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An Optimization Model for Advanced Life Support Ambulance Facility Location Problem †

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Abstract: The survival rate of the patients in medical emergencies depends on the minimize ambulance arrival time on-sites and promptly provides medical care to the patients. Advanced Life Support (ALS) ambulances play a critical role in reducing the fatal and severity rate of emergency patients. The several areas in big cities always encounter with traffic congestion, which is a significant obstacle for ALS ambulances to achieve their service time window target (predetermine as less than 8 min). In light of prior research, arranging appropriate parking locations can solve such a problem. This study proposes a mathematical model of facility location problem to identify the ALS ambulances parking locations. This paper simultaneously considers the minimize of the total number of ALS ambulance parking locations while covering the service areas and service time window are fulfilled. One part of business centers in Bangkok was chosen to correct the data and test the proposed model. This study is distinguished from others in these areas by the only possible parking places, i.e., schools, temples, police stations, and gas stations, which are taking into consideration. IBM ILOG CPLEX Optimization Studio Version 12.6.1 was utilized to solve the problem. The result indicates that there are 26 parking locations, which can enable the service coverage areas. As well as achieve a 54% service time window target.

Keywords: ALS; service time window; medical emergency; facility location problem; service covering problem

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1. Introduction

The decision-making on emergency service activities pertains to transportation, handling, and distribution of emergency resources as well as rescue services to affected people in order to provide the medical care to them in an effective, timely manner. Numerous research provides various relevant studies in these areas, such as earthquake, flood, and emergency medical [1–3]. Obviously, the emergency medical services have been paid attention from many prior scholars. Nevertheless, to our best knowledge, there are few prior studies address the importance of parking locations of Advanced Life Support (ALS) ambulance in emergency medical services [4,5]. The identification of appropriate ALS parking locations is a challenge and complex task. Therefore, this study aims to fill this gap. ALS ambulances play a critical role in reducing the fatal and severity rate of emergency patients, especially in big cities. For Thailand, the ALS ambulance services are operated under Emergency Medical Services (EMS) centers of assigned hospitals [6]. There are nine EMS centers in Bangkok province.

This study proposes a mathematical model of set covering problem to identify the appropriate ALS ambulances parking locations in one of the central Bangkok area. The ALS service time window (the arriving time from each parking point to the rescued point) is predetermined within eight minutes. The goal of this study is to find out the minimum number of ALS parking locations, which simultaneously satisfy the predefined time window, and covering all demand points.

2. Materials and Methods

2.1. Problem Description

For Thailand, the ALS ambulance services are operated under Emergency Medical Services (EMS) centers of assigned hospitals. There are nine EMS centers establishment in Bangkok province. This study uses the EMS center, which takes responsibility in the most critical zone and the highest rate of emergency accidents as a case study. The name of this EMS is "Narenthorn" which managed under Rajvithi hospital. The EMS manager aims to improve the efficiency of ALS ambulances' response time in order to increase the survival rate of emergency patients. To find out the appropriated parking locations around the hospital's services areas and assign the ALS ambulances to them is need to figure out [7,8]. In order to solve this problem, the covering mathematical model is utilized. The objective function is to minimize the ALS parking areas by satisfying both the predefined time window and covered hospital service areas. The assumption of model are; (i) there is one ALS ambulance in each parking location, (ii) the different time interval is not taken into consideration, (iii) the probability distribution of the number occurrence demand at rescued points is assumed to be uniformed distribution by using historical data (in this case 750 occurrence demand), (iv) there are available feasible 44 parking locations for ALS ambulances, (v) due to the time window constraint (within 8 min), the distance between ALS parking point and occurrence demand at rescued point must be less than 1 kilometer. (vi) The transportation cost of ALS ambulances is not taken into consideration. The example of rescued points and ALS ambulance parking locations by geographic coordination is illustrated in Table 1.

Table 1. Example of rescued locations and ALS parking locations by geographic coordination.

Victims Points			ALS Parking Point		
Number	Latitude	Longitude	Name	Latitude	Longitude
1	13.7832832	100.5642451	Police Station Phaya Thai	13.7612	100.53
2	13.76373991	100.5558228	Police Station Chokchai	13.7955	100.59
3	13.7714523	100.5903339	Police Station Bang Sue	13.7868	100.55
4	13.7737754	100.5531721	Bangkok Business college	13.7515	100.53
5	13.7820564	100.5815878	Makkasan School	13.749	100.55
6	13.770607	100.5737361	Kiatthada Golf Training	13.825	100.61
7	13.7893029	100.5391789	Kowit Thamrong School	13.7571	100.54
8	13.8081549	100.560168	Phai Tan Temple	13.7958	100.55
9	13.75880587	100.5533713	Gas Station PTT	13.7825	100.6
10	9.1386368	99.3576835	Crime Division	13.8053	100.6

2.2. Mathematical Model

This section presents the mathematical model of the set covering problem [9], which used in this paper. The objective function (Equation (1)) is to find minimizes the number of parking points. The constraint (Equation (2)) represent the demand points are assigned to at least one selected parking points within the distance limit less than 1 kilometer. In addition, constrain (Equation (3)) represent a decision variable that is a set of binary condition for parking point is selected will have a value of 1 and, 0 otherwise. Decision variables Xj represent a set of binary condition for parking point is selected will have a value of 1 and, 0 otherwise. The parameters aij matrix of binary condition for the distance between the parking points and the demand points less than 1 kilometer will have a value of 1, and 0 otherwise. This paper defines M is demand points 750 points, N is parking points 44 points, I is a set of demand point i, and J is a set of parking point j. The linear programming model of the set covering problem is formulated as follows:

Minimize $$\sum_{j=1}^{n} x_j \tag{1}$$

Subject to $$\sum_{j=1}^{n} a_{ij} x_j \geq 1 \quad \forall i = 1,2,3,\ldots,m \quad \forall j = 1,2,3,\ldots,n \tag{2}$$

$$x_j \in \{0,1\} \quad \forall j = 1,2,3,\ldots,n \tag{3}$$

3. Results

To solve the optimization of set covering problems for identifying the parking location of ALS ambulances, the software IBM ILOG CPLEX Optimization Studio Version 12.6.1 is utilized. This research is differential from other past studies by the set of feasible parking locations is not including the prohibited location i.e., schools, temples, police stations, and gas stations. Hence, this study is more realistic in real-world practice. The coding in CPLEX is depicted in Figure 1.

The result indicated that there are 26 parking locations are feasible (from a total of 44 parking locations)and consider the percent of parking points covers demand points within time window at 8 minutes, show in Table 2.

OPL 12.6.1.0 Model

```
int   M = ...;
int   N = ...;
range Client = 1..M ;
range ALS = 1..N ;
dvar boolean X[ALS];
int Distance[Client][ALS] = ...;
minimize sum(j in ALS)X[j];
subject to {
for all (i in Client, j in ALS :Distance[i][j]==1)
sum (j in ALS)
Distance[i][j]*X[j] >= 1;}
```

(**a**)

OPL 12.6.1.0 Data

```
M = 750;
N = 44;
SheetConnection   sheet ("AlsParkPoint.xlsx");
DistancefromSheetRead(sheet,"sheet2!B2:AS751");
X to SheetWrite (sheet,"sheet1!A1:A44");
```

Problem browser
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Solution with objective is 26

(**b**)

Figure 1. The Coding IBM ILOG CPLEX Optimization Studio Version 12.6.1 to solve this paper (**a**) and (**b**).

Table 2. The solution of parking locations covers service areas within the time window target.

The Solution of Number Parking Points	The Number of Random Demand Points	The Number of Parking Points Covers Random Demand Points	The Percent of parking Points Covers Demand Points
26	750	406	54%

4. Conclusions

There are three folds of main contributions in this paper, as following below.

4.1. Contribution to Academic

This paper study the emergency medical service in the context of ALS ambulance parking locations. Few researchers have addressed such an issue. The set covering problem was applied to identify the minimum parking locations with a predetermined service time window. This study also meticulously considers the set of prohibited parking areas to screen the feasible solutions, which bring a realistic solution close to the real word context. Previous same works have never addressed such an issue.

4.2. Contribution to Practice

This study uses one of the emergency medical centers in central Bangkok as a case study. The result from this study can assist the manager of the emergency medical center to make a decision on selecting the appropriate ALS ambulances parking locations. This might lead to reducing the fatal and severity rate of emergency patients. Moreover, the model from this can be applied to other zones of emergency medical centers.

4.3. Future Research

The study also suggests for the various future research aspects as (i) to develop a heuristic algorithm to expedites the computation process for the bigger problem (ii) to include the transportation cost into the model (iii) to change the objective function from minimize set of coverage to minimize of total distances and (iv) to develop multi-objective mathematic model to simultaneously consider minimum set of coverage together with minimize total distance.

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