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Original Article

Development a Heuristic Method to Locate and Allocate the Medical Centers to Minimize the Earthquake Relief Operation Time

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Abstract

Background: Location-allocation is a combinatorial optimization problem, and is defined as Non deterministic Polynomial Hard (NP) hard optimization. Therefore, solution of such a problem should be shifted from exact to heuristic or Meta heuristic due to the complexity of the problem. Locating medical centers and allocating injuries of an earthquake to them has high importance in earthquake disaster management so that developing a proper method will reduce the time of relief operation and will consequently decrease the number of fatalities.

Methods: This paper presents the development of a heuristic method based on two nested genetic algorithms to optimize this location allocation problem by using the abilities of Geographic Information System (GIS). In the proposed method, outer genetic algorithm is applied to the location part of the problem and inner genetic algorithm is used to optimize the resource allocation.

Results: The final outcome of implemented method includes the spatial location of new required medical centers. The method also calculates that how many of the injuries at each demanding point should be taken to any of the existing and new medical centers as well.

Conclusions: The results of proposed method showed high performance of designed structure to solve a capacitated location-allocation problem that may arise in a disaster situation when injured people has to be taken to medical centers in a reasonable time.

Keywords: Location-allocation, Optimization, Medical center

Introduction

The location-allocation problem belongs to NP-HARD problems which get complicated exponentially by the increase of the number of service centers and customers. As a consequent, the exact and mathematical techniques cannot be applied in many cases, so the proper heuristic methods should be utilized depending on their structures and topics. Li and Yeh (1) classified most of the location- allocation problems as NP hard optimization. If the problem is NP hard, solution of that problem should be shifted from exact to heuristic or Meta heuristic due to complexity of the problem, so meta heuristic solution like genetic algorithm have been exploited to solve location-allocation problem (2). Since majority part of data and analyses applied in the location-allocation problems are spatially reference, GIScience's abilities can be utilized beside optimization methods, simulations and different allocation analyses for better solving these problems (3).

Researches reveal that time is a vital element in reduction of casualty after the earthquake, as the first 24 hours is the most significant time for saving victims, because the possibility of surviving is higher for the victims in these hours (4). Previous studies showed that one of the major medical problems in casualties like earthquake is from delayed medical care (5); therefore the reduction of rescue operation will decrease number of fatalities. One part of this operation is to allocate victims to different medical centers in minimum time. So, development of an appropriate method for optimizing the process of allocating victims to several existent medical centers can help lessen the casualties of an earthquake. Developed models for resource allocation of relief operations can be classified into two different categories of rescue and transport casualties after disaster, and logistics problems to deliver supplies into the disaster-affected areas. While so far, some researchers have worked on resources allocation in relief operations in natural disasters (6-8), other researchers have established some models on logistics problems to deliver supplies into the disaster-affected areas (9, 10).

Despite the significant number of works carried out in the literature, very few researches have been performed in Iran to employ the GIS techniques and artificial intelligence methods for disaster management. In particular, most of the works have concentrated on the statistical aspects of the casualties in earthquakes. Here, we designed and implemented a heuristic method based on two nested genetic algorithm. This method was developed to site selection of Medical centers to achieve optimum allocation of earthquake injuries by using the abilities of GIScience.

Materials and Methods

In this location and allocation optimization problem, demanding points are earthquake injuries located at building blocks. The number of injuries in each of these building blocks shows the number of demanding for any of these points. Another effective parameter is roads network which contains the information of roads blockage and required time of travel for each segment of these roads to calculate the optimal path cost based on time parameter for taking victims from various points to medical centers. The last element in this allocation process is the information of location and service capacity of medical centers.

We postulate that the capacity of J available medical centers is not sufficient for all demanding points' requirements and it is necessary to establish N new medical centers. To establish these new medical centers, there are K potential suitable locations.

In this allocation process the following conditions must also be satisfied:

- The time of relief operation should be minimized.
- All of the injuries must be serviced.
- Each facility center must accept the injuries only as many as its capacity.

Regarding the aforementioned issues, the target function can be defined as follows:

Parameters:

p_i : number of victims in point i

C_j : Capacity of medical center j.

C_k : Capacity of K potential medical centers which N number of them will be established.

p_{ij} : Number of victims in point "i" who are serviced by medical center "j".

p_{ik} :Number of victims in point "i" who are serviced by K potential medical centers which N number of them will be established

N : Number of medical centers that should be established.

Decision variables

t_{ij} : Time of traveling from point "i" to medical center "j"

t_{ik} : Time of traveling from point "i" to K potential medical centers which N number of them will be established.

α_{ij} : Proportion of victims in point "i" who are serviced by medical center "j".

α_{ik} : Proportion of victims in point "i" who should be serviced by K potential medical centers which N number of them will be established.

$$x_k = \begin{cases} 1 & \text{If medical center exists in the suitable area} \\ 0 & \text{If medical center doesn't exist in the suitable area} \end{cases}$$

The formulation for the problem is as follows:

$$\min \sum_i \left(\sum_j \alpha_{ij} P_i t_{ij} + \sum_k \alpha_{ik} x_k P_i t_{ik} \right) \qquad [1]$$

Subject to:

$$C_j + C_k \geq \sum_i \left(\sum_j P_{ij} + \sum_k P_{ik} \right) \qquad [2]$$

$$P_i = \sum_j P_{ij} + \sum_k P_{ik} \qquad [3]$$

$$\sum_k x_k = N \qquad [4]$$

The objective function 1) minimizes the total time needed for taking victims to the new and available medical centers. Constraint 2) shows that none of the new and available medical centers accept more injuries than its capacity. Constraint 3) ensures that all the injuries at any location of demanding points should be serviced and constraint 4) guaranties that the number of new established medical centers should be equal to N.

Development a heuristic method to minimize the relief operation time

Three problems can be defined in order to optimize the cost parameter used for minimizing the relief operation time:

1. The first problem is to calculate the optimal path cost based on time parameter for taking victims from various points to medical centers which are t_{ij} and t_{ik} in target function. This problem will be solved by finding the best path with the minimum time cost.
2. The second one is to find an appropriate method for iterative process to place N new suitable centers and evaluating the quality of combination and allocation of new and existing centers.
3. The third problem is to calculate the parameters of α_{ij} (Proportion of victims in point "i" who are serviced by medical center "j") and α_{ik} (Proportion of victims in point "i" who should be serviced by medical center "K") so that the designed target functions optimized and the constraints in Equations 2 and 3 would be guaranteed.

The results of the first problem which will be used for solving the second and third problems could be extracted as follow. First of all, it is necessary to prepare the input layers of roads network, building blocks, existing and potential medical centers. These layers must also contain the information of roads blockage, required time of travel for each segment, the number of victims in each building block and the capacity of medical centers. Second of all, network dataset is created from input road layers and attribute data. Moreover, all building blocks and medical centers which have polygonal identity are converted into point features and then these point layers are projected into network dataset using proximity analysis. Finally, the O-D Cost analysis is used to calculate the optimal path cost based on time parameter for taking victims from various points to medical centers which are t_{ij} and t_{ik}. Fig. 1 generally shows this process of treating the first problem in ARC-GIS software.

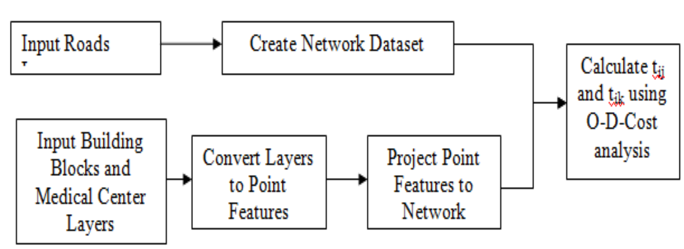

Fig. 1: Flow diagram corresponding to calculate the optimal path cost based on time parameter

Two nested genetic algorithms were applied to solve the second and third problems. In this proposed method, the inner algorithm is designed for optimal allocation which determines the proportion of victims in the demand points serviced by existent and new selected medical centers. The outer algorithm is designed to select the best places for N new medical centers from K potential existing places. These two algorithms are solved simultaneously to achieve the convenient optimization. The next step is to define the criteria to stop or iterate the process based on the quality of achieved results. Here, we applied one stopping criterion. The iteration process will be stopped if the result of 20 last successive generations remains unchanged. These steps were also implemented based on two nested genetic algorithm by programming in Matlab software. Fig. 2 depicts the global structure of two nested genetic algorithms.

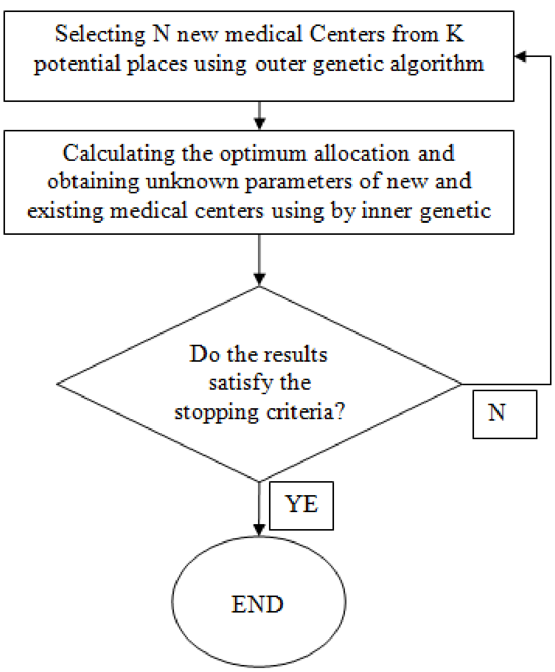

Fig. 2: Structure of two nested genetic algorithms

Since there are also some parameters in implementation of the genetic algorithm, we briefly explain how to apply them in our solving capacitated allocation problem.

Cost function: The target function (Cost function) has been designed for solving this allocation problem and its required constraints are based on Equation 1, 2, 3 and 4.

Chromosome: A matrix chromosome was used to solve the allocation problem (in the inner genetic) which its genes are the arrays of this i*(j+N) matrix. In the outer genetic algorithm that is used to find the N facility centers out of K proper existing places, a chromosome is compounded from a coordinate set of N newly selected points. This chromosome is composed of 2N gens which contain X and Y coordinates of points selected among K potential places.

Initial population: In this study depending on the complexity, the size of population may increase or decrease.

Coding method: Integer encoding was utilized in this research since the unknown variables in the structure of problem are integer form.

Reproduction: The reproduction operator is also called selection operator. Different techniques including single-point, two-point crossover and heuristic technique can be mentioned as combining operators that cannot be claimed which one is better based on Deb theory (11). Therefore, the combining method is selected according the problem conditions and tact. Two-point crossover was applied as a combining operator in this research. In addition, another concept should be outlined here called crossover fraction. This concept indicates the probability of combining indexed by p_c and its value is between 0 and 1. Researches on the parameters of genetic algorithm show the optimal value for crossover operator is between 0.15 and 0.75 (12). In this research, value 0.7 was selected for crossover fraction.

The mutation is the next step after crossover. The mutation of a gene includes conversion of values 0 to 1or vice versa based on a small probability which is the probability rate of mutation of every bite. Some researchers suggest values between 0.01 and 0.05 for the probability rate of mutation (12). The value 0.04 is used for that in this research.

Case study data

Different cases of number of injuries, location of injuries, capacity and number of medical centers were used to evaluate the efficiency of proposed algorithm. Here, the results of one of these implemented are presented.

The central part of region no.17 of Tehran was selected as a case study of this designed algorithm. Its population and density is respectively 32239 persons and 465 people per hectare, and the total number of building blocks is 4843. A disaster scenario of 18 blocked pathways and 3 medical centers were considered. In this scenario, 50 building blocks demonstrating places of victims with a total number of 536 victims were assumed and the capacities of three hospitals were supposed to be 150, 100 and 50. Study area and spatial distribution of injuries in the described scenario is shown in Fig. 3.

Since the existing medical facilities cannot obviously serve to all injuries, establishing two new medical centers with 250 capacities was considered as a solution in this scenario.

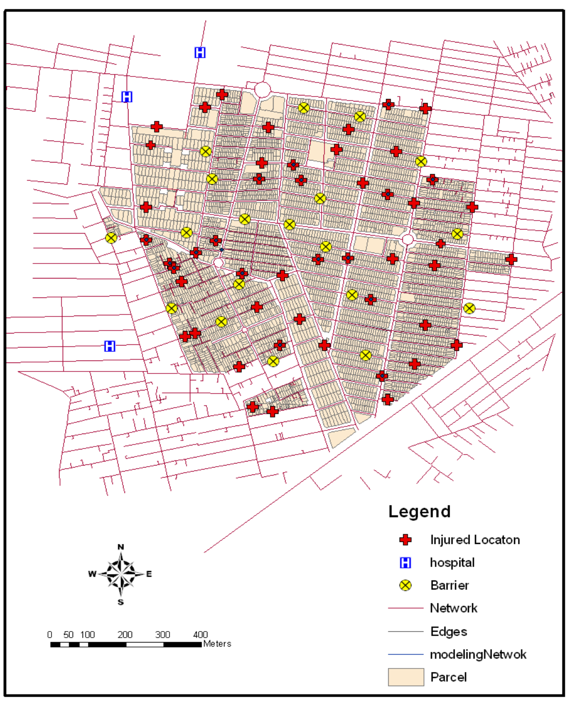

Fig. 3: Spatial distribution of injuries in the described scenario

To establish two new medical centers, nine potential places in the study area were selected whose locations are shown in Fig. 4.

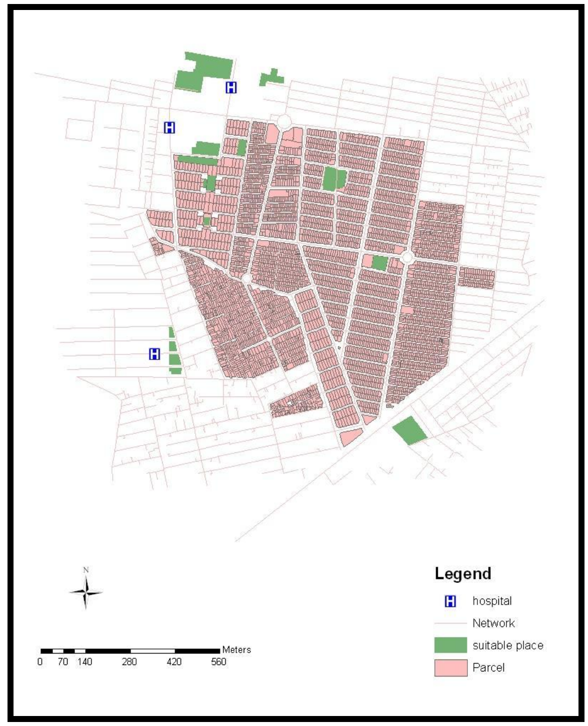

Fig. 4: Spatial distribution of potential places in the described scenario

Results

Considering the defined scenario, implementation of designed methodology was performed by the use of a computer with the following specifications:

Intel(R) Core(TM) 2 Duo CPU, E 8400 @300 GHZ, 2 GB OF RAM

As mentioned before, the core of our processing includes three stages.

The first step stands for calculating the optimal path cost based on time parameter for taking victims from various points to medical centers which are t_{ij} and t_{ik} in target function. This step was carried out on the basis of above explained methodology in ARCGIS software. Fig. 5 shows the results of this process containing shortest path between victims and a medical center.

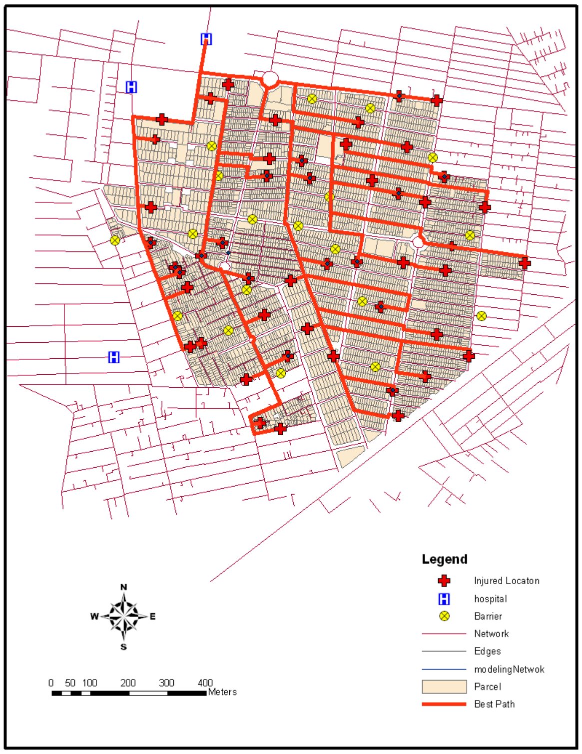

Fig. 5: the shortest path based on travel time between 50 places of victims and a medical center

The second step of our processing include finding an appropriate method for iterative process to place N new suitable centers and evaluating the quality of combination and allocation of new and existing centers and the third one consists of calculating the parameters so that the cost function optimized .These two steps were also implemented based on two nested genetic algorithm by programming in Matlab software. The processing was stopped after 17 minutes and 9 seconds at the time of reaching to the 64th generation. The processing stopped because the stopping criterion was satisfied and the required results were obtained. Figure 6 depict the target function values of the processing in different generations.

One of the main results achieved by the algorithm is the location of two selected medical centers out of 9 potential places. Fig. 7 shows the spatial location of these two selected centers.

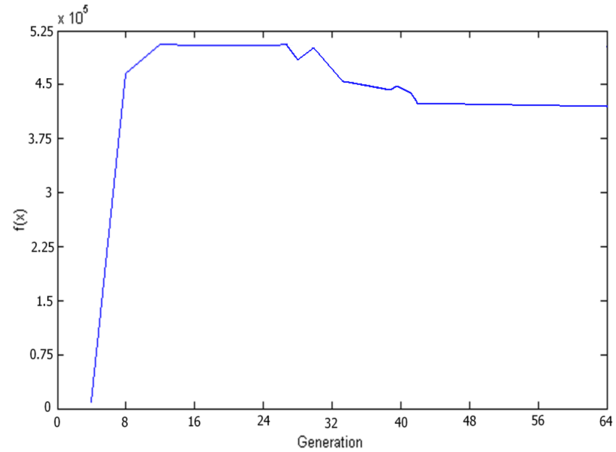

Fig. 6: Optimal values of target function in different generations

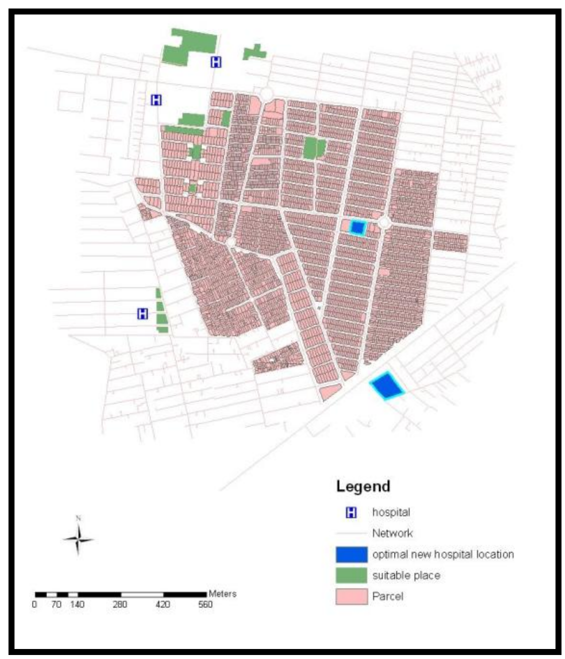

Fig. 7: The location of two medical centers selected from 9 potential places

The other main outcome of our processing shows the number of victims which should be serviced by different exiting and new selected medical centers in each point. Table 1 includes some of these victim points and the number of victims for each point which should be serviced by different existing and new medical centers.

Table 1: Number of victims serviced by existing and new selected medical centers in the scenario for a set of victim points

Victim point number	New selected medical center no.1	New selected medical center no.2	Exiting medical center no.1	Exiting medical center no.2	Exiting medical center no.3
1	0	1	0	0	0
4	2	0	0	0	0
14	0	0	0	4	2
20	2	0	10	0	4
23	0	4	2	0	12

Discussion

Location-allocation problems falls into NP-HARD group of problems. Hence, the heuristic methods could be appropriate to solve them. On the other hand, since majority part of data and analyses applied in the location-allocation problems are spatially reference, GIScience's abilities could be utilized along with optimization methods. Most of the studies in Iran regarding the situations of injuries relief operations usually had only a simple graphical or statistical aspect of disaster data. As an example, Ganjouei et al (5) investigated the injuries pattern and their spatial distribution. They also considered the relief operation process and the problems of services in medical centers as well. They finally proposed to establish a disaster registration system in Iran. Studies like this do not end up with any solution for active decision support with optimum resource allocation in relief operations.

Some other researchers have worked in other countries (6-8). Gong and Batta looked for determining the required number of ambulances for optimum rescue operation in the affected area. Then, they optimized their developed model with changing the situations of damaged area and relief operation in the newly identified areas as being affected. Their used method for optimizing the presented model was deterministic which had the ability of solving the small size of allocation problems. Moreover, they didn't present any solution for determining the shortest path in relief operations.

Paul and Batta studied the hospital location and allocation optimization problem with respect to different scenarios of earthquake and hurricane disasters. In their first part of work, a model of optimum site selection of hospitals regarding their service capability was introduced. The second part of their study included working on reallocation of capacity among hospitals to increase the effectiveness of their work considering the changes of relief operation conditions. Again, although this study included a method for shortest path and moreover, the intelligent optimization methods had been used for solving model, the hospital site selection and injuries optimum allocation were performed separately. If these two problems were being solved simultaneously, it could have improved the results.

Jotshi et al (8) also developed a GIS-based methodology for management of dispatching and routing of emergency vehicles (EVs) in a post-disaster environment with the support of data fusion. They searched for determining the best vehicle and optimum path to dispatch for each effected cluster and service the injuries there. Although they used a proper GIS-based method for determining the best EV to dispatch to the affective area with respect to their location and routing EV for taking the injuries to medical centers, their work lacked of an optimization model for allocation considering all of the injuries.

Here, we designed and implemented a heuristic method based on two nested genetic algorithm to site selection of Medical centers and achieve optimum allocation of earthquake injuries by using the abilities of GIScience. This implementation included three major steps of calculating optimal path cost, finding an appropriate method for iterative process to place N new suitable centers and calculating optimum allocation. First step were performed by using a GIS method and to solve the second and third steps, a two nested genetic algorithm were used.

To evaluate the efficiency of designed algorithm, a scenario for number of injuries, location of injuries, capacity and number of medical centers and roads network status and information was defined. The results showed that the designed structure is able to optimize the process of transporting the earthquake casualties to the treatment centers. The method also calculates that how many of the injuries at each demanding point should be taken to any of the existing and new medical centers as well.

In the current research, all the injuries are considered to have the same severity. However, the routing of the injuries needs to consider this severity so as to minimize the number of human losses. Similarly, it is necessary to consider survivability time.

In this study, the main objective was to minimize the time of taking injuries to appropriate medical centers regarding the capacity of medical centers, road conditions and spatial distribution of earthquake victims. Moreover, this paper worked on solving the problem of optimizing the available resources to minimize the operation time for injury pickup and transportation, and to minimize number of human fatalities.

Conclusion

The proposed methodology could be employed to develop a real-time decision support tool to use in preparedness and response phases of disaster management which will improve the emergency response, and could also be used for planning to establish new medical centers in convenient locations regarding areas prone to earthquake

Ethical considerations

Ethical issues (Including plagiarism, Informed Consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc) have been completely observed by the authors.

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