UNIVERSITI PUTRA MALAYSIA

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By

VINI INDRIASARI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirement for the Degree of Master of Science

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Dedicated to my Mom and Dad,
my elder sister Resy and my younger brother Danang

October 2008, Serdang, Malaysia

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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Chairman : Associate Professor Ahmad Rodzi Mahmud, PhD

Faculty : Engineering

Conventional facility location models only define a facility's service area simply as a circular coverage. Such definition is not appropriate for emergency facilities like fire stations and ambulances, as the services are influenced by road accessibility. To improve service area definition in conventional models, this study developed the model that utilizes the capability of GIS to define service areas as travel time zones generated through road network analysis. The objective of the model is to maximize total service area of a fixed number of facilities. Hence it is called the Maximal Service Area Problem (MSAP). The MSAP is a discrete model where a specified number of facilities that achieve the best objective function value of the model are selected out of a finite set of candidate sites. A method involving multi criteria analysis was introduced to determine candidate sites in a per zone basis. Particular geometric figures commonly used for tessellations, like hexagon and square, were utilized to divide the study area into zones of equal size. The candidate sites were then chosen from the sites that have the highest value of the site suitability index within each zone, combined with the sites of existing facilities. Fire stations in

Jakarta Selatan were chosen for simulation. Two algorithms, Greedy Adding (Add) and Greedy Adding with Travel Time Evaluation (GAT), were applied to solve the optimization problem of the MSAP. The planar space of demand region was divided into regular points to simplify calculation of area of coverage. The number of points intersecting with the set of service area polygons (z) was used as the surrogate information to measure the actual area of coverage (A). This way has made the optimization process faster. In a fine resolution of demand points, percentages of coverage based on z and A values were not much different. Hence, the z values were sufficient to measure solution qualities yielded by the algorithms. Integration of the site suitability evaluation and tessellations has been proved workable to obtain scattered candidate sites that allow good solutions to be achieved in the optimization process. Of four simulations conducted, both Add and GAT yielded better coverage than the existing coverage with the same number of fire stations within the same travel time. Add managed to reach the best 82.81% coverage and GAT did 81.68%, whereas the existing only reaches 73.69%.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

INTEGRASI WILAYAH MASA PERJALANAN BAGI PENENTUAN LOKASI OPTIMAL FASILITI KECEMASAN

Oleh

VINI INDRIASARI

Ogos 2008

Pengerusi : Profesor Madya Ahmad Rodzi Mahmud, PhD

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Model lokasi fasiliti konvensional hanya mendefinisikan kawasan perkhidmatan suatu fasiliti sebagai kawasan bundar. Definisi semacam ini tidak tepat untuk fasiliti kecemasan seperti balai bomba dan ambulan, kerana perkhidmatan kedua jenis fasiliti tersebut dipengaruhi oleh laluan jalan raya. Untuk memperbaiki definisi kawasan perkhidmatan dalam model konvensional, kajian ini membangun sebuah model yang memanfaatkan kemampuan GIS untuk mendefinisikan kawasan perkhidmatan sebagai wilayah masa perjalanan yang dibuat melalui analisis jaringan jalan. Objektif model tersebut adalah memaksimakan keseluruhan keluasan perkhidmatan dari jumlah fasiliti yang tertentu. Kerana itu ia dinamakan sebagai *Maximal Service Area Problem* (MSAP). MSAP merupakan model diskrit dimana satu set fasiliti yang mencapai nilai objektif model paling baik akan dipilih dari satu set terhad lokasi cadangan. Satu kaedah yang melibatkan analisis multi kriteria diperkenalkan untuk menentukan lokasi-lokasi cadangan pada setiap wilayah. Bentuk-bentuk geometri tertentu biasanya digunakan dalam teselasi, seperti heksagon dan segi empat, dimanfaatkan untuk membahagi kawasan kajian ke dalam

beberapa wilayah berukuran sama. Lokasi-lokasi cadangan kemudian dipilih dari tapak-tapak yang memiliki nilai indeks kesesuaian tapak tertinggi dalam setiap wilayah, digabungkan dengan lokasi-lokasi fasiliti yang sedia ada. Balai bomba di Jakarta Selatan dipilih untuk simulasi. Dua algoritma optimisasi, *Greedy Adding* (Add) dan *Greedy Adding with Travel Time Evaluation* (GAT), dipakai untuk menyelesaikan persoalan optimisasi dari model MSAP. Ruang selanjar pada kawasan permintaan dibahagi ke dalam titik-titik beraturan untuk memudahkan penghitungan keluasan perkhidmatan. Jumlah titik-titik yang jatuh dalam satu set poligon kawasan perkhidmatan (z) digunakan sebagai informasi pengganti untuk mengukur keluasan perkhidmatan sebenar (A). Cara ini membuat proses optimisasi menjadi lebih cepat. Dengan resolusi titik-titik yang baik pada kawasan permintaan, peratusan liputan berdasarakan nilai z dan A tidak terlalu berbeza. Jadi, nilai z cukup untuk mengukur kualiti penyelesaian yang dihasilkan oleh algoritma. Integrasi penilaian kesesuaian tapak dan teselasi telah terbukti dapat digunakan untuk memperoleh lokasi-lokasi cadangan yang menyebar sehingga memungkinkan penyelesaian yang baik dicapai dalam proses optimisasi. Dari empat simulasi yang dilakukan, baik Add dan GAT berjaya menghasilkan liputan yang lebih baik daripada liputan yang sedia ada, dengan jumlah balai bomba yang sama dalam masa perjalanan yang sama pula. Add berjaya mencapai liputan terbaik 82.81% dan GAT berjaya mencapai 81.68%, sementara liputan yang sedia ada hanya mencapai 73.69%.

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I certify that an Examination Committee has met on 26 August 2008 to conduct the final examination of Vini Indriasari on her Master of Science thesis entitled "Integration of Travel Time Zone for Optimal Siting of Emergency Facilities" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the student be awarded the Master of Science.

Members of the Examination Committee were as follows:

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

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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.

VINI INDRIASARI

Date: 28 October 2008

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LIST OF ABBREVIATIONS

AHP	Analytical Hierarchy Process
BB	Branch and Bound
DEM	Digital Elevation Model
DLL	Dynamic Link Library
FLP	Facility Location Problems
GA	Genetic Algorithm
GAS	Greedy Adding with Substitution
GAT	Greedy Adding with Travel Time Evaluation
GIS	Geographic Information Systems
GRIA	Global Regional Interchange Algorithm
ILP	Integer Linear Programming
LADSS	Location Analysis Decision Support System
LOLA	Library of Location Algorithms
LP	Linear Programming
LSCP	Location Set Covering Problem
MCDM	Multi Criteria Decision Making
MCLP	Maximal Covering Location Problem
MECP	Maximal Expected Covering Problem
MSAP	Maximal Service Area Problem
OR	Operations Research
PCP	P-Center Problem
PMP	P-Median Problem
RAM	Random Access Memory
RDBMS	Relational Database Management System
SA	Simulated Annealing
SQL	Structured Query Language
T&B	Teitz and Bart
TIN	Triangulated Irregular Networks
TS	Tabu Search

GLOSSARY OF TERMS

Heuristic	A term derived from the same Greek root as Eureka, heuristic refers to procedures for finding solutions to problems that may be difficult or impossible to solve by direct means. In the context of optimization, heuristic algorithms are systematic procedures that seek a good or near optimal solution to a well-defined problem, but not one that is necessarily optimal. They are often based on some form of intelligent trial and error or search procedure.
Operations Research (OR)	An interdisciplinary branch of mathematics which uses methods like mathematical modeling, statistics, and algorithms to arrive at optimal or good decisions in complex problems which are concerned with optimizing the maxima or minima of some objective function. The eventual intention behind using Operations Research is to elicit a best possible solution to a problem mathematically, which improves or optimizes the performance of the system.
Tessellation	A gridded representation of a plane surface into disjoint polygons. These polygons are normally rectangular, triangular, or hexagonal. These models can be built into hierarchical structures, and have a range of algorithms available to navigate through them. A (regular or irregular) 2D tessellation involves the subdivision of a 2-dimensional plane into polygonal tiles (polyhedral blocks) that completely cover a plane. More generally the subdivision of the plane may be achieved using arcs that are not necessarily straight lines.

CHAPTER 1

INTRODUCTION

This chapter provides the background of the study, problem statement, objective of the study, and the scope of work for the study. The last section explains how this thesis is organized to present the entire research in a structured manner.

1.1 Background

Studies about facility location problems (FLP), also known as Location Science, have appeared in the literature since the early of 1970s, even earlier. Problems in facility location were usually denoted as optimization problems which should be solved by certain algorithms in order to optimize single or multiple objective functions. The objective is either to minimize costs or to maximize benefits. The problems include locating hospitals, schools, power plants, ambulances, fire stations, pipelines, conservation areas and warehouses.

Today, with the advent of Geographic Information Systems (GIS) and sophisticated computer technology, decision making in facility site selection can be enhanced into a larger dataset with more complicated data structures, more accurate spatial measurement, spatial analysis and spatial modeling. GIS capability to represent spatial objects as points, line, or polygons has increased the flexibility of entity representations in facility location modeling into various data models. Furthermore, GIS capability to perform surface modeling allows location science to extend its version into 3-dimensional problems.

Several studies have integrated GIS into location modeling. However, there are still some GIS capabilities yet to be explored thoroughly, requiring further investigation into how they may be effectively implemented to improve solutions for facility location problems. This study is intended to improve location analysis and solution quality to the FLP by integrating GIS and location science.

1.2 Problem Statement

Conventional facility location models in pure Operations Research (OR) framework only define a facility's service area simply as a circular-shaped region based on a specified radius. Such definition might be appropriate for facilities which are not influenced by topographical barriers, like sirens or telecommunication transmitters. But for emergency facilities like fire stations and ambulances, accessibility is an important requirement. Therefore, road accessibility should be taken into account in emergency facility location problem to improve emergency services.

GIS can serve this requirement through network analysis. Network analysis in GIS takes into account network attributes such as road width, speed limit, barriers, turn restriction and one way restriction. This advantage provided by GIS should be incorporated in the service area calculation to obtain a more realistic model.

In term of regional demand, service coverage modeling typically divides the region into smaller zones, and the zones are aggregated into nodes located at their centers. This aggregation inevitably reduces the accuracy of spatial measurements between zones. It is necessary to find a way to treat demand of planar space as a complete region without performing data aggregation.

1.3 Objective of the Study

The objective of the study is to develop a facility location model in continuous demand region, with road accessibility considerations. This is performed by integrating travel time zone generated through road network analysis in GIS into emergency facility location problem.

1.4 Scope of the Study

This study concerns with facility location modeling that integrates GIS into the conventional model. Following common procedures in the studies of facility location modeling, the scope of work for this study include:

a. Establishment of the concept and characteristics of the model. This should clarify the objective of the model, for what facilities the model is addressed, backdrops that stimulate the development of the model, what conventional model to be modified, whether the model is designed as a planar, network or discrete model, what GIS functions to be integrated and how the integration will be implemented to improve location analysis and solution quality to the problem.

b. Formulation of the mathematical model. In order to solve the optimization problem of the model mathematically, the model must be formulated in the form of mathematical equation. Formulation of the model will be depending on geometric representation used for facility and demand entities.

c. Design of solution algorithms. The optimization problem of the model must be solved by optimization algorithms. This step should determine appropriate algorithms to solve the problem. Many algorithms are problem specific. That is, they need to be designed specifically according to the complexity of the problem, data size, desired solution quality, limit of processing time and other considerations.

d. Comparison of solutions obtained by the algorithms with different datasets. This should examine the performances of the algorithm in providing good solutions to the problem. Are the solutions optimal enough with the applied algorithms? Can better solutions be obtained with more advance algorithms? In this study, the solutions yielded are also compared with the existing condition to see how far the proposed method could improve the existing facility services.

In more general scope, the study also introduces a method for the site selection process that incorporates a multi-criteria analysis in GIS. The location modeling becomes a part of the whole site selection process.

1.5 Thesis Organization

This thesis is organized into 5 chapters. First chapter contains introductory materials. These comprise the background of the study, problem statement, the objective of the study and the scope of the study.

Chapter 2 is for literature review. The review is addressed to acknowledge facility location models appeared in the literature, explain and discuss the well-known algorithms employed to solve FLP, analyze the link between GIS and location