OPTIMIZATION OF AMBULANCE LOCATION MODEL USING MAXIMAL COVERAGE LOCATION PROBLEM AND GRADUAL COVERAGE LOCATION PROBLEM

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Dedicated to my beloved parent, siblings and future wife.

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ABSTRACT

Emergency Medical Services (EMS) in Malaysia was categorized as underdeveloped emergency care system in 1990s. This was due to the lack of specialty in emergency medical systems and academic activities. By 2007, EMS in Malaysia has been significantly improved and is categorized as in developing phase. In October 2007, Malaysia Emergency Response Services 999 was introduced to combine several emergency service numbers as one emergency number 999. However, Malaysia is still lack of academic contribution in EMS optimization research. One of the ways to improve the efficiency of EMS delivery is the application of ambulance location model. The ambulance location model is used to find the best locations to place ambulances. In this research, a grid map based on Johor Bahru population is created. Euclidean distance is used as distance measurement in the map. Two ambulance location models, Maximal Coverage Location Problem (MCLP) and Gradual Coverage Location Problem (GCLP) are developed, and strategic ambulance location sites in the developed map are solved using Particle Swarm Optimization algorithm. The performances of both models are then measured using the developed simulator by analyzing ambulance response time, simulation coverage, total travel distance and ambulance preparedness. Different settings including current Johor Bahru EMS settings are simulated using the simulator. By using the simulator, advantages and disadvantages of different models are successfully addressed. Simulation results show that EMS setting in Johor Bahru is the least optimized and in most cases, GCLP is better than MCLP. For the deployment of 7 ambulances at 10 km coverage radius, the ambulance response time for setting GCLP is 5.5 minutes, which is lower than setting MCLP (7.4 minutes), and setting hospital (7.02 minutes).

ABSTRAK

Sistem Perubatan Kecemasan (EMS) di Malaysia telah dikategorikan sebagai ketinggalan pada tahun 1990an. Ini adalah disebabkan kekurangan pengkhususan dalam bidang perkhidmatan perubatan kecemasan dan aktiviti akademik. Pada 2007, EMS di Malaysia telah bertambah baik dan dikategorikan di dalam fasa yang sedang berkembang. Pada bulan Oktober 2007, Servis Respons Kecemasan Malaysia 999 telah diperkenalkan untuk menyatukan beberapa nombor perkhidmatan kecemasan ke dalam satu nombor perkhidmatan kecemasan 999. Bagaimanapun Malaysia masih kekurangan sumbangan penyelidikan akademik untuk EMS. Satu daripada cara memperbaiki keberkesanan penghantaran EMS adalah penggunaan model lokasi ambulans. Model lokasi ambulans digunakan untuk mencari tempat yang paling sesuai bagi menempatkan ambulans. Dalam penyelidikan ini, peta grid berdasarkan populasi Johor Bahru dilukis. Jarak Euclid digunakan untuk pengiraan jarak di dalam peta. Dua model lokasi ambulans, Masalah Liputan Lokasi Maksima (MCLP) dan Masalah Liputan Lokasi Beransur (GCLP) dibangunkan, dan lokasi ambulans yang strategik dalam peta diselesaikan menggunakan algoritma Pengoptimuman Kumpulan Partikel. Prestasi bagi kedua-dua model kemudiannya diukur menggunakan simulasi dengan menganalisis masa respons ambulans, liputan simulasi, jumlah jarak perjalanan dan kesediaan ambulans. Beberapa pengesetan digunakan termasuk pengesetan EMS untuk Johor Bahru pada masa ini disimulasikan menggunakan simulator. Jadi, kelebihan dan kekurangan pada model-model yang berlainan dapat diketahui. Keputusan simulasi menunjukkan pengesetan EMS di Johor Bahru adalah paling tidak optima dan pada kebanyakan kes, keputusan GCLP adalah lebih baik daripada MCLP. Untuk pengunaan 7 ambulans pada 10 km jejari liputan, masa respons ambulans untuk pengesetan GCLP adalah 5.5 minit, adalah kurang daripada pengesetan MCLP (7.4 minit), dan pengesetan hospital (7.0 minit).

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LIST OF SYMBOLS

c_1	-	*pbest* coefficient
c_2	-	*gbest* coefficient
D_d	-	Developed map Euclidean distance
D_g	-	Google Euclidean distance
d_i	-	Demand value at point *i*
E_{rr}	-	Error of developed map
$f(r)$	-	Decay function
$gbest^i$	-	The best position among all particles
i	-	Demand point
j	-	Possible ambulance location site
N_j	-	total ambulances that contribute to preparedness in zone *j*
p	-	Number of ambulances to be located
$pbest^i$	-	The best position of particle *i*
r	-	Distance from a point *i* to a location site *j*
R_{max}	-	Large coverage radius
R_{min}	-	Small coverage radius
s_k^i	-	PSO position at particle *i* and k^{th} iteration
v_k^i	-	PSO velocity at particle *i* and k^{th} iteration
V	-	A set of demand points
w_k	-	Inertia weight at k^{th} iteration
W	-	A set of possible location site
x_j	-	Binary variable for location site *j*
y_i	-	Binary variable for demand point *i*
γ^n	-	Contribution factor of ambulance *n*

LIST OF ABBREVIATIONS

ADP	-	Approximate dynamic programming
ALM	-	Ambulance location model
ART	-	Ambulance response time
BACOP1	-	Backup coverage model
BACOP2	-	Backup coverage model
EMS	-	Emergency medical services
FLEET	-	Facility-location, equipment-emplacement technique
GCLP	-	Gradual covering location problem
GA	-	Genetic Algorithm
GMCLP	-	Generalized maximal covering location problem
GUI	-	Graphical user interface
HP	-	Hospital Permai
HSA	-	Hospital Sultanah Aminah
HSI	-	Hospital Sultan Ismail
JB	-	Johor Bahru
LSCM	-	Location set covering model
MALP	-	Maximum availability location problem
MBJB	-	Majlis Bandaraya Johor Bahru
MCLP	-	Maximal covering location problem
MERS999	-	Malaysian Emergency Response Services 999
MEXCLP	-	Maximum expected covering location problem
MOH	-	Ministry of Health
MPJBT	-	Majlis Perbandaran Johor Bahru Tengah
NP-Hard	-	Non-deterministic polynomial-time hard
PLSCP	-	Probabilistic location set covering problem

PSO	-	Particle swarm optimization
TEAM	-	Tandem Equipment allocation model

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Emergency medical services (EMS) refer to emergency services that provide immediate medical care to people that most need it. EMS can reduce fatalities from cases such as heart attack and accident by having a short response time to serve the patient or victim at the call scene.

Arnold (1999) categorized Malaysia as underdeveloped EMS in 1990s**.** In underdeveloped EMS there are no specialty and academic activities for emergency medicine, and injured patients are usually transported to hospital using taxi or private cars. In 1997, there was still no EMS in Kuala Lumpur, the capital of Malaysia (Hauswald and Yeoh, 1997). Since the offering of EMS training program, there were growing number of EMS providers in Malaysia. By 2007, EMS in Malaysia has been significantly improved and is categorized as in 'developing' phase by Hisamuddin *et al.* (2007).

Ng and Ghani (2006) develop a model to predict ambulance service travel times in Penang. Medical information and emergency systems in Malaysia still has several drawbacks.

Most of medical information and emergency systems in Malaysia is still paper based and stand alone systems which does not completely utilize the availability of latest technology such as internet and wireless technologies (Hameed *et al*., 2010). To overcome this Hameed *et al*. (2010) develop a system that integrates a number of medical services such as medical emergency, medical information and healthcare, into one integrated system. However no optimization of EMS delivery is mentioned.

Since October 2007, several emergency service numbers have been combined as one emergency number 999. The service is known as Malaysia's Emergency Response Service 999 (MERS 999) (Ministry of Health Malaysia, 2009). A single number is used for five emergency service providers, namely ambulances, police, fire and rescue department, maritime enforcement and civil defense.

Prior to implementation of MERS 999 system, an average of 20 seconds is used by an operator to validate a call (Kunakornpaiboonsiri, 2012). A call must be first validated by an operator to be a genuine call before being transferred to the corresponding service provider. Through MERS 999 system, it is expected to achieve the target response time of 15-30 minutes. MERS 999 system is also equipped with ProQA by International Academy Emergency Dispatch (IAED), a system which offers automated tools for prehospital patient care. Some of the benefits of using ProQA are: it is an established standard of services; a call can have quality assurance and benchmarking; and, it reduces liability by enabling prioritized responses. In MERS 999 system, an ambulance is required to arrive on the incident site within 30 minutes, if the distance from the responding hospital is within 5 km. Besides, the ambulance must reach the receiving hospital within an hour after being dispatched.

In this research, there are a number of contributions. A grid based map on Johor Bahru (JB) has been created for EMS simulation. Gradual Coverage Location Problem (GCLP) is validated to be better than Maximal Coverage Location Problem (MCLP) using the developed map.

1.2 Problem Statement

There is lacking of study in Malaysia that focuses on EMS delivery optimization through application of ambulance location model (ALM). Other researches related to EMS in Malaysia (Hauswald and Yeoh, 1997; Ng and Abdul Ghani, 2006; Hameed *et al.*, 2010) do not consider the performance of EMS delivery. Previous work by Lim (2011) considers the performance of EMS delivery although by using hypothetical region. This research further expands the work from Lim (2011), by applying and comparing the performance of two ALMs using real map data.

1.3 Objectives of Research

Lim *et al.* (2011) use hypothetical region on a grip map to measure the effectiveness of MCLP and dispatch policies through simulation. In this project, we extend the research by using the map of JB that is partitioned into grid. MCLP and GCLP are used to identify strategic ambulance location sites and the delivery performances are compared through EMS simulation. Effect of using Euclidean distance instead of real road map is discussed. The objectives of this research are as follow:

1. To convert actual JB map into grid region with the resolution of 40 km x 30 km.

2. To apply PSO algorithm to solve ALMs.

3. To analyze the performance of MCLP and GCLP.

1.4 Scope of Project

A simulator is developed using Mac OSX Mountain Lion operating system and coded in Objective-C. A map of JB partitioned into grid is created and demands are generated from population data provided by MBJB and MPJBT. The area of JB is about 1200 km^2. Total population, as given by MBJB and MPJBT is about 1,500,000. Calls data is generated using the simulator. Ambulance locations sites are found using MCLP and GCLP solved by PSO algorithm. To measure distance between two points in the map, Euclidean distance is used. The speed of the ambulance in the simulator is fixed at 60 km/h. Emergency call data is generated based on population data. The simulator is designed so that EMS delivery performance based on ART, coverage and preparedness can be evaluated using different EMS settings applied. An analyzer within the simulator is developed so that the performance of the chosen settings can be quickly evaluated and shown in graph with different metrics. The scope of the project is summarized in Table 1.1.

Table 1.1: Scope of the project

Parameter	Scope
Simulator	Coded in Objective-C on Mac OSX Mountain Lion operating system
Area of simulation	Map of JB partitioned into grid
Size of the grid area	1200 km^2
Population size	1,500,000 (MBJB and MPJBT)
Method of distance measurement	Euclidean distance
Ambulance speed	Constant speed of 60 km/h
ALM	MCLP and GCLP
Algorithm	PSO algorithm
Emergency call data	Generated based on population data
Performance measurement	ART, demand coverage and preparedness

1.5 Research Methodology

A literature review is first carried out to find the potential improvement that can be applied to EMS in Malaysia. Academic contributions for EMS optimization in Malaysia are very limited. Lim *et al*. (2011) use hypothetical region of 4096 km^2 and the evaluated MCLP does seem work well with mentioned area. Though, JB is only about 1200 km^2, a real map data and two ALMs are used in this project. GCLP has been chosen to benchmark with MCLP.

After gathering the necessary information, EMS simulator is developed. Simulator created in this research consists of three components which are map creator, location solver and EMS simulator. All three simulator components are crucial for simulation. The components are developed in parallel and improved from time to time. Map is created using map creator, and all the necessary data such as demands, potential ambulance location sites, hospital and emergency call scenes are created using map creator. By using location solver, strategic ambulance location sites can be solved. PSO algorithm and exact method are developed in location solver and used to find the best ambulance location sites for MCLP or GCLP. EMS simulator takes data from the other simulator components to simulate a complete EMS operation. All functions related to the simulation are integrated into EMS simulator which are call queuing method, call assignment and ambulance dispatch policy. Preparedness which enables the operator to observe preparedness dynamically for each zone is also integrated into EMS simulator.

To validate PSO algorithm, the same problem from Lim *et al*. (2011) is solved by using the developed PSO algorithm. Same settings are used so that an equal result is obtained. After that, grid map based on JB is created. The process for creating the map is explained in Chapter 3. Then, potential ambulance location sites and hospital are set using map creator. Emergency calls are then generated based on demands on the map. For both MCLP and GCLP, strategic ambulance location sites for different number of ambulances are solved using PSO algorithm. Result of strategic ambulance location sites is used by EMS simulator to simulate EMS operations. Multiple settings, including the current EMS settings are simulated in EMS simulator. The results of the settings are then analyzed and concluded. Research methodology is summarized in Figure 1.1. It shows how the research is completed from literature review until the outcome of the research.

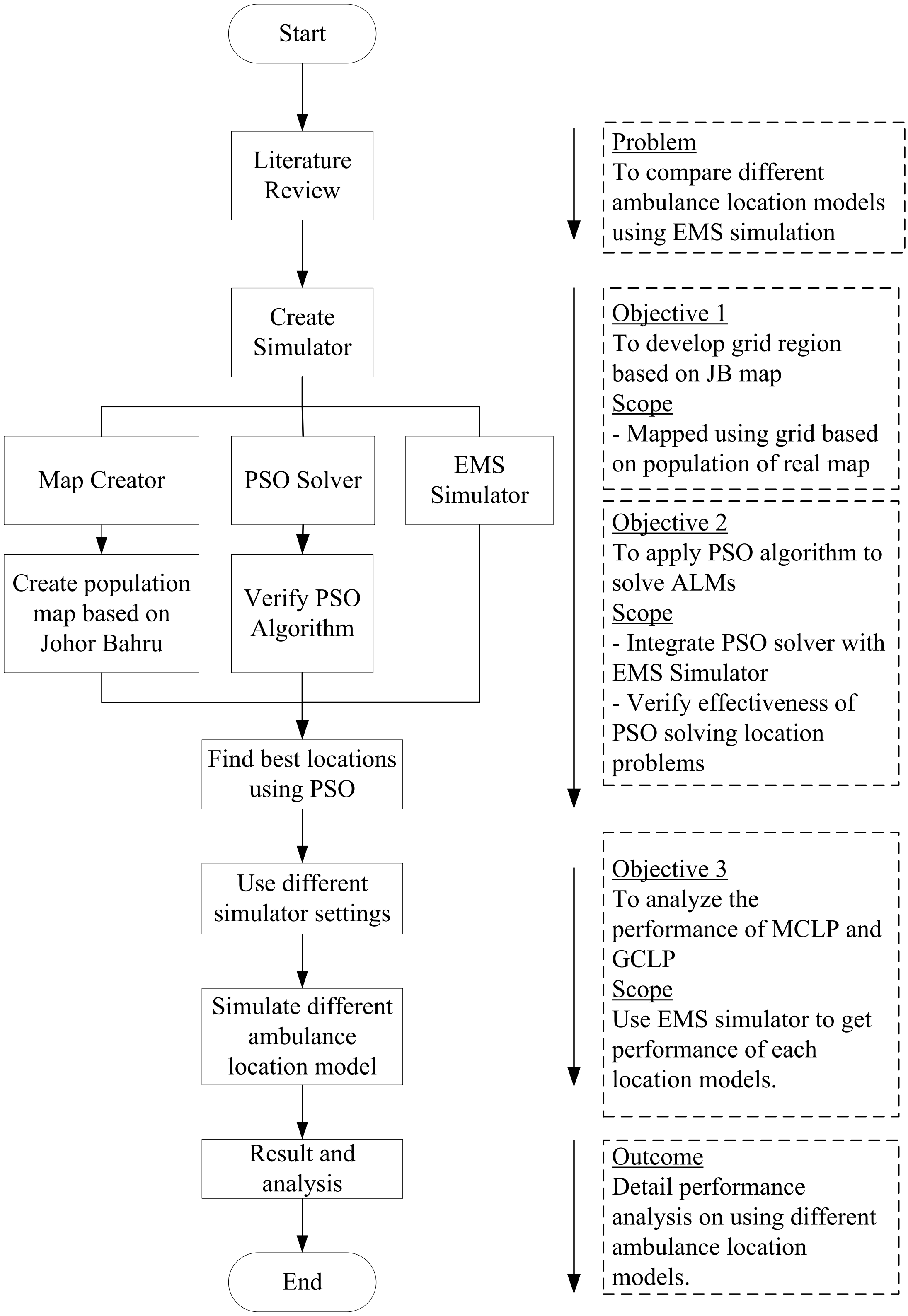

Figure 1.1: Research flowchart

1.6 Thesis Outline

The rest of the thesis is organized as followed. In Chapter 1, introduction to this research is explained including problem statement, research objective and methodology. In Chapter 2, literature review of academic work related to this research is reviewed. The reviews include criteria defining EMS performance, ALM such as MCLP and its extension, variety of coverage models, simulation works pertaining to this research, and PSO algorithm. Chapter 3 presents the used algorithm and the development of EMS simulator in detail. Meanwhile, Chapter 4 presents the finding of this research. Result of the simulations and discussion are given. Lastly, Chapter 5 concludes this research and proposes the future directions of the project.

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