiple objectives spatial
redistricting framework. The analysis of the result managed to demonstrate the concept of the multiple
objectives spatial redistricting solution to generate a pareto-optimal solution set in a reference set. The
overall performance of the developed redistricting algorithm was evaluated under different circumstances
and it clearly showed its advantages. These advantages included the result of the analysis, which is robust
given the realities and nature of multiple objectives spatial information. It also demonstrated an adequate
reflection of the district planner’s perception towards multiple objectives and their degrees of confidence
in their subjective assessment. A comparison with a MADM method also showed concrete evidence on
several aspects that the multiple objectives framework is more promising.
ABSTRAK

Pembahagian semula kawasan adalah satu proses untuk membahagikan permukaan tanah kepada dua atau lebih bahagian dengan memisahkan kawasan geografi kepada sempadan tanah dengan kekangan tertentu. Ia adalah masalah pengoptimum yang penting kerana ia memutuskan pengurusan ruang untuk sesuatu tempat dan ia berkaitan dengan data lokasi. Secara spesifik dan saintifik, pembahagian semula kawasan merupakan masalah pengoptimuman kombinasi pelbagai-objektif kerana ia melibatkan susunan satu kumpulan entiti yang bersaing bagi memenuhi pelbagai kriteria untuk penyemakan kualiti yang dihasilkan daripada susunan susunan atau penyelesaian. Oleh yang demikian, terdapat suatu objektif peminimum atau pemaksimum yang terikat kepada setiap kriteria tersebut. Walau bagaimanapun, tidak terdapat satu penyelesaian yang dapat memenuhi semua objektif pada masa yang sama dan pilihan untuk penyelesaian yang terbaik adalah diperlukan. Tambah pula, biasanya terdapat pelbagai objektif yang sering bersaing dalam situasi dunia sebenar dan penyelesaian yang sempurna yang boleh mencapai antara salah satu objektif adalah mungkin tidak wujud. Satu jurang pengetahuan yang jelas muncul dalam cara penyelesaian terkini untuk masalah pembahagian semula kawasan dengan keadaan pelbagai objektif dalam dunia sebenar. Justeru itu, tesis ini bertujuan menyelesaikan jurang kecenderungan bagi kaedah terkini dengan rangka kaedah pemutusan pelbagai objektif. Oleh itu, kajian ini telah mereka dan menghasilkan satu rangka bantuan pemutusan pelbagai objektif yang generik untuk menyediakan satu persepsi yang realistik bagi masalah pembahagian semula kawasan. Tesis ini mempertimbangkan definisi pelbagai objektif, mengenalpasti pilihan lain yang lebih luas, dan menggambarkan hubungan antara pilihan lain dengan jelas. Penyelesaian masalah pembahagian kawasan yang direka dipanggil sebagai Rangka Kerja Pembahagian Semula Spatial Pelbagai Objektif (Multiple Objectives Spatial Redistricting Framework (MoSReF)) dan ia disokong dengan mereka semula satu strategi pencarian daripada gabungan cara metaheuristic, dipanggil HMH. Dua mekanisma dicadangkan untuk beroperasi bersama-
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<tr>
<td>AHP</td>
<td>Analytical Hierarchical Process</td>
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<tr>
<td>ATSF</td>
<td>Achievement Tchebycheff Scalarising Function</td>
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<tr>
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<td>Decision-maker</td>
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<tr>
<td>ELETRE</td>
<td>Elimination and Choice Translating Reality</td>
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<td>SS</td>
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<td>WAMCF</td>
<td>Weighted Additive Multiple Criteria Function</td>
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Chapter 1 Overview

1.1 Introduction

The process of redistricting involves the division of a land surface into two or more pieces (Leach and Kandel, 1993). According to Bozkaya et al. (2003), the aim of redistricting is to partition geographical zones or districts into territories, subject to some side constraints. Redistricting process is not only relevant to election system, but is also needed in school, business, law enforcement and even forests related planning system. Redistricting is tremendously important as it determines the management of the space of a particular region. According to Agnew (1994), "The spaces within which political, social, cultural, and economic processes unfold are not simply static backdrops or locations reference for human events, but the products of distinct territorial structures, identities, and ambitions, and are deeply implicated in social and political changes". Therefore, in the process of redistricting, it is important to redraw the lines of a district based on the social and natural changes from time to time.

"Seeing relationships based on geography" is the selling point today for many practical oriented fields and 80 percent of decisions by state and local government involve a spatial component either directly or indirectly (Laurini and Thompson, 1992). Geographers are used to thinking spatially, and geography has some common intellectual roots related with spaces. Therefore, the study of spatial redistricting decision support system looks at a discipline that provides formalisms and theories fundamental to the management of space and automations of the land division process.
Redistricting can be classified as a location search problem, which involves the search for an appropriate location for an activity; and the spatial relationships between defined demand and facility (Church, 1999). Nevertheless, the coverage on redistricting in Geographical Information System (GIS) journals and magazines makes it clear that the attention of technical staff in redistricting area is very much taken up with the acquisition and preparation of data. For this purpose, a full ‘generic’ range of multiple objectives redistricting decision support model with the help of GIS functionality is quite appropriate (Horn, 1999).

In addition, redistricting process involves specialised requirements and it is normally carried out as a distinct activity (Alvanides and Openshaw, 2001; Fischer, 2000). Information uncertainty and conflict management are critical issues that may emerge in evaluating alternatives (Vreeker et al., 2002). Therefore, it is useful to have the multiple objectives redistricting decision support in GIS environment to provide assistance in making redistricting plans. It will help to investigate the performance in satisfying a set of relevant criteria for the “optimal solutions”, which aims at achieving a desired degree of balance between the competing objectives.

1.2 Background of the study

Throughout this thesis, the term redistricting is synonymous with and sometimes used interchangeably with classification, clustering, partitioning, segmentation, aggregation and the creation or generation of zones, territories, beats (as in police) or routes (as in vehicle). According to Helbig et al. (1972), redistricting and its consequences, should not be taken lightly. Redistricting is a problem on the aggregation of some physical phenomena such as human distribution into location or zonal pattern with respect to multiple natural or artificial criteria thereby allowing man to be served by existing limited facilities or for some human activities. It has two main tasks: spatial data aggregation; and functions to be optimised subject to certain constraints. The aggregation process is due to space constraints or scarce resources. The optimisation process helps to avoid transportation problem due to natural geography. It also helps to provide a fundamental platform for analysis and study of a more dynamic human behaviour.
or needs. In short, redistricting problem is both a spatial optimisation problem and a multiple criteria decision problem.

1.2.1 Redistricting a spatial decision problem

Redistricting is geographically related and it is certainly a spatial optimisation problem. Spatial is a term that refers to location data for objects positioned in any space that are not just geographical (Laurini and Thompson, 1992). This term will be used in this research to denote world space. Spatial data are special compared to data usually stored in databases because it has to deal with an infinite number of points in space, not a fixed number of entities. Therefore, analysis for spatial data is concerned with the distribution of spatial objects represented as points, lines and polygons (Sadahiro and Umemura, 2000). Spatial data are different compared to non-spatial data. They are special because of its continuity in space and multi-dimensionality. A significant amount of spatial information is being created, updated and manipulated on a daily basis (Murray, 1999). The analysis of spatial data is called spatial analysis. Spatial analysis has led to the view of a key area for geographical concerns on the analysis of the aggregation of spatial information into zones (Rustiadi and Kobayashi, 2001).

In a general perspective, redistricting is a normative spatial model for dividing land into territories for schools, sales or services, voting, and others for identifying sites or patterns of sites to provide service accessibility. As classified by Church and Sorensen (1996), it has to serve two main purposes: to describe the reason for the choice of the existing facility locations; and to prescribe the selection of a new location in a general location model. Redistricting is extremely important because all human activities involve choices of location, either explicitly or implicitly. It also gathers and records location data, or searches for optimal location for an economic function like warehousing and distribution. Therefore, polygon-redistricting problem is a capacity constrained 0/1 assignment problem. It is not a problem of locating facilities, but of dividing territory. Location-allocation cannot solve redistricting with capacity constraints,