EMERGENCY MEDICAL SERVICES DELIVERY PERFORMANCE BASED ON REAL MAP

MOHD HAFIZ BIN AZIZAN

UNIVERSITI TEKNOLOGI MALAYSIA

EMERGENCY MEDICAL SERVICES DELIVERY PERFORMANCE BASED ON REAL MAP

MOHD HAFIZ BIN AZIZAN

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Engineering (Electrical)

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

JANUARY 2014

Dedicated to my beloved parents, siblings and friends.

ACKNOWLEDGEMENTS

First and foremost, I would like to use this great opportunity to express my sincere gratitude to my supervisor, Dr. Lim Cheng Siong for the continuous support of my study. His motivation, guidance, patience and valuable comments have helped me a lot on the long journey to finish my research and completing of this thesis. Without his continuous support, the objectives of this study would not be accomplished as expected.

I also would like to extend my sincere thanks to MPJBT personnel, Ms. Salidah Selamat for her cooperation in providing the GIS data. Warmest thanks go to Malaysia Government for giving me the scholarship to further my study in master degree. I am thankful to Universiti Teknologi Malaysia (UTM) as well for granting the Research Student Grant (RSG) under the Research University Grant (GUP) to provide a financial support throughout my study.

Besides, I would like to thank my friends for their encouragement and involvement during completing my research. Finally, I would like to express my deepest appreciation to my beloved family for their love and endless encouragement. Their enormous support has given me the strength to complete my study successfully. Thanks again for all of you.

ABSTRACT

Performance of emergency medical services delivery is normally benchmarked via ambulance response time. Quick ambulance response can efficiently reduce the disability and mortality of emergency patients. Ambulance dispatch policy and location model both have a significant impact on the response time. A proper dispatch policy can determine the right ambulance for the incoming emergency call. Meanwhile, the use of location model can increase the ambulance coverage. Nevertheless, the applications of both dispatch policy and location model are yet to be seen in Malaysia ambulance services. There is also a lack of academic contributions focusing on a simulation study of emergency medical services in Malaysia, especially those using local geographic information. In this research, a simulation framework is presented to study the response time performance of a simulation model that consists of both the dispatch policy and location model. Several real-life dispatch policies were simulated in a real map by using actual geographic information to evaluate the efficiency of ambulance services in Johor Bahru. By using a suitable dispatch policy, the simulation results show an improvement in average response time for higher-priority call while the total covered calls have increased significantly with the application of maximal covering location problem. At nine ambulances, the achieved maximum coverage is 68% for using the location model compared to merely 45% prior to the implementation.

ABSTRAK

Prestasi penghantaran perkhidmatan perubatan kecemasan biasanya dinilai melalui masa tindak balas ambulans. Tindak balas ambulans yang pantas boleh mengurangkan kecacatan dan kadar kematian pesakit kecemasan. Polisi penghantaran ambulans dan model lokasi ambulans kedua-duanya mempunyai kesan yang ketara terhadap masa tindak balas. Polisi penghantaran yang baik boleh menentukan ambulans yang sesuai untuk dihantar ke tempat kecemasan. Sementara itu, penggunaan model lokasi boleh meningkatkan liputan ambulans. Walau bagaimanapun, penggunaan polisi penghantaran dan juga model lokasi masih belum dapat dilihat dalam perkhidmatan ambulans di Malaysia. Selain itu, terdapat juga kekurangan sumbangan akademik yang memberi tumpuan kepada kajian simulasi terhadap prestasi penghantaran perkhidmatan perubatan kecemasan di Malaysia terutamanya yang menggunakan maklumat geografi tempatan. Dalam penyelidikan ini, satu rangka kerja simulasi dibentangkan untuk mengkaji prestasi masa tindak balas ambulans bagi model simulasi yang terdiri daripada polisi penghantaran dan juga model lokasi. Beberapa polisi penghantaran telah disimulasikan dengan menggunakan peta dan maklumat geografi sebenar untuk menilai kecekapan perkhidmatan ambulans di Johor Bahru. Dengan menggunakan polisi yang sesuai, hasil simulasi menunjukkan terdapat peningkatan dalam masa tindak balas purata bagi panggilan yang mempunyai keutamaan yang lebih tinggi, sementara jumlah panggilan yang dapat dicapai dalam masa yang ditetapkan telah meningkat dengan ketara apabila masalah lokasi liputan maksimum digunakan. Pada penggunaan sembilan ambulans, liputan maksimum yang diperolehi apabila menggunakan model lokasi adalah 68% berbanding hanya 45% sebelum penggunaannya.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENTS	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENTS	vii
	LIST OF TABLES	x
	LIST OF FIGURES	xi
	LIST OF SYMBOLS	xiii
	LIST OF ABBREVIATIONS	xiv
	LIST OF APPENDICES	xvi
1	**INTRODUCTION**	1
	1.1 Introduction	1
	1.2 Background of Study	2
	1.3 Problem Statement	6
	1.4 Objectives of Research	7
	1.5 Scopes of Research	7
	1.6 Significances of Research	9
	1.7 Research Methodology	9
	1.8 Thesis Outline	12

2	**LITERATURE REVIEWS**		13
	2.1	Introduction	13
	2.2	EMS Definition	13
	2.3	EMS Key Performance Indicator	14
	2.4	Decomposition of EMS Dispatch Policy	16
	2.5	Covering Location Model	22
	2.6	Previous Simulation Works	26
	2.7	Summary	31
3	**MAP DEVELOPMENT AND EMS SIMULATION**		32
	3.1	Introduction	32
	3.2	Map Development	32
		3.2.1 Study Area	33
		3.2.2 OpenStreetMap	34
		3.2.3 Road Network	36
		3.2.4 Demand Distribution	37
	3.3	EMS Simulation	38
		3.3.1 Simulation Model	38
		3.3.2 Simulation Setup	43
	3.4	EMS Simulator	47
	3.5	Summary	48
4	**RESULTS AND DISCUSSION**		50
	4.1	Introduction	50
	4.2	EMS Simulator	50
		4.2.1 Real Map	51
		4.2.2 Network Analysis	53
		4.2.3 Demand Distribution	55
		4.2.4 Simulator GUI	56
	4.3	Simulation of Dispatch Policies	58
		4.3.1 Results of Simulation Using Hospital as Ambulance Station	58

	4.3.2	Results of Simulation Using Ambulance Location Model	61
	4.3.3	Discussion	65
	4.4	Summary	68
5	**CONCLUSIONS AND FUTURE WORK**		70
	5.1	Introduction	70
	5.2	Conclusion	70
	5.3	Limitations	72
	5.4	Direction for Future Work	73
REFERENCES			75
Appendices A-F			83 - 97

LIST OF TABLES

TABLE NO.	TITLE	PAGE
1.1	Scopes of the research	8
2.1	Advantages and disadvantages of the covering location models based on category	25
2.2	Previous simulation works in the past 10 years	30
3.1	Dispatch policies used in the simulation	45
3.2	Comparisons between a grid system and a real map	48
4.1	Simulation results for using hospital as ambulance station	60
4.2	Results of the implemented MCLP	62
4.3	Simulation results for using ALM	64
4.4	List of the main features for the developed simulator	69
5.1	List of research limitations and recommendations for future work	74

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
1.1	Flowchart of the research methodology.	11
2.1	Block diagram of ADP components decomposition.	17
3.1	Map of Johor Bahru in OpenStreetMap.	35
3.2	Main GUI of JOSM map editor.	35
3.3	The UML state diagram for the EMS delivery.	39
3.4	The main components for the simulation of a real-life EMS delivery.	40
4.1	Boundary of the study area and the road network.	52
4.2	Locations of hospital and the identified possible ambulance station within the study area. The geographic coordinates for the potential ambulance stations are given in Appendix A.	52
4.3	The shortest path between two locations in OpenStreetMap using Dijkstra’s algorithm. The blue and red flags are starting and finishing points respectively.	54
4.4	The result of the Quick Hull algorithm for ambulance station no. 14 (circled red box). The convex hull (magenta polygon) represents a perimeter of a 5-minutes coverage area for ambulance station no. 14.	54
4.5	Demands dot density map for the study area. The green and white areas represent the populated and unpopulated areas respectively.	56
4.6	Graphical representation of the running simulation on the real map.	57

4.7	Graphical representation of the MCLP results for a fleet size of four ambulances and an 8-minute time threshold.	63
4.8	Percentages of total covered calls for the first (hospital) and second (MCLP) set of simulations.	66
4.9	The relationship between the average ART and the utilization rate for hospital (a) and MCLP (b).	67

LIST OF SYMBOLS

d_i	-	Demand value at vertex i
d_i^k	-	Demand value at vertex i in residential k
D_k	-	Total demands in residential k
G	-	A traversal graph of road network
i	-	Vertex of road network / demand point
j	-	Possible location site within study area
k	-	Residential within study area
p	-	Number of ambulances to be located
S_k	-	Total vertices of road network in residential k
V	-	A set of demand points
W	-	A set of possible location site
W_i	-	A set of location site that covered demand point i
x_j	-	Binary variable for location site j
y_i	-	Binary variable for demand point i
α	-	A proportion value for total demands covered by MCLP

LIST OF ABBREVIATIONS

2-D	-	Two-dimensional space
AAM	-	Ambulance assignment method
ADP	-	Ambulance dispatch policy
ALM	-	Ambulance location model
ALS	-	Advanced life support
AMPDS	-	Advanced medical priority dispatch system
AOD	-	Add-on dispatch policy
ART	-	Ambulance response time
BACOP	-	Backup coverage model
BLS	-	Basic life support
CAD	-	Computer-aided dispatch
CBD	-	Criteria-based dispatch
CPR	-	Cardiopulmonary resuscitation
CQM	-	Calls queuing method
DACL	-	Dynamically available coverage location
$DDSM^t$	-	Dynamic double standard model
DSM	-	Double standard model
ED	-	Emergency department
e.g.	-	For example
EMS	-	Emergency medical services
GB	-	Gigabyte
GHz	-	Gigahertz
GIS	-	Geographic information services
GPS	-	Geographic positioning system
GUI	-	Graphical user interface
HOSC	-	Hierarchical objectives set covering

HP	-	Hospital Permai
HSA	-	Hospital Sultanah Aminah
HSI	-	Hospital Sultan Ismail
i.e.	-	That is
KPI	-	Key performance indicator
LPCC	-	Lower-priority calls coverage
LSCM	-	Location set covering model
MALP	-	Maximum availability location problem
MBJB	-	Majlis Bandaraya Johor Bahru
MCLP	-	Maximal covering location problem
MECC	-	Medical Emergency Call Center
MERS999	-	Malaysian Emergency Response Services 999
MEXCLP	-	Maximum expected covering location problem
MOH	-	Ministry of Health
MPJBT	-	Majlis Perbandaran Johor Bahru Tengah
NGO	-	Non-governmental organization
OS	-	Operating system
UML	-	Unified modeling language

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Geographic coordinate for ambulance station	83
B	Population data for MPJBT and MBJB	85
C	Main GUI for EMS simulator	94
D	Symbols representation	95
E	GUI for simulation settings	96
F	Example of chart for the recorded ART	97

CHAPTER 1

INTRODUCTION

1.1 Introduction

Emergency medical services (EMS) delivery is a critical part of public health, especially when it involves a life-threatening situation such as an emergency call for cardiac arrest. Commonly, the performance of EMS delivery is benchmarked based on the efficiency of ambulance services. Many studies have shown that a quick ambulance response during an emergency case can significantly increase the survival rate of emergency patients. Pell *et al.* (2001) and Vukmir (2006) have reported the existence of a positive relationship between a faster ambulance response and survival of prehospital cardiac arrest patients. Meanwhile, the performance of one-tier EMS system in urban area is studied by Blackwell and Kaufman (2002). In their findings, a response time less than five minutes could have an improved survival rate compared with a longer response time. Furthermore, Sánchez-Mangas *et al.* (2010) have suggested that the mortality rate of road traffic accidents can be reduced to one third with a 10-minute reduction of response time.

Ambulance response time (ART) is usually measured as an interval between the time when the emergency call is received by the call center and the time when the assigned ambulance arrives at the emergency scene (Sasaki *et al*., 2010). Generally, ART is used in conjunction with the coverage percentage as a standard preset value to establish a Key Performance Indicator (KPI) for EMS delivery's performance measurement. Every country has its own KPI for EMS delivery. For example, in Western Australia, the required ART is within 15 minutes, and at least 90% of total calls must be covered (Health Information and Quality Authority, 2012). On the contrary, The United States Emergency Medical Services Act stated that 95% of the received emergency calls should be served within 10 minutes and 30 minutes in urban and rural areas respectively (Ball *et al.*, 1993). The ART and the coverage percentage improvements can help an EMS provider to meet the established KPI and maintain its performance at a desired level. Therefore, both the ART and the ambulance coverage are vital components in studying the performance of EMS delivery.

1.2 Background of Study

The public awareness for the need of a better ambulance service is very common in any developing country, including Malaysia. Hisamuddin *et al*. (2007) have described current Malaysia EMS delivery as in the developing phase where its importance has started to attract serious attention from the government in recent years. The traditional function of ambulance as a patient transport vehicle (i.e., scoop-and-run) has been gradually changed into a rescue service that includes on-board trained paramedics and life-support equipments.

Moreover, in 2007, Malaysian Emergency Response Services 999 (MERS999) has been introduced by the government where a single “999” telephone number is used for ambulance services nationwide. MERS999 is set to replace the previous system that has no uniform communication for ambulance services and lacks coordination between the EMS providers (Hisamuddin *et al.*, 2007; Anisah *et al*, 2008). The main objective of MERS999 system is to improve the efficiency of EMS delivery by reducing the ART (Government: MERS 999, 2013). Nevertheless, the use of a single emergency number can improve the time taken to activate the EMS delivery compared to a direct calling to a hospital emergency department (Mayron *et al.*, 1984), which can reduce the ART as well.

Any emergency call received by a call center is analyzed before any ambulance is dispatched to the emergency scene. The standard process includes call screening and classification that can help the call taker to identify the type of call, the location of call and most importantly, to ensure that the call is genuine. In April 2012, the number of prank calls reported is about 254,487, which are contributed to 12.32% of total calls received by MERS999 in a month (Rozinah, 2012). Therefore, the call identification process is essential as any false call can lead to inefficient use of resources that certainly can affect the performance of EMS delivery.

In a triage system, the emergency call is categorized based on the level of urgency. In Northern Ireland, the emergency call is classified into three categories namely Category-A call for a life-threatening case, Category-B call for a serious but not life-threatening case and Category-C call for a non-serious and not life-threatening case. Each category of call can have a different targeted response time that reflects its priority. Often a higher-priority call is served within a lower response time. For instance, the KPI for ambulance services in Northern Ireland has stated that any Category-A call which is the highest priority call should be served within 8 minutes. On the other hand, Category-B and Category-C calls should be served within 18 minutes and 21 minutes in rural and sparsely populated areas respectively (Health Information and Quality Authority, 2012).

The triage system provides an appropriate response for the emergency call and can contribute to a better use of ambulances. Consequently, many countries have implemented the triage system to sort the incoming calls. However, in some countries like France, Norway and Italy, all emergency calls are treated equally where each arriving call is simply sorted based on the first-in-first-out approach (Health Information and Quality Authority, 2012). Criteria-based Dispatch (CBD) and Advanced Medical Priority Dispatch System (AMPDS) are the most widely used priority-based dispatch especially in the developed countries (Black and Davies, 2005). Ambulance services in U.K. have implemented the priority-based dispatch by using the AMPDS software to replace the first-in-first-out approach, and the decision has resulted in increasing about 3.9% of the total Category-A calls that were served within an 8-minutes response time (U.K. National Statistics, 2009).

Once an emergency call has completely identified, classified and prioritized, the next process is to find the most appropriate ambulance to be dispatched to the call scene. Usually, the closest available ambulance is dispatched by the EMS dispatcher to serve the emergency call as fast as possible. In a real-life situation, a first responder can be utilized prior to the ambulance arrival to perform basic emergency treatments at the scene such as cardiopulmonary resuscitation (CPR) and basic wound management (Pozner *et al*., 2004). The approved first responder can be a police personnel, firefighters and volunteers who have undergone a basic life-support training (Pell *et al.*, 2001). Nonetheless, the impact of first responder on survival is critical, especially during cardiac arrest treatment (Pell *et al.*, 2001; Vukmir, 2006).

Basically, the ambulances used in EMS delivery can be categorized into two types namely Basic Life-Support (BLS) and Advanced Life-Support (ALS). BLS ambulance is equipped with equipments that can provide less advanced care such as CPR and oxygen monitoring. Meanwhile, on top of the BLS capabilities, ALS ambulance can perform advanced medical procedures (e.g., administering drugs, administering defibrillator shocks and inserting breathing tubes) (Mandell, 1998). Any EMS delivery that implements a one-tier system can only deploy one type of ambulance regardless the types of emergency. In a two-tier system, both types of ambulances are utilized where usually the BLS ambulance is deployed for most of the received emergency call, and the ALS ambulance is only used during serious life-threatening situations (Eaton *et al*., 1985; Lim *et al*., 2011). In addition, some EMS providers used BLS and ALS ambulances in a tandem where the BLS ambulance acts as a first responder and has a shorter targeted response time compared to ALS ambulance (Nichol *et al*., 1996).

The methods used in the process of sorting the emergency calls and assigning the appropriate ambulances can be defined as ambulance dispatch policy (ADP). ADP arguably has a significant impact on the performance of EMS delivery. According to Lim *et al*. (2011), any real-life ADP can be divided into three components namely calls queuing method (CQM), ambulance assignment method (AAM) and add-on dispatch policy (AOD). Priority and first-in-first-out dispatches are examples of CQM that have been applied by many EMS providers. In addition, sending the closest ambulance is the most commonly used AAM (Repede and Bernardo, 1994). The AOD is a complementary method that is applied to achieve a specific objective in the performance of EMS delivery by altering the CQM and AAM accordingly.

In Malaysia, MERS999 system has been incorporated with emergency department (ED) of government hospital in every state via Medical Emergency Call Center (MECC). The ambulance is dispatched by ED personnel to serve the emergency call from the nearest hospital. However, a direct calling to the hospital ED is still supported (Hisamuddin *et al*., 2007). In the worst case, some of the emergency patients are transported to the hospital by their family or bystanders, especially in a rural area. Meanwhile, the ambulances provided by the non-governmental organizations (NGOs) are only located at an urban area in several states. Thus, it can be concluded that Malaysia EMS delivery lacks a strategic ambulance deployment where most of the ambulances have been located at the hospital.

Many ambulance location models (ALMs) have been proposed by researchers to solve the ambulance deployment problem (Brotcorne *et al.*, 2003). The proposed models can be further classified as a deterministic, probabilistic or dynamic model. Deterministic model is often used during planning stage, and only considers the static problems of the system. It ignores completely the dynamic of the problems such as the varying demands over time and time-dependent travel time. In a real-life situation, the ambulances are not always available to serve the emergency call at all times. Due to the problem, several probabilistic models have been developed. Meanwhile, a dynamic model requires the implementation of advanced technologies and heuristic methods, but it could promise the best solution for ambulance location and relocation problem (Brotcorne *et al.*, 2003).

A strategic ambulance location can ensure the arrival of an ambulance at the emergency scene within the targeted response time. Moreover, the ALM is not only successful in reducing the ART, but also can be implemented as a cost-saving tool. For example, in 1984, a plan to reorganize the EMS in Austin, Texas was established by using a modified maximal covering location problem (MCLP) and the results showed that $3.4 million in construction cost and $1.2 million annually in operating cost were saved (Eaton *et al*., 1985). With the introduction of Geographical Information System (GIS) application into the EMS delivery, now the ambulances can be deployed even better.

The most advanced technology that has been implemented in EMS delivery is the Computer-Aided Dispatching (CAD) system, which combines the technologies of Global Positioning System (GPS), GIS and Internet into a sophisticated and computerized dispatching system. In the CAD system, the emergency calls are geographically located and recorded in a real map while the ambulances are provided automatically by the system with the best route to the call scene by considering real-life traffic congestion. The implementation of CAD system requires the ambulances to be equipped with a mobile data terminal or GPS devices that surely can increase the overall cost of EMS delivery. Consequently, the implementation of CAD system in EMS delivery can be seen mostly in developed countries.

1.3 Problem Statement

The main problem in the previous works is neither the proposed ADP presented by Lim *et al.* (2011), nor others' policy used in EMS simulation (Repede and Bernado, 1994; Gendreau *et al.*, 2001; Andersson and Värbrand, 2006), has taken into account the variant in a real-life EMS delivery. For example, the study area used by Lim *et al.* (2011) is a hypothetical region, and it is defined by using a grid system where there is no real-life data implemented. Therefore, their simulation results can be classified as a generalized result on the performance of EMS delivery. Nonetheless, Lim *et al.* (2011) have suggested an integration of real data (e.g., actual road network and demand) in the simulation to obtain a result that is closer to the real-life EMS implementation. Consequently, a real map of a local area is introduced in this research as the study area. Actual road network and demand are used so that the simulation results are as close as to the real-life performance.

Besides, there is still lacking of study that targeting on the performance of Malaysia EMS delivery, especially in terms of ambulance services. Moreover, a study by Hamzah (2005) has shown that despite improving, the current performance of Malaysia EMS delivery is yet to reach the international level. As mentioned earlier, the performance of EMS delivery is always measured based on the ART and the coverage where both can be enhanced by using appropriate ADP and suitable

ALM. However, most of the previous studies have only focused on improving the EMS performance by using either ADP or ALM. Therefore, this research strives to study the performance of local EMS delivery by looking at both the impacts of ADP and ALM.

1.4 Objectives of Research

The objectives of the research are defined as the following:

a) To develop an EMS simulator that can evaluate the EMS performance based on local geographic information; and,

b) To study the impact of ADP components and application of ALM on ART using simulation based on the real map.

1.5 Scopes of Research

Several scopes have been outlined in order to justify the objectives of the research. First of all, an object-oriented programming and a discrete-event simulation technique are used to design the simulator. An EMS simulation is used instead of a real experiment for the advantages of the flexibility, time-saving and low cost. The simulation can provide a comprehensive decision support tool for operational planning analysis. In addition, the designed simulator can evaluate the performance of local EMS delivery in terms of both the ADP and ALM based on a real map. Next, the road network and EMS demands for simulation are based on the collected data from Majlis Perbandaran Johor Bahru Tengah (MPJBT) and Majlis Bandaraya Johor Bahru (MBJB) administrative areas. Besides, the map of the study area is developed by using OpenStreetMap, which is an open-source world map provider. As the research is still at an early phase and focusing more on the planning stage, all the simulation parameters (e.g. numbers of ambulance and emergency call) are mainly based on assumption values. Finally, a static ALM is implemented where the travel time and demand are made unchanged throughout the simulation. The scopes of the research are summarized in Table 1.1.

Table 1.1: Scopes of the research

Parameter	**Scope**
Simulator	Coded using object-oriented programming (i.e. Java programming language) and discrete event simulation technique.
Study Area	Based on real map of MPJBT and MBJB areas.
Map Size	≈ 500 km^2
Map Platform	OpenStreetMap
Distance Measurement	Based on actual road network within the study area using Dijkstra's algorithm.
Road Network	The road network considers one-way and two-way streets but does not include the traffic conditions.
Call Data	Generated using Poisson distribution based on population size.
Ambulance Speed	Based on the speed limit of a road.
ALM	Static deterministic model (MCLP)
Performance Measurement	ART and coverage percentage.

1.6 Significances of Research

The significances of the research can be highlighted in several aspects. First, the analyses conducted in this research can provide a useful guideline for EMS providers, especially for Ministry of Health (MOH) in improving the performance of ambulance services in Malaysia. This is in line with the need highlighted by MERS999 system that is to reduce the ART during emergency (Government: MERS 999, 2012). The simulation results which include ART performance for several combinations of practical ADP components are presented. EMS dispatcher then can use the result to decide on the best policy that needs to be applied for achieving a desired performance. In addition, the solution of the implemented ALM can provide several strategic locations for ambulance stations that practically can increase the EMS coverage. Besides, by comparing to the others' EMS related study in Malaysia (Hameed *et al*., 2006; Hong and Ghani, 2006; Hameed *et al*., 2010), this research can be considered as a pioneer work in Malaysia that looks into EMS delivery performance study, particularly in considering the local geographic information. As a result, not only it can contribute to academic literature enrichment, but also can encourage more researchers to focus on EMS delivery optimization in Malaysia.

1.7 Research Methodology

The research methodology is summarized in Figure 1.1. It shows the process of identifying the potential solutions to enhance the existing EMS in Malaysia. The process starts with the literature review to gather the critical knowledge that is related to the research. The literature review is carried out based on the defined problem of EMS performance improvement. The previous works in current literature which have focused on improving the EMS performance are identified. Then, an EMS simulator is developed to provide a simulation framework for the EMS performance study. Besides, the simulation is preferred than the real experiment primarily due to its ability to provide a comprehensive decision support tool that can greatly benefit the EMS during planning stage and decision making. In addition, many researchers have been using simulation to study the EMS performance (Ingolfsson *et al*., 2003; Su and

Shih, 2003; Henderson and Mason, 2004; Aringhieri *et al*., 2007; Silva and Pinto, 2010; Lim *et al.*, 2011).

In order to obtain a simulation result that is much closer to the actual implementation, a real map is used instead of a hypothetical region to represent the study area. The developed simulator can simulate the dynamic states of EMS delivery, including the geographical locations of ambulance and emergency call. Another component of the simulator is the application of ALM, which enables the simulator to find the strategic positions for locating the ambulances in order to increase the EMS coverage. Besides, the simulator supports the implementation of ADP components that allow each of the components to be explored using simulation.

After the simulator is completely designed, two case studies are being analyzed to identify the best setting for Malaysia EMS delivery. The first case is an approximate to existing EMS system where all ambulances are located at hospitals whereas in the second case, the application of ALM is introduced. In both cases, several combinations of ADP components are simulated, and the ARTs are recorded for analysis purposes. As a result, the possible ambulance locations and ADP that satisfy the desired performance of Malaysia EMS can be identified.

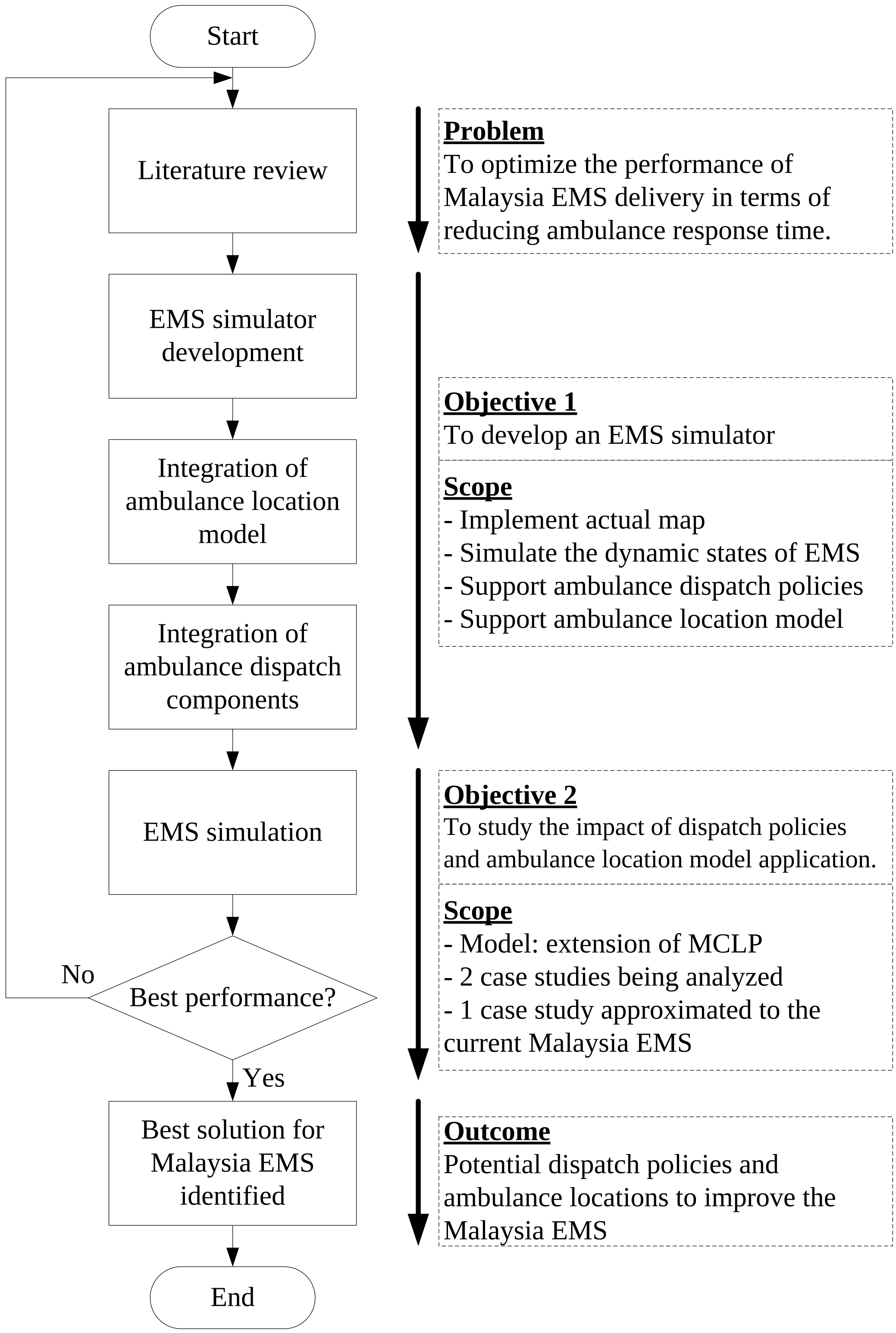

Figure 1.1: Flowchart of the research methodology.

1.8 Thesis Outline

This thesis is structured in the following manner. In Chapter 1, the background and motivations of the study are presented. It also includes the problem statements, objectives, scopes and research methodology. The literature review is presented in Chapter 2. It consists of academic reviews on several subjects that are deemed to be important for the research. The reviews include EMS definition, EMS performance measurement, decomposition of ADP, covering location model and previous EMS simulation works. Meanwhile, Chapter 3 describes the map development and EMS simulation work in detail. Data collection and analysis are presented in this chapter as well. In addition, Chapter 3 highlights the simulation setup and the development of EMS simulator. The findings of the research are presented and discussed in Chapter 4. These include the results for the developed simulator and the simulation of dispatch policies. A comprehensive discussion on the obtained results is also provided in this chapter. Chapter 5 summarizes the whole research. In this final chapter, the research outputs are well concluded, and several recommendations are emphasized for future work.

REFERENCES

Al-Shaqsi, S. Z. K. (2010). Response time as a sole performance indicator in EMS: Pitfalls and solutions. *Open Access Emergency Medicine*, *2*, 1-6.

Alexandris, G. and Giannikos, I. (2010). A new model for maximal coverage exploiting GIS capabilities. *European Journal of Operational Research*, *202*(2), 328-338.

Andersson, T., Petersson, S., & Varbrand, P. (2004). Calculating the preparedness for an efficient ambulance health care. *Proceedings of the 7th International IEEE Conference on Intelligent Transportation Systems*. 3-6 October. 785-790.

Andersson, T. and Värbrand, P. (2006). Decision support tools for ambulance dispatch and relocation. *Journal of the Operational Research Society*, *58*(2), 195-201.

Anisah, A., Chew, K. S., Mohd Shaharuddin Shah, C. H. and Nik Hisamuddin, N. A. R. (2008). Patients' perception of the ambulance services at Hospital Universiti Sains Malaysia. *Singapore Medical Journal*, 49(8), 631-635.

Aringhieri, R., Carello, G. and Morale, D. (2007). Ambulance location through optimization and simulation: the case of Milano urban area.

Ball, M. O. and Lin, F. L. (1993). A reliability model applied to emergency service vehicle location. *Operations Research*, 41(1), 18-36.

Barber, C. B., Dobkin, D. P. and Huhdanpaa, H. (1996). The quickhull algorithm for convex hulls. *ACM Transactions on Mathematical Software (TOMS)*, *22*(4), 469-483.

Başar, A., Çatay, B. and Ünlüyurt, T. (2012). A taxonomy for emergency service station location problem. *Optimization Letters*, *6*(6), 1147-1160.

Bevan, G. and Hamblin, R. (2009). Hitting and missing targets by ambulance services for emergency calls: effects of different systems of performance measurement within the UK. *Journal of the Royal Statistical Society: series A (statistics in society)*, *172*(1), 161-190.

Black, J. J., & Davies, G. D. (2005). International EMS systems: United Kingdom. *Resuscitation*, 64(1), 21-29.

Blackwell, T. H. and Kaufman, J. S. (2002). Response time effectiveness: comparison of response time and survival in an urban emergency medical services system. *Academic Emergency Medicine*, *9*(4), 288-295.

Braun, O., McCallion, R. and Fazackerley, J. (1990). Characteristics of midsized urban EMS systems. *Annals of emergency medicine*, *19*(5), 536-546.

Brotcorne, L., Laporte, G. and Semet, F. (2003). Ambulance location and relocation models. *European journal of operational research*, *147*(3), 451-463.

Carter, G. M., Chaiken, J. M. and Ignall, E. (1972). Response areas for two emergency units. *Operations Research*, *20*(3), 571-594.

Church, R. and Velle, C. R. (1974). The maximal covering location problem. *Papers in regional science, 32*(1), 101-118.

Clawson, J. J., Martin, R. L. and Hauert, S. A. (1994). Protocols vs. guidelines. Choosing a medical-dispatch program. *Emergency Medical Services*, *23*(10), 52.

Culley, L. L., Henwood, D. K., Clark, J. J., Eisenberg, M. S. and Horton, C. (1994). Increasing the efficiency of emergency medical services by using criteria based dispatch. *Annals of emergency medicine*, *24*(5), 867-872.

Cuninghame-Green, R. A. and Harries, G. (1988). Nearest-neighbour rules for emergency services. *Mathematical Methods of Operations Research*, *32*(5), 299-306.

Daskin, M. S. and Stern, E. H. (1981). A hierarchical objective set covering model for emergency medical service vehicle deployment. *Transportation Science*, *15*(2), 137-152.

Daskin, M. S. (1983). A maximum expected covering location model: formulation, properties and heuristic solution. *Transportation Science*, *17*(1), 48-70.

Daskin, M. S. (2008). What you should know about location modeling. *Naval Research Logistics (NRL)*, *55*(4), 283-294.

Department of Statistics, Malaysia. Population and Housing Census 2010. Retrieved on 9 Sept. 2012.

Eaton, D. J., Daskin, M. S., Simmons, D., Bulloch, B. and Jansma, G. (1985). Determining emergency medical service vehicle deployment in Austin, Texas. *Interfaces*, *15*(1), 96-108.

Eckstein, M., Isaacs, S. M., Slovis, C. M., Kaufman, B. J., Loflin, J. R., O'Connor, R. E. and Pepe, P. E. (2005). Facilitating EMS turnaround intervals at hospitals in the face of receiving facility overcrowding. *Prehospital Emergency Care*, *9*(3), 267-275.

Eisenberg, M. S., Bergner, L. and Hallstrom, A. (1979). Cardiac resuscitation in the community. *JAMA: the journal of the American Medical Association*, *241*(18), 1905-1907.

Fujiwara, O., Makjamroen, T. and Gupta, K. K. (1987). Ambulance deployment analysis: a case study of Bangkok. *European Journal of Operational Research*, *31*(1), 9-18.

Gallo, G. and Pallottino, S. (1988). Shortest path algorithms. *Annals of Operations Research*, 13(1), 1-79.

Gendreau, M., Laporte, G. and Semet, F. (1997). Solving an ambulance location model by tabu search. Location science, 5(2), 75-88.

Gendreau, M., Laporte, G. and Semet, F. (2001). A dynamic model and parallel tabu search heuristic for real-time ambulance relocation. *Parallel computing*, 27(12), 1641-1653.

Government: MERS 999, TM - Business – Government. (2013). http://www.tm.com.my/ap/business/government/Pages/government3.aspx. Retrieved on March 25, 2013.

Graf, F., Kriegel, H. P., Renz, M. and Schubert, M. (2010). PAROS: pareto optimal route selection. *Proceedings of the 2010 ACM SIGMOD International Conference on Management of data*. 6-11 June. Indianapolis, Indiana. 1199-1202.

Haklay, M. and Weber, P. (2008). Openstreetmap: User-generated street maps. *Pervasive Computing, IEEE, 7*(4), 12-18.

Hameed, S. A. and Shabnam, M. S. S. (2006). An Intelligent Agent-Based Medication and Emergency System. *Proceedings of the Information and Communication Technologies.* 24-28 April. Vol. 2. 3326-3330.

Hameed, S. A. and Miho, V. (2010). Medical, healthcare, and emergency model: Mobile web to enhance patients' facilities. *Proceedings of the 2010 International Conference on Computer and Communication Engineering (ICCCE).* 11-12 May. Kuala Lumpur. 1-6.

Hamzah MSSC. (2005). Ambulance Service at Hospital University Sains Malaysia and Hospital Kota Bharu: A Retrospective Study Of Calls. *Malaysian J Med Sci 2005*; 2:34-43.

Heward, A., Damiani, M. and Hartley-Sharpe, C. (2004). Does the use of the Advanced Medical Priority Dispatch System affect cardiac arrest detection?. *Emergency medicine journal*, *21*(1), 115-118.

Hisamuddin, N. A. R., Hamzah, M. S. and Holliman, C. J. (2007). Prehospital emergency medical services in Malaysia. *The Journal of emergency medicine*, *32*(4), 415-421.

Health Information and Quality Authority (2012). Pre-hospital Emergency Care Key Performance Indicators for Emergency Response Times: October 2012 (Version1.1). *Dublin: Health Information and Quality Authority*.

Henderson, S. G. and Mason, A. J. (2004). Ambulance service planning: simulation and data visualisation. *Operations research and health care: a handbook of methods and applications*, *70*, 77-102.

Hentschel, M. and Wagner, B. (2010). Autonomous robot navigation based on OpenStreetMap geodata. *Proceedings of the 13th International IEEE Conference on Intelligent Transportation Systems*. 19-22 September. Funchal.1645-1650.

Hogan, K. and ReVelle, C. (1986). Concepts and applications of backup coverage. *Management Science*, *32*(11), 1434-1444.

Hong, N. C. and Ghani, N. A. (2006). A Model for Predicting Average Ambulance Service Travel Times in Penang Island. *Proceedings of the 2nd IMT-GT Regional Conference on Mathematics, Statistics and Applications, Universiti Sains Malaysia*.

Horan, T. A. and Schooley, B. L. (2007). Time-critical information services. *Communications of the ACM*, *50*(3), 73-78.

Ingolfsson, A., Erkut, E. and Budge, S. (2003). Simulation of single start station for Edmonton EMS. *Journal of the Operational Research Society*, 54(7), 736-746.

JOSM website, http://josm.openstreetmap.de/. Retrieved on September 17, 2013.

Li, X., Zhao, Z., Zhu, X. and Wyatt, T. (2011). Covering models and optimization techniques for emergency response facility location and planning: a review. *Mathematical Methods of Operations Research*, *74*(3), 281-310.

Lim, C. S., Mamat, R. and Braunl, T. (2011). Impact of ambulance dispatch policies on performance of emergency medical services. *IEEE Transactions on Intelligent Transportation Systems*, *12*(2), 624-632.

Mandell, M. B. (1998). Covering models for two-tiered emergency medical services systems. *Location Science*, *6*(1), 355-368.

Marsden, A. K. (1995). Getting the right ambulance to the right patient at the right time. *Accident and emergency nursing*, *3*(4), 177-183.

Mayron, R., Long, R. S. and Ruiz, E. (1984). The 911 emergency telephone number: Impact on emergency medical systems access in a metropolitan area. *The American Journal of Emergency Medicine*, *2*(6), 491-493.

MBJB (2010). Data Kelulusan Sementara Taska/Tadika di MBJB sehingga Disember 2010.

McLay, L. A. and Mayorga, M. E. (2010). Evaluating emergency medical service performance measures. *Health care management science*, *13*(2), 124-136.

McLay, L. A. and Mayorga, M. E. (2011). Evaluating the impact of performance goals on dispatching decisions in emergency medical service. *IIE Transactions on Healthcare Systems Engineering*, *1*(3), 185-196.

Mooney, P. and Corcoran, P. (2011). Integrating volunteered geographic information into pervasive health computing applications. *Proceedings of the 5th International Conference on Pervasive Computing Technologies for Healthcare (PervasiveHealth)*. 23-26 May. Dublin: IEEE. 93-100.

MPJBT (2010). Senarai Taman Dalam Kawasan Pentadbiran MPJBT.

Myers, J. B., Slovis, C. M., Eckstein, M., Goodloe, J. M., Isaacs, S. M., Loflin, J. R., Mechem, C. C., Richmond, N. J. and Pepe, P. E. (2008). Evidence-based performance measures for emergency medical services systems: a model for expanded EMS benchmarking. *Prehospital Emergency Care*, *12*(2), 141-151.

Nichol, G., Detsky, A. S., Stiell, I. G., O'Rourke, K., Wells, G. and Laupacis, A. (1996). Effectiveness of emergency medical services for victims of out-of-hospital cardiac arrest: a metaanalysis. *Annals of emergency medicine*, *27*(6), 700-710.

Nicholl, J., Coleman, P., Parry, G., Turner, J. and Dixon, S. (1999). Emergency priority dispatch systems—a new era in the provision of ambulance services in the UK. *Pre-hospital Immediate Care*, *3*, 71-5.

O’Meara, P. (2005). A generic performance framework for ambulance services: an Australian health services perspective. *Journal of Emergency Primary Health Care*, *3*(3), 4.

Pell, J. P., Sirel, J. M., Marsden, A. K., Ford, I. and Cobbe, S. M. (2001). Effect of reducing ambulance response times on deaths from out of hospital cardiac arrest: cohort study. *BMJ: British Medical Journal*, *322*(7299), 1385.

Persse, D. E., Key, C. B., Bradley, R. N., Miller, C. C. and Dhingra, A. (2003). Cardiac arrest survival as a function of ambulance deployment strategy in a large urban emergency medical services system. *Resuscitation*, *59*(1), 97-104.

Pons, P. T., Haukoos, J. S., Bludworth, W., Cribley, T., Pons, K. A. and Markovchick, V. J. (2005). Paramedic response time: does it affect patient survival?. *Academic emergency medicine*, *12*(7), 594-600.

Pons, P. T. and Markovchick, V. J. (2002). Eight minutes or less: does the ambulance response time guideline impact trauma patient outcome?. *The Journal of emergency medicine*, *23*(1), 43-48.

Pozner, C. N., Zane, R., Nelson, S. J. and Levine, M. (2004). International EMS systems: the United States: past, present, and future. *Resuscitation*, *60*(3), 239-244.

Rajagopalan, H. K., Saydam, C. and Xiao, J. (2008). A multiperiod set covering location model for dynamic redeployment of ambulances. *Computers & Operations Research*, *35*(3), 814-826.

Repede, J. F. and Bernardo, J. J. (1994). Developing and validating a decision support system for locating emergency medical vehicles in Louisville, Kentucky. *European Journal of Operational Research*, *75*(3), 567-581.

ReVelle, C. and Hogan, K. (1989). The maximum availability location problem. *Transportation Science*, *23*(3), 192-200.

Rifat, M. R., Moutushy, S., Ahmed, S. I. and Ferdous, H. S. (2011). Location based Information System using OpenStreetMap. *Proceedings of the IEEE Student Conference on Research and Development.*19-20 December. Cyberjaya. 397-402.

Rozinah, A. (2012). GIS in Emergency Communication - the MERS 999 Experience. *5th National Geospatial Information Symposium, Session IV: Geospatial*

Information for Public Safety, Paper 1.

Sánchez-Mangas, R., García-Ferrrer, A., De Juan, A. and Arroyo, A. M. (2010). The probability of death in road traffic accidents. How important is a quick medical response?. *Accident Analysis & Prevention*, *42*(4), 1048-1056.

Sasaki, S., Comber, A. J., Suzuki, H. and Brunsdon, C. (2010). Using genetic algorithms to optimise current and future health planning-the example of ambulance locations. *International journal of health geographics*, *9*(4), 1-10.

Silva, P. M. S. and Pinto, L. R. (2010). Emergency medical systems analysis by simulation and optimization. *Proceedings of the Winter Simulation Conference*. Winter Simulation Conference. 2422-2432.

Su, S. and Shih, C. L. (2003). Modeling an emergency medical services system using computer simulation. *International Journal of Medical Informatics*, *72*(1-3), 57-72.

Tippett, V., Woods, S., FitzGerald, G. and Clark, M. (2003). Towards a national research agenda for the ambulance and pre-hospital sector in Australia. *Journal of Emergency Primary Health Care*, *1*(1-2), 1-8.

Toregas, C., Swain, R., ReVelle, C. and Bergman, L. (1971). The location of emergency service facilities. *Operations Research*, *19*(6), 1363-1373.

U.K. National Statistics (2009). Ambulance Services England 2008–2009, NHS Inform. Cent.

VanRooyen, M. J., Thomas, T. L. and Clem, K. J. (1999). International emergency medical services: assessment of developing prehospital systems abroad. *The Journal of emergency medicine*, *17*(4), 691-696.

Vukmir, R. B. (2006). Survival from prehospital cardiac arrest is critically dependent upon response time. *Resuscitation*, *69*(2), 229-234.