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An Optimization Model to Relocate Ambulance

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Abstract
Aiming to improve the proficiency and credibility of ambulance services, different models of ambulance facility allocation have been developed in the operations research literature. Location search coverage model with the aim of optimizing (deterministic or probabilistic) the number of existing ambulance call requests. This study presents a dynamic model approach in the ambulance allocation process in a medical emergency service system, where the research focuses on the types of emergency ambulance services. The main purpose of this allocation model is to anticipate the availability of ambulance vehicles so as to maximize the number of calls or requests that can be fulfilled. This research represents the development of the MEXCLP model in the form of a linear program with a constraint value of 0-1 for the variable γ_ij which states the point of location of the request for an ambulance unit and δ_ij which states the allocation status of an ambulance unit at location i, so that a model is obtained that can be used to determine the departure and relocation of the ambulance at the available request locations.

Keywords: *Ambulance, Medical emergency services, Relocation, Dynamic model.*

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I. INTRODUCTION

The term "ambulance" refers to a component of EMS, which stands for emergency medical services and is offered around the clock in most hospitals. [1] contends that the efficiency of the service quality provided by the EMS component may be evaluated based on a variety of factors, including as the typical response time, the kinds of EMS service provided to each hospital staff member, and the type of medical equipment that is utilized. In this scenario, the comparison between the number of requests fulfilled within a certain time limit, 8 to 10 minutes, is the indicator that is often used in determining the quality of EMS services. In other words, the higher the number of requests fulfilled within the allotted time limit, the higher the quality of the EMS services. So that in the planning model, the number of requests is always determined using the concept of coverage, where there is a point of request that is assumed to be fulfilled by an ambulance if the standard response time has a time limit.

[2] added that the level of risk of death of a patient is highly dependent on the response time of the ambulance to the request for ambulance services. The response time defined is the time when the operator receives an ambulance service request call, so that response time becomes an important component in determining the quality of EMS performance. [3] provides the view that the EMS component is an out-of-hospital care service provided by a hospital and provides transportation for patients who need medical care to the hospital.

The coverage model and the median model are two of the many allocation models for ambulance stations that have been created and published in the research operations literature. These models were designed with the goal of enhancing the effectiveness and dependability of ambulance services. The coverage model is a model that is used to maximize the number of requests for ambulance services that are fulfilled, making this model a reliability-oriented model in either a deterministic or probabilistic way. This model is used to maximize the number of requests for ambulance services that are fulfilled. In contrast, the goal of the median model is to reduce the total distance that an ambulance must travel between the hospital and the location where a call was placed. This is done so that the efficiency weights associated with ambulance operations can be calculated using the median model [4].

Most of the models are based on static and deterministic location problems by ignoring the existence of stochastic considerations [5]. Several literatures related to the problem of ambulance location have been developed and some probabilistic models have been obtained as a reflection of the fact that the operating ambulance is assumed to be a server in a queuing system which at a certain time cannot fulfil an ambulance service call.

In addition, [5] emphasizes that there are significant distinctions to be made between emergency medical services (EMS), fire departments, and police departments. To begin, an ambulance station is not based on a specific structure but rather on a fundamental site such as a parking space with the consideration that ambulances are placed periodically with the aim of being able to reach certain areas of call for ambulance requests. So, the problem of allocation is very important in terms of making decisions about the best configuration for at least one facilities in order to meet the level of demand in a population [6], [7].

There are three classification models that have been developed previously in the literature related to the problem of relocating ambulance facilities:

(i) real-time integer program completion for ambulance relocation decisions (see [5], [8]–[10]). The objective function of the integer program obtained is a combination for forecasting the level of demand for ambulance services in the future and the required ambulance relocation costs.
Computationally, this assessment requires implementation within the scope of parallel computing to assist the decision-making process which has an efficient complexity in terms of real-time application,

(ii) the model that was used to calculate the ideal position of the ambulance in the context of satisfying the number of requests for available ambulances. Using an integer program formulation as the solution obtained (see [11], [12]). Unlike the first two models previously described,

(iii) a model that converts random properties into an explicit system is obtained.

One estimate has been established to describe the problem of relocating the ambulances as a Markov decision process, which was then used to find an optimal rule by employing a dynamic programming system [13], [14]. In order to determine the relocation decision making based on an approximation in a certain configuration system, another heuristic assessment has been established. [15], [16] perform an analysis of the "availability function" with the intention of assessing the capability of a specific configuration to satisfy the overall demand for ambulance services. This value function is identical to the one obtained by the algorithm for dynamic programming; the only difference is that this availability function is presented in heuristic form.

The ambulance facility relocation model in this study is based on a dynamic program structure so that the model can be used as a simulation model for Emergency Medical Services (EMS) by considering the relocation rules given.

II. PROBLEM FORMULATION

One of the developments of an ambulance facility relocation model has been carried out previously by [5]. The weakness of this model is the ambulance facility relocation model with a dynamic program structure without paying attention to the rules of the relocation model according to accurate ambulance allocation time data. The purpose of this study is to model the problem of relocation of ambulance service facilities based on the modification of the dynamic program structure of the MEXCLP model accompanied by the modification of the algorithm of the relocation model in real time. The relocation model obtained can be used to solve optimization problems in the health sector which are components of Emergency Medical Services (EMS), such as the problem of ambulance allocation.

III. MODEL SIMULATION

In modelling the problem of relocating ambulance facilities, it is necessary to determine the simulation model on the medical emergency service system using a discrete-time system for requests or emergency calls, namely: (1) there is an emergency call, (2) the ambulance arrives to the location, (3) the medical team provides action at the location, (4) the ambulance takes the patient to the hospital, (5) the medical team takes the patient to the hospital for follow-up, and (6) the ambulance returns to the place. In this simulation there are two random data, namely the number and location of requests for ambulance services at a certain time.

There are two distinct cases of dynamic facility location issues: location and location-relocation issues. The two types of cases are distinguished by factors:

- In a time-bound location problem, the decision maker chooses an optimal or good location for a certain time area
- In the case of location-relocation, the decision maker chooses a primary location, the time of relocation and the location of the facility specified for the relocation of a facility

In the relocation model simulation, there are several components of medical emergency services used in this study. In medical emergency services, there are several components that affect the relocation model obtained, such as the location of the source of the ambulance, the location of the hospital, the wide transportation network of a particular location, the location of requests for ambulance facilities, scheduling, and operating status of an ambulance whether an ambulance is available to meet emergency calls.

3.1 Relocation Model for Ambulance Facility

Define the relocation model problem for an ambulance facility by representing a graph $G = (V \cup W, E)$ where $V = \{v_1, v_2, \dots, v_n\}$ and $W = \{v_{n+1}, \dots, v_{n+m}\}$ are two sets of vertices that represent the location of the request for ambulance facilities and the area of potential locations and $E = \{(v_i, v_j): v_i, v_j \in V \cup W, i < j\}$ is a set of edges. The point of request location expressed by a vertex is equal to λ_i, with each edge associated with a parameter representing the travel time t_{ij}. For $v_i \in V$ and $v_j \in W$, given as follows:

$$\gamma_{ij} = \begin{cases} 1, t_{ij} \leq r_1 \\ 0, other \end{cases} \tag{1}$$

And

$$\delta_{ij} = \begin{cases} 1, t_{ij} \leq r_2 \\ 0, other \end{cases} \tag{2}$$

There is a total number of available ambulance facilities provided and equal to $p(p \leq m)$, then the maximum number of ambulance facilities in the "waiting period" is p_j in $v_j \in W$. M_{jl}^t set as the penalty coefficient associated with the relocated ambulance facility $l = 1, \dots, p$ from the current request location at time t to the destination request location $v_j \in W$. From the following assumptions it is known that the coefficient M_{jl}^t always changes in each period t. as a result, α is the proportion of the number of demand levels that must be met by the ambulance allocated by the unit r_1.

In this study, the following variables were used: y_{jl} is a binary variable that has value 1 if and only if ambulance l is allocated to $v_j \in W$ and x_i^k is a binary variable with the value 1 if and only if v_i is a location that is satisfied at least k times, so that the relocation problem at time t is:

$$\max \sum_{i=1}^{n} \lambda_i \, x_i^2 - \sum_{j=1}^{m} \sum_{l=1}^{p} M_{jl}^t \, y_{jl} \tag{3}$$

Constraint

$$\sum_{j=1}^{m} \sum_{l=1}^{p} \delta_{ij} \, y_{jl} \geq 1, \forall v_i \in V \tag{4}$$

$$\sum_{i=1}^{n} \lambda_i \, x_i^l \geq \alpha \sum_{i=1}^{n} \lambda_i \tag{5}$$

$$\sum_{j=1}^{m} \sum_{l=1}^{p} \gamma_{ij} \, y_{jl} \geq x_i^l + x_i^2, \forall v_i \in V \tag{6}$$

$$x_i^2 \leq x_i^l, \forall v_i \in V \tag{7}$$

$$\sum_{j=1}^{m} y_{jl} = 1, l = 1, \dots, p \tag{8}$$

$$\sum_{l=1}^{p} y_{jl} \leq p_j, \forall v_j \in W \tag{9}$$

$$x_i^l = 0 \text{ or } 1, \forall v_i \in V \tag{10}$$

$$x_i^2 = 0 \text{ or } 1, \forall v_i \in V \tag{11}$$

$$y_{jl} = 0 \text{ or } 1, \forall v_j \in W \text{ and } l = 1, \dots, p \tag{12}$$

In this relocation model, constraints (4) and (5) indicate that the demand level requirement can be met by units r_2. Constraints (5) and (6) indicate the need relative to the level of demand for ambulance services that can be met. Constraint (5) explains that the proportion α at all levels the demand can be met when constraint (5) determines the number of ambulances allocated by unit r_1 must be at least one if $x_i^1 = 1$ or at least two if $x_i^2 = x_i^1 = 1$. Constraint (6) ensures that a point location request cannot be satisfied twice if it was not previously satisfied at least once. Constraint (7) dictates that each available ambulance facility must be allocated to a possible demand area location. Finally, constraint (8) shows an upper limit of the number of ambulance facilities in 'waiting period' status at a certain request location.

3.1 Algorithm Procedure

The following algorithm procedure has been previously studied by [17] in determining the relocation of ambulance facilities. The algorithm procedure in determining this relocation model has been modified according to the model that has been obtained in Equation (3) -(12) as follows.

a. Take $w_i(t)$ as a function of time which can change every period. Take $t_1 = 0$ and $t_n = T$ as a relocation-location point from the total n existing demand location points with m requests. Calculate

$$w_i^j = \int_{t_j}^{t_{j+1}} w_i(t) \, dt, j = 1, \dots, n-1, \quad i = 1, \dots, m$$

b. Set $w_i^{jk} = \int_{t_j}^{t_k} w_i(t) \, dt, k = j+1, \dots, n, \quad j = 1, 2, \dots, n-1, \quad i = 1, 2, \dots, m$ with $j < k$. For each point of request location i, calculate w_i^{jk} value for all values of j and k which are integrated with the graph weight of the i-th request location for the location of the ambulance facility at interval $[t_j, t_k)$.

c. For each interval $[b_j, b_k)$, determine the optimal value for the facility (x_{jk}, y_{jk}) with w_i^{jk} and coordinates of the location of the ambulance facility (a_i, b_i), then the optimal solution for the facility location is obtained.

d. If the location point of the new relocation facility is the same request location at the time interval $[t_j, t_k)$, calculate C_{jk}, the cost of allocating ambulance facilities using the provisions

$$C_{jk} = \sum_{i=1}^{m} w_i^{jk}\ d(X^{jk}, P_i)$$

where $d(X^{jk}, P_i)$ is the distance between the optimal location at the new request relocation location and the request location point i for $[t_j, t_k)$ and X^{jk} can be calculated in step c.

e. Calculate the relocation of the ambulance at time t:

$$\max \sum_{i=1}^{n} \lambda_i\, x_i^2 - \sum_{j=1}^{m}\sum_{l=1}^{p} M_{jl}^t\, y_{jl}$$

Constraint

$$\sum_{j=1}^{m}\sum_{l=1}^{p} \delta_{ij}\, y_{jl} \geq 1, \forall v_i \in V$$

$$\sum_{i=1}^{n} \lambda_i\, x_i^l \geq \alpha \sum_{i=1}^{n} \lambda_i$$

$$\sum_{j=1}^{m}\sum_{l=1}^{p} \gamma_{ij}\, y_{jl} \geq x_i^l + x_i^2, \forall v_i \in V$$

$$x_i^2 \leq x_i^l, \forall v_i \in V$$

$$\sum_{j=1}^{m} y_{jl} = 1, l = 1, \ldots, p$$

$$\sum_{l=1}^{p} y_{jl} \leq p_j, \forall v_j \in W$$

$x_i^l = 0$ or $1, \forall v_i \in V$
$x_i^2 = 0$ or $1, \forall v_i \in V$
$y_{jl} = 0$ or $1, \forall v_j \in W$ and $l = 1, \ldots, p$

IV. CONCLUSION

In this paper, an ambulance relocation model has been introduced by modifying the Maximal Expected Covering Location Problem (MEXCLP) model with the probability that each demand location is estimated for the total number of existing locations. In this study, a simulation model of the medical emergency service system was used, namely the number of emergency calls and available ambulance units that were allocated to ambulance units returning to their respective posts. This research represents the development of the MEXCLP model in the form of a linear program with a constraint value of 0-1 for the variable γ_{ij} which states the point of location of the request for an ambulance unit and δ_{ij} which states the allocation status of an ambulance unit at location i, in order to obtain a model that can be used to determine the departure and relocation of the ambulance at the available request location.

The relocation model for ambulance facilities needs to be developed, especially the dynamic program structure by simulating the ambulance relocation model according to accurate ambulance allocation time data. Further modification of the relocation model is expected to provide a more efficient model for the Emergency Medical Services (EMS) emergency service unit.

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