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Framework of TAZ_OPT Model for Ambulance Location and Allocation Problem

Adibah Shuib and Zati Aqmar Zaharudin

***Abstract*—**Our study is concerned with the development of an Emergency Medical Services (EMS) ambulance location and allocation model called the Time-based Ambulance Zoning Optimization Model (TAZ_OPT). This paper presents the framework of the study. The model is formulated using the goal programming (GP), where the goals are to determine the satellite locations of ambulances and the number of ambulances to be allocated at these locations. The model aims at maximizing the expected demand coverage based on probability of reaching the emergency location within targetted time, and minimizing the ambulance busyness likelihood value. Among the benefits of the model is the increased accessibility and availability of ambulances, thus, enhanced quality of the EMS ambulance services.

***Keywords*—**Optimization; Ambulance Location; Location facilities.

I. INTRODUCTION

AMBULANCE is one of the EMS components and it is available 24 hours per day in most hospitals. The EMS ambulance services provide emergency care and transport patients to hospital immediately to reduce patients' mortality, disability or suffering. The risk of death of patients requiring emergency treatment might increase due to long ambulance's response time. Response time is defined by the time elapse between the minutes an operator finished receiving information from a caller to the time an ambulance arrives at the emergency site [1]. Since time is the main concern to those involved in the emergency, therefore EMS ambulance response time plays an important role to measure the quality of the EMS ambulances' performance. Strategic ambulance location and allocation is a way to reduce the extensive response time. This paper presents the conceptual framework of our study, which concerns with the development of a mathematical model for ambulance location and allocation problem.

This paper is organized as follows; I. Introduction, II. Literature review, III. Conceptual Research Framework, and IV. Summary.

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II. LITERATURE REVIEW

Several studies regarding the ambulance location and allocation model can be found as early as in 1970s. One of the earliest models that can be found is the Location Set Covering Model (LSCM) introduced by Toregas et al. in 1971 [2]. LSCM determines the suitable ambulance locations to cover all demands within pre-specified time and distance while limiting the number of ambulances. Later in 1974, Church et al. [3] proposed the Maximum Coverage Location Problem (MCLP) to determine the EMS ambulances' stations by maximizing demand covered with one condition that is limiting the number of ambulances allocated at these potential stations. Even though both models proposed by [2] and [3], respectively, are able to cover all demands, an important factor which is the ambulance busyness has been neglected. Here forth, various models were developed based on these two models, where some of them take into consideration the ambulance busyness as a parameter.

Some extensions to the LSCM are the probabilistic LSCM (PLCSM) developed by ReVelle and Hogan [4], the Reliability model (Rel-P) by Ball and Lin [5] and the Ambulance Allocation Coverage Model (AACM) by Shiah and Chen [6]. The PLSCM [4] proposed the probability value of the server (ambulance) busyness constraint into the LSCM. This model was then extended to the Queuing PLSCM (QPLSCM) by Marianov and ReVelle [7]. Meanwhile, Rel-P [5] is capable of covering all demands using unlimited number of ambulances while considering the minimum cost to locate the ambulances at potential locations. On the other hand, the AACM [6] incorporates the capacity of ambulance service area into LSCM by considering the city's physical road structure (single line road map) and population distribution (address point map).

The Maximum Expected Covering Location Problem (MEXCLP) by Daskin [8], Maximum Availability Location Problem (MALP) by ReVelle and Hogan [9] and the GP model by Alsalloum and Rand [10] are some extension models for the MCLP. MEXCLP [8] considers the probability of server (ambulance) being busy when maximizing demand covered, where the probability was

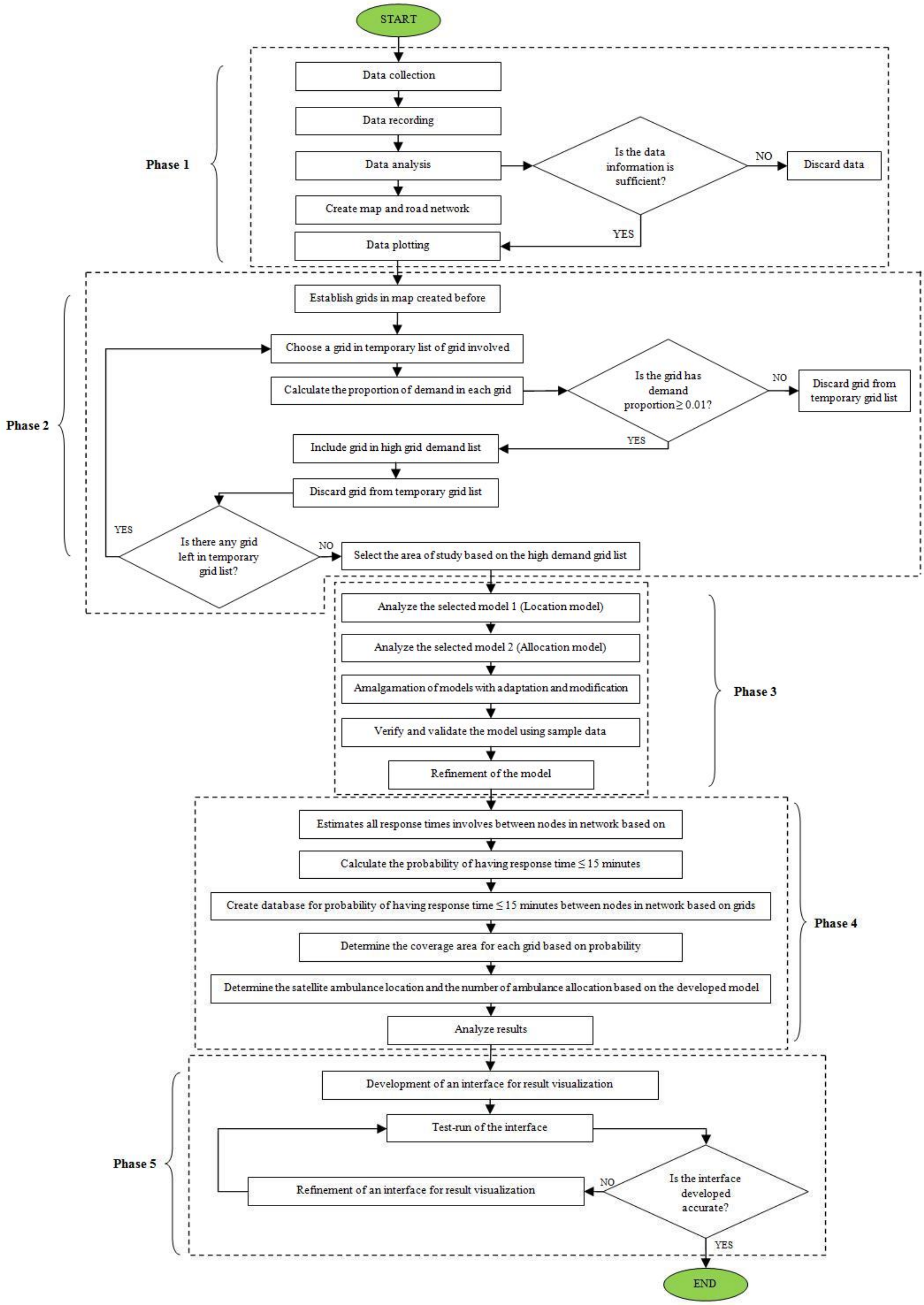

Fig. 1 Research Conceptual Framework

determined by using a heuristic procedure. Model called Local Reliability-based MEXCLP (LR-MEXCLP) is proposed by Sorensen and Church [11] as one of the extension of MEXCLP. Meanwhile, MALP [9] employs the probabilistic assumption in which number of ambulances is limited and ambulance availability is within standard reliability. LR-MEXCLP [11] and the GP model of Alsalloum and Rand [10] have been selected as reference models when developing the model for our study. These models will be described next.

Model A: LR-MEXCLP

The LR-MEXCLP of Sorensen and Church [11] is a combination of MALP II by ReVelle and Hogan [9] and MEXCLP by Daskin [8]. LR-MEXCLP aims at finding suitable locations to place ambulances within the area of concern and to determine suitable number of ambulances to be positioned at these locations. Thus, the concept of reliability of ambulance service from the MALP II has been incorporated into the mathematical formulation of MEXCLP to form the LR-MEXCLP. The objective function of the LR-MEXCLP is to maximize the sum of the demand level for all nodes (as defined for the MEXCLP) multiplied by the reliability of coverage (as described in the MALP II).

Model B: GP Model

In their GP model, Alsalloum and Rand [10] defines demand coverage as probability of covering a demand within the target time rather than using the common 0 – 1 concept, where the demand node is covered (assigned a value 1) if it is within the target time or distance, otherwise, 0. The model objectives are: (i) to identify the optimal locations of a specified number of EMS stations so that the maximum expected demand might be reached within a pre-specified target time; and (ii) to ensure that any demand arising located within the service area and the target time will find at least one ambulance available. Thus, the goals of the model are first to maximize the expected demands covered, and second to reduce the spare capacities of located ambulances. The objective function of the model is achieved by minimizing the under-achievement of the first goal and the over-achievement of the second goal. Alsalloum and Rand [10] utilized the probability concept to determine the expected coverage value for any location, namely j. After the strategic location j is found, the Erlang's Loss formula is used to determine the minimum number of ambulances to be placed at j.

Goal Programming

GP is a multi-criteria decision making technique, which is an extension of the linear programming, with multiple objectives expressed by means of the attempted achievement of goal target values for each objective [12]. GP model even allows the conflicting goals that have different measurements to be in the objective function. Sharma and Sharma [13] stated that, in GP, instead of maximizing or minimizing the objective function directly, the deviations between goals and what can be achieved within the given set of constraints are minimized. Ramero [14] stated that nowadays GP is the most widely used multi-criteria decision making technique. GP can be found in wide range of applications in many disciplines [15].

III. Research Conceptual Framework

The conceptual framework for our research is as illustrated in Fig. 1. This framework consists of five major phases namely Phase I: Data Collection and Data Analysis, Phase 2: Establishment of the Area of Study, Phase 3: Formulation of Model; Phase 4: Computational Experiments, and Phase 5: Development of Automated Template.

Phase 1 contains five steps, which are data collection, data entry, data analysis, development of the road network map and plotting of demand data onto the map. Our study is carried out in the District of Klang, Malaysia. Initial area being focused for the study is the area served by ambulances located at the HTAR and various policlinics, which are administered by the Hospital Tengku Ampuan Rahimah (HTAR), Klang. This area is located within the Klang Valley, an area with the highest population density in Malaysia. Currently, the service coverage of HTAR ambulance services includes both cities of Klang and Shah Alam. However, the ambulance services provided are sometimes extended to areas like Telok Panglima Garang, Banting, Subang Jaya and other areas. Thus, unavailability of ambulances or longer ambulance response times usually occur. Data collected include one-year data on emergency locations, time of emergencies, details of ambulances covering the emergencies, ambulances' departure times from respective stations and arrival times at the emergency locations. A database was created to store all related data to be used for the study.

During analysis of data, the data screening procedure is performed. Data screening is the process of eliminating insufficient data information such as emergency cases with inaccurate locations of emergencies or those outside the services' coverage of the HTAR-administered ambulances. Next, the map representing the area of respective ambulance services is created. This map is then furnished with road network. Finally, emergency locations (demands) based on the data are plotted on this map. Fig. 2 illustrates distribution of annual demands of ambulances that are under the management of the HTAR.

In Phase 2, focused area of study is determined by completing the following steps: establish grids for the map, calculate the proportion of demands in each grid, determine high demand grids and determine the area for the study. Each grid is representing an area of 4.84 km^2. Only grids which have node(s) and road network are labeled. Number of demands in each grid is calculated. Temporary list of all grids is formed. For each grid in the temporary list, the proportion of daily demand is calculated. If this grid's proportion is greater than or

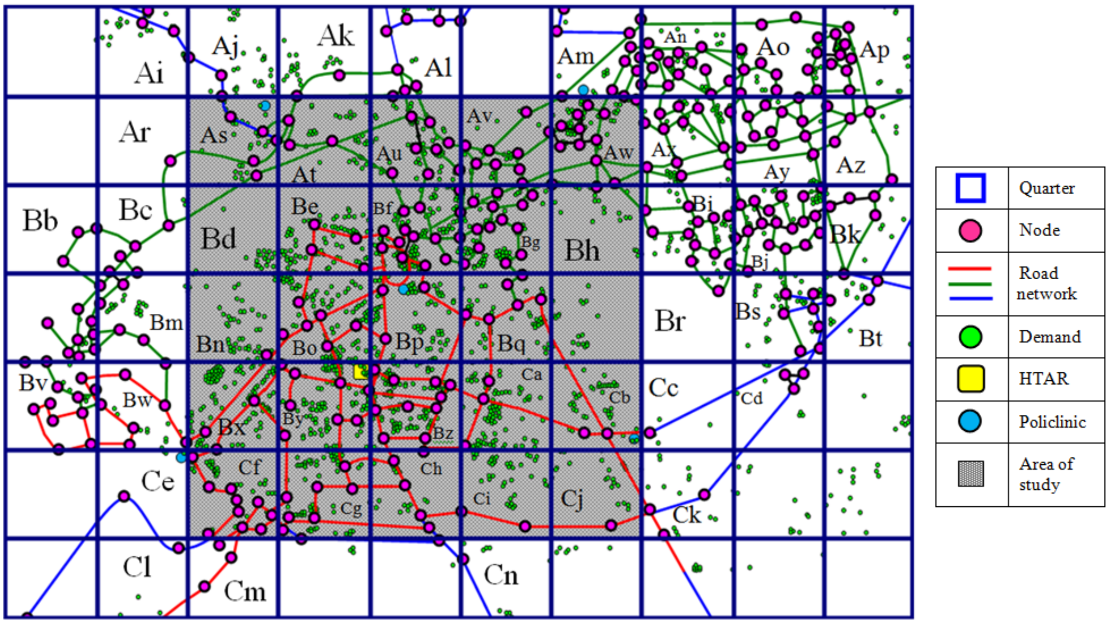

Fig. 2 Distribution of Annual Demands (Emergencies) requiring HTAR Ambulance Services

equal to 0.01, the grid will be included in the list of high demand grids. Otherwise, the grid is discarded from the temporary list. The 0.01 value represents that at least 1% of the whole demand (3466 emergency cases per year) are located at the grid. Based on the list of high demand grids, the area of the study is identified, as shown in Fig. 2.

Development of the TAZ_OPT model is carried out in Phase 3. Two models, Model A (LR_MEXCLP) and Model B (GP Model), are selected as reference models. These models are used as foundation to the development of the two goals of our TAZ_OPT GP model. Model A, as described, emphasizes on ambulance location problem, thus can be used to determine the strategic ambulance satellite locations. Model B, on the other hand, can be adapted for the purpose of finding suitable number of ambulances to be allocated at the satellite locations. The satellite location stated before is defined as the grid where a host building (preferably government-own building) is identified to be the location to park the ambulance(s). These satellite locations specify the zones which the ambulances provide maximum accessibility and availability for their services.

Analysis of reference models gives understanding of these models' uniqueness as well as their strength and weaknesses (if any). Parameters and variables for our model are then confirmed. The structure of our TAZ_OPT model is established based on the amalgamation of these models, with some adaptations and modifications and also introduction of new approach. The objectives of this model are to maximize expected demand coverage based on probability of reaching the emergency location within targeted time, and to minimize the ambulance busyness likelihood value. Our TAZ_OPT model is validated and verified using the sample data. Refinement of model is performed if necessary. TAZ_OPT GP model has two goals. The general formulation of this model is as follows;

$$Min\ P_0 d_0^- + P_1 d_1^+ \tag{1}$$

where;

P_0 : first goal

P_1 : second goal

d_0^- : under attainment

d_1^+ : over attainment

The first goal is to determine the potential strategic ambulance satellite locations by maximizing the expected demand coverage based on probability of reaching the emergency location within targeted time. The second goal is to determine the optimal number of ambulance(s) allocated at potential locations through minimizing the ambulance busyness likelihood value. The objective function (1) minimizes the total deviations of the under attainment and over attainment of these two goals.

Phase 4 is concerned with the computational experiments. The estimated response times between nodes in the corresponding network are determined using the CTT-based Dijkstra model ([16], [17], [18], [19] and [20]). Any response time from a node in one grid *i* to a node in another grid *j* is assigned a frequency value 1 if the response time is less than or equal to the targeted response time of 15 minutes; and 0, otherwise. Frequencies of all response times between two nodes in different grids that are less than 15 minutes are calculated. Table I shows example of calculation of these frequencies.

Table I highlights all response times from nodes in the starting grid *i* to nodes in other grids; *j*, *k* and *l* (ending grids). For example, response times from node i_1 in grid *i* to all nodes l_1, l_2 and l_3 in grid *l* are within 15 minutes, thus assigned the frequency value 1. Then, total frequency of 1's is calculated for each end grid. The total frequency of response times within 15 minutes from one grid to another grid is found by adding up respective total frequencies. The total frequency of such response time, for example, between grid i and l, equals to 3 + 3 + 2 = 8. Based on these frequencies, probabilities of ambulance reaching the emergency location from grid i to grid j within 15 minutes can be found. All response times between nodes, based on grids, along with respective frequencies and probabilities is stored in a database.

TABLE I.
CALCULATION OF FREQUENCY BASED ON RESPONSE TIME

Start Grid	SN	End Grid	EN	RT of SN – EN (min.)	Freq. (is RT within the target RT?)	Total Freq.
i	i_1	j	j_1	20.02	0	1
			j_2	14.94	1	
		k	k_1	1.21	1	1
		l	l_1	5.01	1	3
			l_2	8.84	1	
			l_3	6.65	1	
	i_2	j	j_1	20.19	0	1
			j_2	15.00	1	
		k	k_1	1.34	1	1
		l	l_1	6.73	1	3
			l_2	7.17	1	
			l_3	5.75	1	
	i_3	j	j_1	21.67	0	0
			j_2	16.72	0	
		k	k_1	1.01	1	1
		l	l_1	8.61	1	2
			l_2	16.50	0	
			l_3	5.22	1	

Note: SN–Start Node, EN–End Node, RT–Response Time, Freq.–Frequency

The next step involved in this Phase 4 is finding coverage area for each grid. The coverage area is determined by using the variable Y_{ij} that represents the accessibility of grid i from grid j. Y_{ij} is determined using the following criteria: i) For each grid j, all grids within a 3x3 grids square centered at grid j are considered as neighboring grids of grid j. ii) For each neighboring grid i, if probability of reaching nodes in grid i from nodes in grid j within 15 minutes is greater than or equal to 0.10, then Y_{ij} is assigned a value 1, else 0. All neighboring grids with Y_{ij} equals 1 are included in the coverage area of grid j. All Y_{ij} values calculated are stored in the database.

The TAZ_OPT model is utilized to determine the ambulance locations and the optimal number of ambulances to be allocated at these locations. Expected demand coverage and ambulance busyness likelihood are calculated using the existing stations and number of ambulances. These values are then compared to the expected demand coverage and ambulance busyness likelihood obtained using the ambulance satellite locations and number of ambulances found using the TAZ_OPT model. These comparisons determine the efficiencies of the proposed TAZ_OPT model.

The last phase, Phase 5, covers the development of the interface (using GUI) that links the TAZ_OPT databases, computations, results and simulations. The interface can be used to provide better understanding of the model. The interface provides simulation of ambulance busyness likelihood based on various inputs on number of ambulances allocated at the proposed ambulance satellite locations. Test runs will be performed to validate and verify the interface created.

IV. CONCLUSION

Our study focuses on development of a model, namely the TAZ_OPT model, which is capable of determining ambulance locations and allocations based on demand coverage and busyness likelihood. The locations obtained may include the existing locations or new locations to be proposed as satellite locations for the ambulances. The number of ambulances will include the current existing ambulances or and increase or decrease in this number depending on user's preference on ambulance busyness likelihood. The TAZ_OPT is hoped to maximize ambulance accessibility and availability for the benefit of the public. The framework of this model is presented, containing major five phases including data collection and data analysis, determining focused area of study, development of model, computational experiments and development of interface.

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