EMS LOCATION ANALYSIS TO MINIMIZE SERVICE RISK

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ABSTRACT The main objective of emergency medical service (EMS) is to save patient's lives. The challenge of the EMS personnel is to work under time pressure in order to reach to the patients as soon as possible. One of the key important assessment factors is the patient survival. In order to pursue the emergency services assessment, it is common to use response time as a key performance index. Response time can be determined as the duration of time form the receiving of emergency call to the reaching of the EMS personnel to the emergency scene. If the patient can be reached in short response time, it can be assumed that there is high probability to save patient's lives. Nevertheless, the faster the EMS vehicle travels in order to reach the patient, the higher the risk of accident may occur to EMS personnel. Service risk can be assessed using relative risk function determined by vehicle traveling speed. This research proposed a mathematical model called minimum service risk problem (MSRP) to determine additional EMS locations in such a way that the risk of EMS personnel is minimized whilst the response time to reach patient is still in 8-minute period. The test problem of 831 demand points was run on our proposed MSRP model. The result yields that 12 additional EMS locations needed to be added to area in order to reduce the service risk of emergency personnel to be within acceptable range and reach the patient within proposed response time.

1. INTRODUCTION

Emergency medical service (EMS) is one of important healthcare services that is vital to save patient lives. Efficient EMS helps reducing the risk of fatality and improves the quality of living of the people in every country. In order to improve service efficiency, it is necessary to determine appropriate service performance indices that correspond to the fundamental infrastructure of each country. Rahman, et al (2015) stated that it is better to compare emergency medical service with other regions or countries; however, it is challenging to benchmark this service performance among these regions or countries with different stages of service development or the level of service maturity. Rahman et al (2015) also concluded from the study and survey in seven cities in six Asian countries that the common EMS assessment factor is response time. Erkut, et al (2008) confirmed from their study that the patient's survival depends on short response time that EMS personnel use to reach patient. They proposed the maximal survival location problem (MSLP) to locate station locations in order to maximize the patient's survival rate. The MSLP is modeled based on the assumption of De maio, et al (2003) stating that the survival rate relies on short response time and emergency vehicle speed. Grant & Merrifield (2011) mentioned that most EMS usually travels at high speed during the service handle while using sirens and emergency lights. High vehicle speed also increases the risk of high casualty rate to the service personnel as well as the patient. Therefore, it is essential to incorporate risk computation in the emergency service location model.

Kloeden, et al (2002) studied the relationship between emergency vehicle accident rate and emergency vehicle speed with the conclusion that the increase of accident rate varies directly to the vehicle speed beyond average travel speed. Locating service stations appropriately is an efficient way to reduce vehicle speed beyond average travel speed to reach patient within specified response time. This paper proposed a mathematical model to determine additional emergency service locations to be added in the area in such a way that emergency service personnel risk from travel is minimized and response time to the patient is within 8-minute period.

The literature related to this work was first introduced by Jia et al (2005). They surveyed general facility location problems and identified various models used to address common emergency situations, such as regular healthcare needs. It can be concluded from their study that the P-median model, introduced by Hakimi (1964), is suitable to solve for the number of locations or facilities in such a way that the average (or total) response time or total distance travel is minimized. Carbone (1974) formulated a deterministic P-median model to determine the minimum distance traveled by a number of patients to fixed medical facilities. Carson & Batta (1990) incorporated a P-median model to the dynamic ambulance positioning strategy for a campus emergency service to determine the number of appropriate locations and ambulances at different time periods in order to minimize the average response time to the service calls. Erkut et al (2008) introduced the maximal survival location problem (MSLP) by incorporating the idea of survival function to the P-median model. The MSLP aims to decide the number of ambulance locations with the target to maximize the patient's survival rate by reducing the response time.

Moreover, Kloeden, et al. (2002) studied that the risk of emergency vehicle accident depends mainly on the speed of EMS vehicles. They proposed the "relative risk function" to calculate the relative risk based on emergency vehicle travel speed. The solution from this model yields the likelihood of casualty risk based on different speeds traveled deviating from the normal average travel speed.

2. THE MINIMIZE SERVICE RISK PROBLEM

It is our objective to study the location problem for emergency vehicles in such a way that each vehicle reaches the patient within specified response time and travels at the speed that causes low casualty risk. We proposed the mathematical model, which is formulated based on the P-Median and relative risk function, called the minimize service risk problem (MSRP).

2.1 Risk function

The probabilities of patient's survival depend on short response time and high speed of ambulance vehicle that EMS personnel use to reach demands (De maio, et al. (2003)). However, ambulance vehicles travel at high speed leading to an increase of casualty risk of EMS personnel. Kloeden et al (2002) proposed the logistic regression to study the relationship between the accident risk and the vehicle speed. This research yields that a major factor contributing in high accident risk relies on ambulance travel speed. The higher the travel speed is, the higher the accident risk may occur. Then the relative risk function is defined by Kloeden et al (2002) as:

$$r(D) = e^{(0.1133374D + 0.0028171D^2)}$$

Where D = difference in traveling speed in km/h

2.2 Model Formulation

The objective of MSRP is to determine the additional ambulance locations in the study area in order to minimize the overall service risk of emergency personnel. Let r_{ij} denote the service risk that EMS vehicle from station j travels to serve patient at demand node i. It is assumed that each patient is served by the closest ambulance. The objective function is:

$$\text{Minimize } \sum_{i=1}^{m} d_i \sum_{j=1}^{n} r_{ij} \qquad (1)$$

Where m is the number of nodes, n is the number of candidate ambulance locations, and d_i is the demand at node i. In MSRP we need to keep track of which station serves which demand point, so we define decision variables y_{ij} equal one if demand node i is served by an EMS vehicle at location j, and zero otherwise. Then

$$r_{ij} = \begin{cases} r(v_{ij}-v_{avg}) & \text{if } y_{ij}=1 \\ 0 & \text{if } y_{ij}=0 \end{cases} = r(v_{ij}-v_{avg})y_{ij} \qquad (2)$$

Where v_{ij} is the travel speed from candidate location j to demand node i and v_{avg} is the average ambulance speed recommended for each EMS vehicle to travel within the zone. In this study travel speed and average speed zone are assumed to be deterministic. Let p be the number of facilities, and let x_j equal to one if a candidate EMS location j is selected, and zero otherwise. The formulation for the MSRP can be showed as follows:

MSRP:

$$\text{Minimize } \sum_{i=1}^{m} d_i \sum_{j=1}^{n} r_{ij} = \sum_{i=1}^{m} d_i \sum_{j=1}^{n} r(v_{ij}-v_{avg})y_{ij} \qquad (3)$$

Subject to

$$\sum_{i=1}^{m} y_{ij} \le m x_j \quad (j=1,\dots,n) \qquad (4)$$

$$\sum_{j=1}^{n} y_{ij} = 1 \quad (i=1,\dots,m) \qquad (5)$$

$$\sum_{j=1}^{n} x_j \le p \qquad (6)$$

$$x_j \in \{0,1\} \quad (j=1,\dots,n) \qquad (7)$$

$$y_{ij} \in \{0,1\} \quad (i=1,\dots,m),\ (j=1,\dots,n) \qquad (8)$$

2.3. Assumptions and Relevant Factors

In order for the MSRP to represent the real situation, the following assumptions and factors are assumed.

(1) Data for planning period: It is essential to collect data during the time period in the past that represents the planning period in the future.

(2) Patient category and EMS vehicle category: Patient can be categorized into three types according the severity of the symptom. Type I patients are the patient with the critical symptom that needed to be transported hastily by Type A emergency vehicle with full medical equipment and medical staff. Type II patients are the patient with urgent symptom that needed to be transported by Type B emergency vehicle with full

medical equipment (medical staff are not required for this type of vehicle, staff with at least 110 training hours are eligible to travel with this vehicle type). Type III patients are the general patient that needed to be transported by Type C emergency vehicle with essential life-saving equipment and staff with at least 16 training hours.

(3) It is essential for the dispatching center to assign the right emergency vehicle that matches the symptom of each patient.

(4) All EMS vehicles are assumed to be available for service at all time.

(5) Response time for emergency vehicle to reach the patient in this study is assumed not to exceed eight minutes, which is the target response time set by the National Institute of Emergency Medicine of Thailand.

(6) Emergency vehicle travel speed is allowed in this study to be deviated from average travel speed in the range of $-20 \le D \le 475$.

3. TESTING DATA

In order to test the validity of the MSRP model, a testing data from real situations of 2,809 demand calls for emergency services in the local area of 831 km^2 was used. Currently, there are 7 emergency stations in the area that provide full emergency services with full medical team support. There are 51 potential locations in this area that can be upgraded to be full-service emergency station. The objective of this research is to increase the minimum number of full-service emergency stations that provides the safe service to the patient with the travel speed lower than the average speed of the zone.

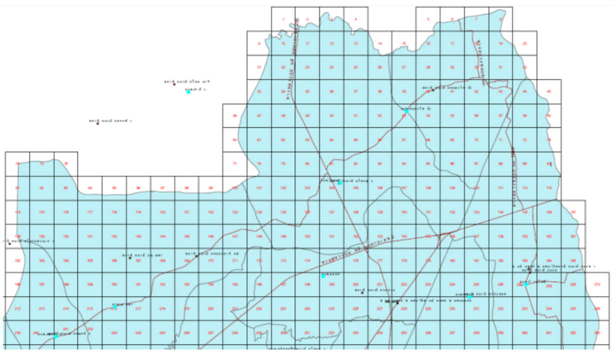

Fig. 1 The study area of testing data

3.1 Data Setting

In order to ease the complexity of the study area, we divide the area into small grids of size 1x1 km^2. Hence, there are 831 grids in this testing data as can be seen in figure 1. Let i be the grid number, where i=1,…,831. There are 2,809 patient requests in this area. Currently, there are 7 emergency medical service stations available to provide full emergency services with full medical team support ($x_j = 1$, for j=1,…,7). Due to resource and budget restrictions, it is assumed that the number of emergency stations that can be upgraded cannot exceed 15 stations. Currently, there are 51 candidate locations to be selected. Let $x_j \in \{0,1\}$ be the decision variables representing all candidate locations in this study where j = 8,…,58.

4. RESULTS AND DISCUSSION

The MSRP model was run using the aforementioned testing data on LINGO version 11.0 on a PC with CPU Intel Core i5 2.67 GHz with 4.00 GB RAM. The objective of this model is to determine the number of candidate locations to be upgraded for full emergency service stations in such a way that the emergency service vehicles can reach the patient within 8-minute response time and service risk of emergency service personnel is minimized.

The results of upgrading one candidate location for emergency service station at a time and the values of service risk of emergency personnel are shown in table 1. If there is no upgrading of emergency stations to the area, the service risk value equals to 2.208×10^{17}. By upgrading one candidate emergency location at a time, the service risk values are decreased as shown in figure 2. According to the number of demands we have in this testing data, the service risk should not exceed 2,809. Hence, the minimum number of emergency stations that should be upgraded in this area is 12 stations, which are stations numbers 13, 14, 16, 18, 19, 24, 26, 38, 46, 48, 54, and 56 with the service risk value of 2,625, which is 6.55% below the maximum risk value allowed for this number of demand requests.

Table.1 Results of upgrading emergency stations and the service risk values

Add	Stations	Results
0	-	2.208×10^{17}
1	25	3.609×10^{14}
2	21 57	4.986×10^{11}
3	13 21 48	1.204×10^{7}
4	10 13 17 48	62,756.400
5	12 13 15 23 25	54,517.820
6	12 13 15 17 25 46	19,382.010
7	12 13 15 18 25 35 56	10,466.130
8	12 13 15 18 25 32 35 56	7,585.257
9	12 13 15 17 21 22 35 45 56	5,143.232
10	12 13 15 18 21 22 26 45 46 56	3,506.997
11	13 15 18 19 21 26 38 46 48 54 56	2,941.476

Add	Stations	Results
12	13 14 16 18 19 24 26 38 46 48 54 56	2,625.000
13	13 14 16 18 19 24 26 38 42 48 49 54 56	2,370.497
14	13 14 16 18 19 24 26 38 42 45 48 49 56 57	2,166.187
15	13 14 16 18 19 24 26 27 38 42 45 48 49 56 57	2,041.098

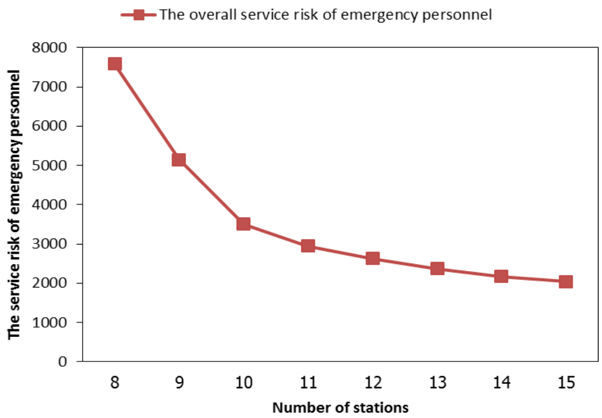

Fig 2 Relationship between the number of upgrading emergency stations and the overall risk values

CONCLUSION

Emergency medical service plays an important role in saving patient lives. The shortest time the emergency service personnel used to reach the patient is an important factor to save patient’s lives. Thus, EMS vehicles tend to travel as fast as possible to reach the patient within specified response time. This leads to the increase of accidents and fatality rate to the emergency service personnel. This research incorporated the importance of reducing service risk of emergency personnel and maintaining the 8-minute response time requirement to reach the patient by upgrading the candidate locations to be full emergency service locations. The results of the testing data shows that by upgrading 12 candidate locations, the service risk is reduced to be on par with the standard value. Future work is recommended for the study by taking the fact that there are different types of patients and service vehicles into consideration. This will make the model much more similar to the real life situation.

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