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A two-stage mathematical model for evacuation planning and relief logistics in a response phase

Hasti Seraji [1], Reza Tavakkoli-Moghaddam [2*], Roya Soltani [3]

[1] *School of Industrial Engineering, South Tehran Branch, Islamic Azad University, Tehran, Iran*
[2] *School of Industrial Engineering, College of Engineering, University of Tehran, Tehran, Iran*
[3] *School of Industrial Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran*
hasti.seraji@yahoo.com, tavakoli@ut.ac.ir, royasoltani@alumni.iust.ac.ir

Abstract

Crises and natural disasters are always existed in human history, and continue to exist in the future; therefore, people are always affected by these natural disasters. Hence, evacuation planning after natural disasters (e.g., earthquakes, floods, tsunamis, fire, storms, warfare and nuclear explosions) is vital. Given that natural disasters cause irreparable financial loss and the loss of life every year for governments and communities, one of the important issue addressed in all countries is crisis management in recent years. By improving the conditions after natural disasters, this paper presents a two-stage mathematical model to improve post-earthquake conditions. The first stage investigates the locations of shelters for the primary accommodation of people, the location of first aid warehouses, and distances travelled by people from crisis areas to shelters in the event of the earthquake. Furthermore, relief and coverage of demands after accommodation of people in shelters are studied in the second stage of the proposed model. Then, the integer linear programming model is solved in GAMS software. Finally, the obtained results are analysed.

Keywords: Humanitarian behaviour, evacuation planning, shelter and warehouse selection, relief logistics, crisis management

1- Introduction

Natural disasters (e.g., earthquakes, floods and storms) impose a great deal of financial loss and loss of life every year to different governments and societies. In recent years, an important issue addressed in all countries is that of management and confrontation with critical conditions, and all countries need to be capable of managing and encountering these horrible events. Within the past 27 years, 3.9 million people have been killed around the world as a result of natural disasters, and a loss of 260 million dollars has been incurred by countries. About 75% of people in the world live in regions that have undergone events (e.g., earthquakes, storms, floods and drought) at least once during that period. The disasters and crises resulting from natural energies are an experience shared by many countries. Available evidence suggests that natural disasters cause irreversible casualties, psychological traumas, and financial losses in different parts of the world every year. Furthermore, the number of natural

*Corresponding author
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disasters has had an upward trend rather than decreased over time. Reports provided from 2009 to 2017 indicate this dramatic increase (Natural disasters in the world have quadrupled, 2017).

The comprehensive investigation of the consequences of natural disasters in the past demonstrates that more than half of these losses originate from the earthquakes. Over 1000 destructive earthquakes have occurred in 70 worldwide countries in the recent century. Table 1 shows that China, Japan, Iran, Turkey, India, Chile, Pakistan, and Guatemala are recognized as regions with the highest earthquake risks, associated with around 80 percent of the earthquakes that have occurred.

Table 1. Statistics related to the world's most important earthquakes

No.	Year	Location	Magnitude (Richter)	Loss of life (People)	No.	Year	Location	Magnitude (Richter)	Loss of life (People)
1	1556	China	8.1	830000	16	2005	Pakistan and India	7.6	250000
2	1908	India	7.9	300000	17	2008	China	7.8	87600
3	1908	Italy	7.5	120000	18	2010	Haiti	7	316
4	1920	China	7.5	180000	19	2010	Chile	8.8	500
5	1923	Japan	8.3	143000	20	2011	Turkey	7.2	600
6	1927	China	8.3	200000	21	2011	Tokyo	8.5	16000
7	1939	Chile	8.3	30000	22	2012	Iran	6.4	300
8	1970	Peru	7.8	66000	23	2013	Pakistan	7.7	825
9	1976	China	8.1	255000	24	2014	China	6.3	600
10	1976	Austria	7.6	24000	25	2015	Nepal	7.8	8000000
11	1988	Armenia	7	45000	26	2015	Afghanistan	6.8	400
12	1990	Iran	7.7	50000	27	2016	Ecuador	7.8	650
13	1999	Turkey	7.4	17000	28	2016	Italy	6.2	300
14	1999	Taiwan	7.3	12400	29	2017	Mexico	7.1	369
15	2004	Iran (Bam)	6.5	40000	30	2017	Iran (Kermanshah)	7.2	Unspecified

The statistics obtained during the past years demonstrate that the number of events has dramatically increased, about six times higher than in 1980. At least three human factors have been identified by experts as the most important reasons for the increase in the number of natural disasters (Monthly earthquake statistics in Iran, 2017). Economic losses at the national level and secondary psychological and sociological effects are the results of the damage to products and destruction of food materials, disruption of flows production, disruption of the ordinary flow of life, destruction of livelihood status, disruption of the ordinary process of providing necessary services, damage to infrastructures and governmental systems. All these items require disaster management in all countries as an important issue in the recent years. Disaster management can be regarded as a series of regulations defined for mitigation of or confrontation with the probable hazards of any natural or unnatural crisis. It is of great importance to plan evacuation after the occurrence of the natural disaster (e.g., earthquake). Evacuation planning includes a large number of items, such as evacuation routing, different types of required vehicle for evacuation, evacuation scheduling, routing, allocation, distribution of required relief supplies, and reliability of routes. Given the type of event and priorities, there are different types of evacuation, methods of relief provided for the location of the event, and demands and durations of evacuation.

One of the most important issues is to study earthquakes and consider the necessities required encountering it. Therefore, two phases, namely preparedness and response are examined in this research in a disaster management system when the earthquake occurs. The present research is focused on the location of shelters and warehouses in the event of an earthquake, since shelters hold the necessary conditions and criteria, and people travel the shortest distances to take the shelters. Furthermore, a new two-stage model is presented in this research in order to cover people's demands after they take refuge in the selected shelters. Moreover, cost statements (e.g., travel and idle vehicle costs) are considered in the objective function of the proposed model.

The remainder of the paper is organized as follows. The theoretical foundations of the study and the literature on the topic are examined in section 2. Section 3 is dedicated to the introduction of the proposed two-stage mathematical model. Data analysis and computational results are presented in section 4. The conclusions and suggestions for future studies are provided in section 5.

2- Literature review

At the beginning of this section, some notions in this research area are defined. A particular case is referred to an event caused by an external agent (e.g., nature or man) unpleasantly affecting people's lives and environment (or the environment without people), in which the consequences lead at later stages to a crisis and eventually to a disaster. The step following an event is an accident, which is actually a horrible occurrence striking several aspects of people's lives and environment. Extension of an accident is considered as one of the factors causing a crisis, which causes naturally, by man, or suddenly and increasingly. It also imposes difficulties on the society that requires emergency, substantial, and extraordinary measures to be eliminated Tavakkoli and Razmi (2012).

International City/County Management Association has defined and classified cyclic crisis management as follows:

- Mitigation: a series of long-term measures taken for reduction or elimination of hazards of natural and technological disasters in order to save people's lives and property,
- Preparedness: a series of measures taken to increase operational capability and facilitate effective reaction against an event that may occur in future,
- Response: a series of measures taken during or after the occurrence of an event to save people's lives and minimize damage to their property,
- Recovery: a series of long-term measures taken for regaining facilities Rahnavard and Mohammadpour (2013).

Following, the studies available in the research area are examined. Rahman and Smith (2000) presented a review article in the area of location and allocation in planning health service development in developing countries, where health care has been unavailable due to geographical weakness. Balcik et al. (2010) studied the earlier research on coordination of humanitarian measures, and described the coordination in the current measures in relief and humanitarian aid. Mete and Zabinsky (2010) presented a crisis management optimization approach for storage and distribution of medical materials problem. The proposed two-stage model addresses the warehouse location at the first level and transportation planning at the second one. Li et al. (2011) studied a logistic model for relieving people with goods in conditions following natural disasters considering goods prioritization. They considered multiple periods, multiple vehicles, and multiple strategies in their study. Bish et al. (2014) presented a model of emergency evacuation in critical conditions for planning and utilizing in order to minimize hazard. They classified the hazards into two groups: 1) evacuation hazard in critical conditions and 2) patient transportation hazard.

Lin et al. (2012) investigated the location of temporary warehouses around the crisis area considering transportation equipment and logistics resources and utilization. Chen et al. (2012) studied the effectiveness of supply chain line recovery strategies lost as a result of the occurrence of unanticipated disasters. Yushimito et al. (2012) studied the specification of a limited number of distribution centers to investigate short response time for relief from natural disasters considering social costs. Zanjirani Farhani et al. (2012) conducted a review study of covering problems due to their ever-increasing application, particularly in real-world problems. Afshar et al. (2012) studied integrated supply chain logistics in relief operations in their research given the importance of resource and staff transportation for maximization of real-time covered population and reduction of operating cost in conditions following natural disasters. Edrissi et al. (2013) presented a formulation for coordination in the problem of retrofitting organization planning in vulnerable regions.

Najafi et al. (2013) proposed a multi-objective, multi-article, and multi-period stochastic model for logistics management. The model includes consideration of goods and people for the confrontation with an earthquake. Barzinpour et al. (2014) studied natural disasters to locate a two-stage relief chain. Abounacer et al. (2014) presented a model with three contradictory objectives to determine the number and locations of humanitarian aid distribution centers in the disaster area. The objectives include minimization of the total time required for transportation of the demanded products from the distribution centers to the demand points, the number of factors required for selection of distribution centers, and the number of uncovered demands. Goerigk et al. (2014) investigated the problem of evacuating an urban area considering different aspects of evacuation (separately). Having studied the previous research, Wang and Sum (2014) investigated four aspects of evacuation (i.e., population, evacuation modeling, evacuation decision-making, and evacuation risk assessment). Goerigk et al. (2015) investigated bus fleet scheduling for evacuation of people from the endangered area before the occurrence of a disaster. Nappi et al. (2015) investigated important criteria and aspects using a multivariate model for hazard management, particularly in regard to transferring people and sheltering the injured population temporarily. They also identified the qualitative and quantitative aspects and expressed them as ten criteria.

Bayram and Souza (2015) developed an optimization model for the location of shelters and the allocation of evacuation zones to the closest shelters to minimize the evacuation time. Ng et al. (2015) studied planning for the evacuation of populations of the sick and the weak and the differences between these two groups of people in the time required for evacuation. Li et al. (2015) investigated congestion in unpredictable events. Since evacuation routes are often prone to congestion, this research has led to the development of a primary model of crowd movement along evacuation routes and accurate analysis of population density. Chen et al. (2015) studied the effect of unpredicted events on supply chain members. Khayal et al. (2015) presented a novel model for temporary facility distribution planning for reaction in emergency conditions and specification of temporary facility distribution and resource allocation in such conditions.

Kılcı et al. (2015) addressed shelter location by considering people's need for shelter after the occurrence of natural disasters. Shahparvari et al. (2016) presented a multi-objective integer programming model for investigating the reliability of the routes available for evacuation and collection of people from the crisis area to the predetermined locations, i.e. shelters. Cavdur et al. (2016) addressed the allocation of local facilities and equipment as a temporary response to natural disasters and allocation of facilities for disaster relief operations upon the occurrence of an earthquake. Wood et al. (2016) investigated pedestrian evacuation in regard to tsunami hazards and prioritization of densely populated areas. Bellomo et al. (2016) studied people's behavior and disaster management in abnormal conditions. Goerigk et al. (2018) investigated hybrid optimization problems using the solution ranking method and determining solution robustness. Rabbani et al. (2018) studied hospital evacuation under uncertainty conditions. The purpose of this research is to simultaneously minimize the total evacuation time and the total weight of patients not evacuated in each period, where patients in critical conditions are prioritized. Pillac et al. (2016) in fact investigated the problem of evacuation process and evacuation plan optimization because evacuation planning and scheduling is a fundamental aspect of disaster management and national security.

Vermuyten et al. (2016) studied optimization models for the pedestrian evacuation problem, pedestrian behavior, and population dynamicity. Wang et al. (2016) predicted evacuation planning by considering peripheral restrictions and scenarios based on travel time and capacity. Yilmaz et al. (2016) presented a multi-objective decision-making model for the location of disaster response centers. Saeidian et al. (2016) stated that the sufficient coverage of urban areas is an important issue, just as an important stage in earthquake management is to set up temporary relief centers to back up first aid in the short run. Trivedi et al. (2017) presented a hybrid multi-objective decision-making model for management of the location/relocation of projects based on the hierarchical process with a fuzzy theory. Pérez-Galarce et al. (2017) developed a flexible plan for the problem of locating shelters and allocating victims after a disaster using an optimization approach. Perrucci et al. (2016) investigated the increase in the global need for temporary dwelling due to the increase in the number of natural disasters. Duque et al. (2016) suggested that the number of casualties after natural disasters increases with a lack of clean water, food, shelter, and health care.

Tavakkoli et al. (2008) studied the conditions of provision, preservation, and distribution of food in Bam County, having undergone an earthquake. Shoja Araghi et al. (2011) addressed the optimal location of disaster management bases. They also stated in their research that a point to be noted before construction of these relief bases is to investigate and select the geographic locations appropriate for the establishment of shelters. Ahmadi et al. (2013) presented a model of relief logistics with the mixed-integer nonlinear programming approach considering the destruction of transportation routes after the occurrence of an earthquake and the international standard time of relief using spatial information for the location of local centers for relief goods distribution and routing of transportation means. Mohammadi et al. (2014) collected the information required for the process of secure emergency evacuation in a practical case. Alinaghian et al. (2015) presented a relief vehicle routing model for covering tour routing in the affected area.

Aalami et al. (2017) considered that at the time of disaster, people prefer to evacuate the critical area by foot and with their personal belongings. This personal equipment as a part of evacuation can increase the travel time. Allocation of the transportation resource in the emergency evacuation is studied since the personal requirement causes massive traffic and multiple accidents, which leads to road blockage. The aim is to find a method for the resource allocation in the evacuation process that is fair, reasonable, efficient, dynamic and consistent with incident circumstances. This research contains four important issues for evacuation, namely maximum output rate, minimum allocation time, maximum social welfare and fair allocation. In addition, a dynamic model is referred that is a change in an evacuated population parameters, travel time, disaster intensity, fleet size, etc.

Boonmee et al. (2017) studied the problems before and after the disaster including location of distribution centers, warehouses, shelters, landfills and medical centers. They also categorized all humanitarian problems according to various modelling methods, different problems and considered the conditions before and after disaster. These problems were dwelled the location, maximum covering problem, minimum response time and minimum evacuation time, minimum time that contains: transportation time (or distance), fixed cost of facility, operational costs and costs of demands that are not investigated. They considered these four main problems as both deterministic and non-deterministic problems.

Behl et al. (2018) reviewed 362 papers from 2011 to 2017, in which focuses on nine main issues in a supply chain interested by researchers. These main issues were humanitarian provisions, mathematical model, humanitarian supply chain characteristics, and essential resources for efficient management of the humanitarian operation. These papers have been categorized from different aspects, such as subject and quantity in different years.

Loree et al. (2018) investigated the location of distribution points for humanitarian provisions. The proposed model reduces the deprivation cost through determining location and distribution points and inventory allocation in human procurement, whose results in the costs have incurred by the survivors' non-availability to critical resources. They also considered facility and provision costs. This model allows demand points to receive service from different points, which is important under the conditions that inventory cannot cover a demand point. The proposed model optimizes distribution points and their location for determining and minimizing social costs considering different resources. Each point receives service from the closest distribution point in order to minimize the transportation and provision costs. Also, in this study, the shortage is considered so that a distribution point can receive service from every other distribution points if the distribution point has low inventory regardless of the distance.

Xu et al. (2018) presented a multi-purpose model in location and shelter allocation problem for evacuation in the earthquake. According to the shelter site and their allocation as an important part of disaster management, a multi-objective model was presented and the objectives were as follows: total shelter number, total evacuation distance, evaluating weights of evacuation time and total shelter space. In this study, the model that contains candidate shelters, distributing population and assigning them to the shelters was investigated by using safety, capacity and investment evaluation. In this model, the first objective function was the total number of shelters and shelter area and the second objective function was the total evacuation distance and the weight of evacuation time. The presented model was implemented in Beijing, which results in 85 solution methods for the four objective functions of the considered problem and these methods were evaluated through different indices and factors.

3- Description of the problem and mathematical model

Since natural disasters are unpredictable, organizations are obliged to provide the essential facilities by predicting the post-disaster conditions. For this purpose, a two-stage mathematical model is introduced for the location of shelters and warehouses and also the people allocation from the crisis area to the shelters. Demand coverage of shelters for relief in critical conditions is investigated here, and it is stated how people are relieved after being sheltered.

This study represents an integrated model, which contains critical management before and after the disaster. In the first level, selection of shelters and warehouses before the disaster is carried out and in the second level, allocation of goods after the disaster is mentioned. In this model, shelters are selected considering the weight of criteria among candidate shelters and the closest warehouse is assigned to shelters. As a result, the distance between critical areas and shelters is minimized in times of disaster. The second level of model considers delivery cost with allowed delay, delivery cost with non-allowed delay, delivery cost of goods from warehouses to shelters and injustice cost in distributing goods. If there is a delivery with non-allowed delay, the goods are not delivered to people and injustice costs play the main role due to the intense reaction of people in times of disaster facing injustice, which worsen the critical conditions. Also, it considers the cost of idle vehicles in warehouses.

- There is no partial delivery in this problem. That is, people cannot attend warehouses themselves to receive goods, and a demand at any point is met only with a vehicle.
- People who need to be hospitalized are injured, and those who are cured as outpatients are considered as healthy people.
- The preparedness and response phases are studied in this research, and the others are excluded.
- There are two types of vehicles (i.e., buses and ambulances) for evacuation of people.
- Vehicles at the disposal of a warehouse are all the same with the similar capacity.
- The time of each voyage begins for distribution of goods at a warehouse and ends at a shelter.
- If goods are delivered with disallowed delay, they will not be received by people.
- Time ranges in this research are considered discrete.
- Warehouses are all the same with the similar capacity.
- The number of vehicles needed by a warehouse is pre-determined.
- Points selected for construction of shelters are optimal ones selected from among the introduced candidate points.

Following, we describe the sets, indices, parameters, decision variables, objective functions, and constraints in the model.

3-1- Sets and indices

J	Set of crisis areas
K	Set of routes
k_{ji}	Set of numbers of routes between crisis area *j* and shelter *i*
k_{pi}	Set of numbers of routes between warehouse *p* and shelter *i*
O	Set of vehicle types required for evacuation of people from crisis areas to shelters
P	Set of warehouse
I, I', I''	Set of shelter
m	Type of vehicles required for evacuation of people from crisis areas to shelters
p	Warehouses
i, i'	Shelter
j	Crisis area
k_1	Route between crisis areas and shelters
k_2	Route (arc) between warehouses and shelters
n	Type of goods
l	Vehicle counter for transportation of goods from warehouses to shelters
t	Time

3-2- Parameters

Cap_i	Capacity of shelter *i*
p_n	Cost of penalty for delivery of goods to shelters with allowed delay
c_m	Capacity of vehicle *m*
μ	Total number of temporary warehouses
a_n	Unit weight of goods *n*
b_n	Unit volume of goods *n*
ω	Maximum shipment weight capacity of each truck
F	Maximum shipment volume capacity of each truck
E	Maximum number of shelters that can open, given administrative, financial, and other issues
N	Minimum number of warehouses allocated to each shelter
N'	Maximum number of warehouses allocated to each shelter
fp_n	Cost of penalty for delivery of goods to shelters with disallowed delay
p_{health}	Probability that people are healthy
U_n^p	Amount of an article of type *n* available at warehouse *p*
d_{jik}	Distance from crisis area *j* to shelter *i* on route *k*
d_i^{health}	Distance from shelter *i* to the closest healthcare center
$DistRoad$	Maximum allowed distance from the shelter to the main road
d_i^{road}	Distance from shelter *i* to the main road
Jp	Cost of parked vehicles in warehouses
$DistHealt$	Maximum allowed distance of a shelter to a healthcare center *h*
w_1	Weight of people's dissatisfaction cost upon delivery of goods with allowed delay
w_2	Weight of people's dissatisfaction cost upon delivery of goods with disallowed delay
w_3	Weight of travel cost from warehouses to shelters
w_4	Weight of injustice cost in the distribution of goods
d_{pi}	Distance between warehouse *p* and shelter *i*
$Distance$	Maximum allowed distance that people can travel from a crisis area to arrive at a shelter
α	Minimum number of people required for the alternative candidate shelter to open
β	Threshold value percentage for a shelter to open
$Demand_j$	Total demand of crisis area *j* for evacuation
Q_j	Number of vehicles to be evacuated from crisis area *j*
c_k	Cost of travel from warehouses to shelters
ζ_p	Total number of vehicles at the disposal of a warehouse (traveling or parked vehicles)
t_{kli}^p	Time of travel from warehouse *p* on route *k* to shelter *i* with the *l*-th vehicle
t_2	Allowed delay for delivery of goods from warehouses to shelters
t_3	Disallowed delay for delivery of goods from warehouses to shelters
T	Available time period

3-3- Decision variables

s_i	Cost of shelter *i* dissatisfaction
S	Cost of injustice in the distribution of goods
w_{min}	Minimum weight of a candidate site for shelter construction
σ_P	Number of available (parked) vehicles at warehouse *p*
y_p	1 if warehouse *p* is selected for the allocation of goods; and 0, otherwise
x_i	1 if site *i* is selected for shelter construction; and 0, otherwise
v_{jik}	Percentage of people that move from crisis area *j* to shelter *i* on route *k*
x_i^p	1 if demand point *i* is allocated to warehouse *p*; and 0, otherwise
a_{jik}	Number of vehicles available for transfer of people from crisis area *j* to shelter *i* on route *k*
x_{niklt}^p	Amount of goods of type *n* delivered for the demand of point *i* from warehouse *p* on voyage *k* with the *l*-th vehicle at time *t*
y_{jim}	1 if people are allocated from crisis area *j* to shelter *i* with a vehicle of type *m*; and 0, otherwise
y_{klti}^p	1 if the *l*-th vehicle travels from warehouse *p* to shelter *i* on route *k* at time *t*; and 0, otherwise

3-4- Bi-objective mathematical model

The novel two-stage mathematical model is presented below:

$$\text{Max } z = \sum_i x_i w_i \tag{1}$$

$$\text{Min } ((\sum_{i\in I}\sum_{p\in P} d_{pi} x_i^{\,p}) + \sum_{p\in P} y_p) + \sum_{i\in I}\sum_{j\in J}\sum_{k\in k_1} d_{jik}\, v_{jik}\; demand_j \tag{2}$$

s.t.

$$w_{\min} \le x_i w_i \quad ; \ \forall i \in I \tag{3}$$

$$\sum_{m\in o}\sum_{j\in J}\sum_{k\in k_1} y_{jim} v_{jik}\, Demand_j \le Cap_i x_i \quad ; \forall i\in I, k_1 \le k_{ji} \tag{4}$$

$$d_i^{healt} x_i \le DistHealth \quad ;\forall i \in I \tag{5}$$

$$d_i^{road} x_i \le DistRoad \quad ;\forall i \in I \tag{6}$$

$$\sum_{j\in J}\sum_{m\in o}\sum_{k\in k_1} y_{jim} v_{jik}\, Demond_j \ge \beta x_i Cap_i \quad ; \ \forall i \in I, k_1 \le k_{ji} \tag{7}$$

$$\frac{\sum_{j\in J}\sum_{m\in o}\sum_{k\in k_1} y_{jim} v_{jik} Demand_j}{Cap_i} - \frac{\sum_{j\in J}\sum_{m\in o}\sum_{k\in k_1} y_{ji'm} v_{ji'k} Demand_j}{Cap_{i'}} \tag{8}$$
$$\le \alpha + (1-x_i) + (1-x_{i'}) \quad ; \quad \forall i \in I\,,\, i' \in I'\,,\, i \ne i', (\mathrm{I}, \mathrm{I}' \in I''), k_1 \le k_{ji}$$

$$\sum_{i\in I}\sum_{k\in k_1} v_{jik} = 1 \quad ;\forall j \in J\,, k_1 \le k_{ji} \tag{9}$$

$$\sum_{k\in k_1} v_{jik} \le \sum_{m\in o} y_{jim} \quad ; \forall j \in J\,,\ \forall i \in I,\ k \le k_{ji} \tag{10}$$

$$\sum_{j\in J} y_{jim} \le x_i \quad ;\forall i\in I,\forall m\in o \tag{11}$$

$$\sum_{i\in I} x_i \le E \tag{12}$$

$$\sum_{k\in k_1} y_{jim} d_{jik} \le Distance \quad ;\ \forall i\in I,\forall j\in J\ ,\ \forall m\in o, k_1 \le k_{ji} \tag{13}$$

$$a_{jik} \ge \frac{demand_j v_{jik}\ p_{health}}{c(m_1)} + \frac{demand_j v_{jik}\left(1-p_{health}\right)}{c(m_2)} \tag{14}$$

$$;\forall j\in J\ ,\ \forall i\in I\ ,\mathrm{k}\in k_1, k_1 \le k_{ji}$$

$$\sum_{i\in I}\sum_{k\in k_1} a_{jik} \le Q_j \quad ;\ \forall j\in J, k_1 \le k_{ji} \tag{15}$$

$$a_{jik} \le \sum_{m\in o} My_{jim} \quad ;\forall i\in I,\forall j\in J, k\in k_1, k_1 \le k_{ji} \tag{16}$$

$$N \le \sum_{p\in P} x_i^{\,p} \le N' \ ;\ \forall i\in I \tag{17}$$

$$\sum_{p\in P} y_p \le \mu \tag{18}$$

$$\sum_{i\in I} x_i^p - My_p \le 0 \quad ;\forall p\in P \tag{19}$$

$$\sum_{p\in P} x_i^p \le Mx_i \quad ;\forall i\in I \tag{20}$$

$$\mathrm{y}_{jim_1} \ge \frac{\sum_{k\in k_1} v_{jik}\, demand_j\, p_{health}}{M} \quad ;\forall i\in I, j\in J, k_1 \le k_{ji} \tag{21}$$

$$\mathrm{y}_{jim_2} \ge \frac{\sum_{k\in k_1} v_{jik}\, demand_j \left(1-p_{health}\right)}{M} \quad ;\forall i\in I, j\in J, k_1 \le k_{ji} \tag{22}$$

The first objective function in equation (1) maximizes the weights of the sites selected for construction of shelters. Equation (2) minimizes the distances from warehouses to the shelters in question and the distances that people travel from crisis areas to the shelters. Constraint (3) ensures that a candidate site will be selected for construction of a shelter if its weight is greater than or equal to the minimum candidate site weight. Constraint (4) ensures that the number of people evacuated from crisis areas and allocated to a shelter once constructed will not exceed the capacity of the shelter. Constraint (5) ensures that the distance from each shelter to healthcare centers will not be more than a certain value. Constraint (6) ensures that the distance from each shelter to the main road cannot exceed a certain value. Constraint (7) ensures that a minimal number of people should be allocated to a shelter once it is constructed for people to be allocated to it. Preventing congestion of population at one shelter while another is totally empty, Constraint (8) ensures that allocation of people to shelters once one is constructed for people to be allocated to it should be balanced.

Constraint (9) ensures that people’s entire demand for evacuation from the crisis area will be responded to. Constraint (10) ensures that people evacuated from the crisis area will be allocated to shelters. Constraint (11) ensures that people will be allocated to a shelter from crisis areas if it has been constructed. Constraint (12) ensures that the number of open shelters will not exceed a certain value. Constraint (13) ensures that the distance people travel to arrive at a shelter from the crisis area once allocated to that shelter should not be more than a certain value. Constraint (14) ensures that the number of vehicles that travel from the crisis area to the shelter for evacuation of people should cover people's demand for evacuation. Constraint (15) ensures that the number of vehicles used for evacuation of people from the crisis area to shelters will not exceed the number of vehicles available at the crisis area. Constraint (16) ensures that vehicles evacuated from the crisis area will be allocated to shelters. Constraint (17) expresses that minimum and maximum numbers of warehouses allocated to each shelter. Constraint (18) ensures that the number of constructed warehouses will not be more than a certain value. Constraint (19) ensures that each shelter will be allocated at least to one warehouse. Constraint (20) ensures that a shelter is allocated to warehouses if it has been constructed. Constraints (21) and (22) ensure that people are definitely allocated shelters if evacuated from the crisis area.

$$\begin{aligned}
\text{Min} & \left[\left(\sum_{n\in n'}\sum_{i\in I}\sum_{t\in t_2}\left(\sum_{p\in P}\sum_{k\in k_2}\sum_{l}^{\zeta_p} x^{p}_{niklt}\right)\right)p_n\right]w_1 + \\
& \left[\left(\sum_{n\in n'}\sum_{i\in I}\sum_{t\in t_3}\left(\sum_{p\in P}\sum_{k\in k_2}\sum_{l}^{\zeta_p} x^{p}_{niklt}\right)\right)fp_n\right]w_2 + \\
& +\left[\sum_{k\in k_2}\sum_{l}^{\zeta_p}\sum_{t\in T}\sum_{i\in I}\sum_{p\in P} c_k\, y^{p}_{klti}\right]w_3 + [s]w_4 + \left[\sum_{p\in P}\sigma_p j_p\right]
\end{aligned} \tag{23}$$

s.t.

$$\sigma_p \le \zeta_p Y_P \quad ;\forall p\in P \tag{24}$$

$$\sigma_p \le \zeta_p - \left(\max\left\{\frac{\sum_{n\in n'}\sum_{i\in I} a_n x^{p}_{niklt}}{\omega}, \frac{\sum_{n\in n'}\sum_{i\in I} b_n x^{p}_{niklt}}{F}\right\}\right) \tag{25}$$

$$;\forall p\in P, \forall k\in k_2, \forall l\in \zeta_p, \forall t\in T$$

$$\sum_{k\in k_2}\sum_{l=1}^{\zeta_p}\sum_{t\in T}\sum_{i\in I} y^{p}_{klti} - MY_p \le 0 \quad ;\forall p\in P, k_2\le k_{pi} \tag{26}$$

$$\sum_{i\in I}\sum_{k\in k_2} y^{p}_{klti} t^{p}_{kli} \le T \quad ;\forall p\in P,\ \forall l\in\zeta_p,\ \forall t\in T, k_2\le k_{pi} \tag{27}$$

$$x^{p}_{niklt} \le M y^{p}_{klti} \quad ;\forall p\in P, \forall n\in n', \forall i\in I, \forall k_2\in K, k_2\le k_{pi}, \forall l\in\zeta_p, \forall t\in T \tag{28}$$

$$\sum_{p\in P}\sum_{k\in k_2}\sum_{l} x^{P}_{niklt} \ge \sum_{k\in k_1}\sum_{j\in J} v_{jik}\, Demand_j \quad ;\forall n\in n',\ \forall i\in I, \mathrm{t}\in \mathrm{T}, \mathrm{k}_2\le k_{pi}, \mathrm{k}_1\le k_{ji} \tag{29}$$

$$\sum_{n\in n'}\sum_{i\in I} a_n (x^{P}_{niklt}) \le \omega \quad ;\forall p\in P, \forall k\in k_2, k_2\le k_{pi}, \forall l\in\zeta_p, \forall t\in T \tag{30}$$

$$\sum_{n\in n'}\sum_{i\in I} b_n (x^{P}_{niklt}) \le F \quad ;\forall p\in P, \forall k\in k_2, k_2\le k_{pi}, \forall l\in\zeta_p, \forall t\in T \tag{31}$$

$$\sum_{k\in k_2}\sum_{l}^{\zeta_p} x_{niklt}^{p} \le U_n^p x_i^p \qquad (32)$$

$$;\forall n\in n', \forall p\in P, \forall i\in I, t\in T, \mathrm{k}\le \mathrm{k}_{pi}$$

$$S_i = \left[\left(\sum_{n\in n'}\sum_{t\in t_2}\sum_{p\in P}\sum_{k\in k_2}\sum_{l}^{\zeta_p} x_{niklt}^{p}\right)p_n + \left(\sum_{n\in n'}\sum_{t\in t_3}\sum_{p\in P}\sum_{k\in k_2}\sum_{l}^{\zeta_p} x_{niklt}^{p}\right) fp_n\right] \qquad (33)$$

$$;\forall i\in I, k_2\le k_{pi}$$

$$S = \max s_i - \min\ s_i \quad ; \forall i\in I \qquad (34)$$

$$a_{jik}\ge 0 \ \ and\ \ \mathrm{int}eger \quad ;\forall k_1\in K, \mathrm{k}_1\le k_{ji}, \forall j\in J, \forall i\in I \qquad (35)$$

$$x_i\in\{0,1\} \qquad (36)$$

$$y_{jim}\in\{0,1\} \qquad (37)$$

$$x_i^P \in\{0,1\} \qquad (38)$$

$$Y_P\in\{0,1\} \qquad (39)$$

$$y_{klti}^P\in\{0,1\} \qquad (40)$$

$$0\le\sigma_P\le\zeta_p \quad \text{and integer} \qquad (41)$$

$$v_{jik}\ge 0 \qquad (42)$$

$$x_{niklt}^p\ge 0 \ \text{ and integer} \qquad (43)$$

$$;\forall p\in P, \forall n\in n', \forall i\in I, \forall k_2\in K, \forall l\in\zeta_p, \forall t\in T$$

The second-stage objective function in equation (23) minimizes the cost of allowed and disallowed delays in response to demands, travel cost for delivery of goods from the warehouse to shelters, cost of injustice, and cost of the number of vehicles parked at warehouses. Constraint (24) ensures that the number of vehicles parked at a warehouse is not greater than the number of vehicles at its disposal if it is open. Constraint (25) calculates the number of vehicles parked at a warehouse. Constraint (26) ensures that a vehicle can be selected only from the warehouse, if they are open. Constraint (27) ensures that the duration of travel will not exceed total available time if it takes place from the warehouse to shelters. Constraint (28) ensures that goods are delivered if travel begins at the warehouse. Constraint (29) ensures that the amount of goods delivered from warehouses to the shelter should be at least equal to the demand at the shelter.

Constraint (30) ensures that the weight of goods delivered from a warehouse to shelters will not be more than the weight capacity of the vehicles at the disposal of the warehouse. Constraint (31) ensures that the volume of goods delivered from a warehouse to shelters will not exceed the volume capacity of the vehicles at the disposal of the warehouse. Constraint (32) ensures that the number of goods delivered to a shelter from a warehouse will not be more than its capacity if the shelter is allocated to the warehouse. Constraint (33) calculates the cost of dissatisfaction at a shelter. Constraint (34) calculates the cost of injustice. Constraint (35) suggests that the variable concerning the number of vehicles traveling from the crisis area to the shelter should be a positive integer in the problem. Constraints (36) to (40) pertain to the binary variables in the problem. Constraint (41) suggests that the vehicle variables in the problem are integers, and specifies their upper limits. Constraint (42) suggests that the problem variables are positive. Constraint (43) suggests that the problem variables are positive integers.

4- Experimental results

In this section, we design a problem and examine the results to achieve the purposes of the research. The GAMS software and CPLEX solver are utilized for solving the considered problem on an Intel Core i5 2.50 GHz PC system with 8 GB of RAM.

The hypothetical region studied in the designed problem is composed of two crisis areas, in which 10 candidate sites are introduced for the construction of shelters. Based on the evaluation criteria, a specific weight is defined for each of the shelters. It is assumed here that the number of vehicles at the disposal of each warehouse is five, and the minimum and maximum numbers of warehouses that can be allocated to each shelter are 1 and 2, respectively. The time period required for goods to be delivered from the warehouses to the shelter with no delay is three hours, the time for delivery with allowed delay is two hours, and disallowed delay is three hours. Furthermore, the goods selected in this study include water, tents, food, and relief vehicles. The maximum number of shelters that can be constructed is eight. Injured people, who need to be hospitalized, are regarded here as the injured, and ambulances are required for evacuation of these people from crisis areas to shelters. Besides, the number of affected people in the neighborhood is considered as the demand in the crisis area for evacuation. The candidate sites for construction of shelters and locations of the available hospitals are shown in figure 1.

Furthermore, the population, the probability that the people are healthy, and the number of vehicles required for evacuation of the people in the selected neighborhoods are stated in table 2. The weights and capacities of candidate sites for the construction of shelters and their distances from warehouses are shown in table 3. Distances of the hospitals available in the region and on the main road from candidate sites for the construction of shelters are shown in table 4.

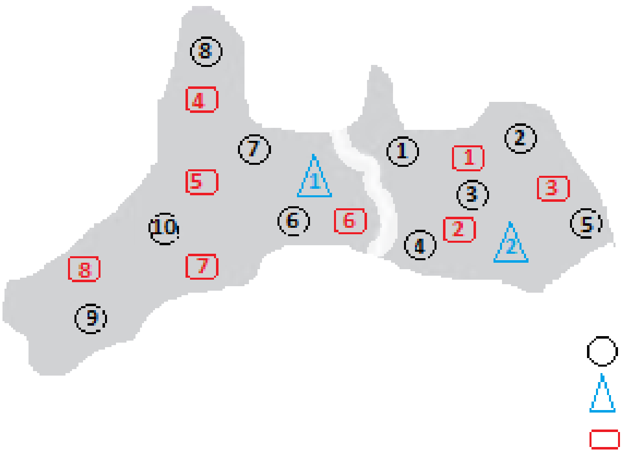

Fig 1. Locations of the candidate shelters, warehouses, and hospitals

Table 2. Required data in the crisis areas

	Population	Health probability	Number of vehicles
First neighborhood	10500	0.98	520
Second neighborhood	11224	0.97	450

Table 3. Weights of the candidate sites for the construction of shelters

Respective distances of the candidate sites from the two candidate warehouses	Capacity	Weight	Site number	Respective distances of the candidate sites from the two candidate warehouses	Capacity	Weight	Site number
1	0.1	1000	(205-120)	6	0.1	950	(195-228)
2	0.05	800	(378-113)	7	0.1	750	(141-121)
3	0.02	700	(205-243)	8	0.05	890	(178-248)
4	0.03	500	(193-157)	9	0.05	1000	(328-146)
5	0.2	1000	(224-176)	10	0.3	780	(154-143)

Table 4. Distances of candidate sites for shelter construction from available hospitals in the region and on the main road

Site No.	Hospital No.								Main road
	1	2	3	4	5	6	7	8	
1	356	383	247	176	165	194	290	295	157
2	179	344	47	34	30	153	296	300	115
3	102	274	243	143	144	234	154	167	124
4	239	344	365	280	285	360	341	359	190
5	293	286	185	112	118	186	303	306	138
6	110	307	81	71	84	222	292	267	134
7	108	298	76	98	101	252	297	264	182
8	199	329	220	177	183	223	361	374	159
9	213	426	222	111	190	222	366	366	192
10	66	436	226	250	260	280	417	428	185

The above problem is solved by GAMS software and CPLEX solver. The optimal values of the objective functions are as follows:

- The first objective value: 0.85,
- The second objective value: 2457629,
- The third objective value (second stage): 1.9873*10E6.

Furthermore, the runtime is 17 minutes. For a better understanding of the design proposed for the problem, the optimal design is shown in figure 2. According to this figure, candidate sites 1, 3, 4, and 5 from neighborhood and sites 6, 8, 9, and 10 in the second neighborhood are selected as qualified proposed shelters. Given the capacity of selected shelters, the critical area demand is clearly covered. Furthermore, the number of selected shelters is not exceeded the relevant upper bound. Besides, it is obvious in the proposed design that people are allocated to the constructed shelters, and no constructed shelter becomes unused and no crisis area is uncovered. A number of vehicles available on the routes for evacuation of people from crisis areas to shelters are suggested in Table 5. The output data in this table indicate that demand at the crisis areas has been covered. Furthermore, the number of vehicles available on the routes has not been more than available one at crisis areas. It is also shown in the table that all the constructed shelters have been allocated to one warehouse. It is found based on the output data in this table that the percentage of people allocated to each shelter does not exceed its capacity and that demand for evacuation of crisis areas is covered.

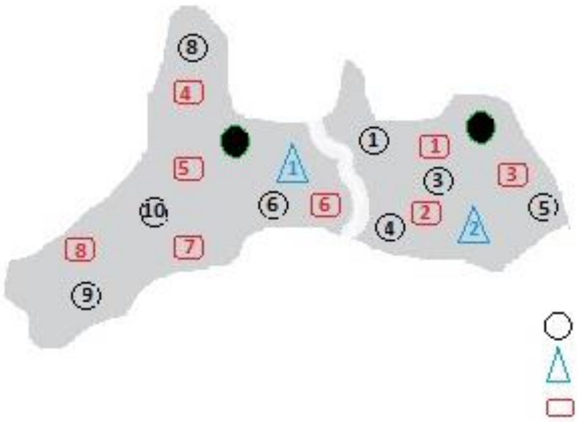

Fig 2. Shelters selected among candidate sites

Table 5. Numbers of vehicles on the routes, allocations of the shelters to the warehouses, and percentage of people on each route

Site No.	Number of vehicles	Warehouse No.	Percentage of people on each route	Site No.	Number of vehicles	Warehouse No.	Percentage of people on each route
1	K1-106	2	0.267	6	K2-104	1	0.283
2	-	-	-	7	-	-	-
3	K2-101	1	0.254	8	K2-103	1	0.280
4	K2-84	2	0.212	9	K1-104	2	0.286
5	K1-106	2	0.267	10	K2-55	2	0.150

5- Conclusion

Crisis management is of great importance in today's societies, as the number of crises that occur in the world increases every year. Relief logistics includes about 80 percent of activities in preparedness and response, two of the four phases of crisis management. Therefore, all societies should prevent and predict the needs by utilizing their capabilities. As clear from the occurred events, much more damage was incurred in cases of defective crisis management and lack of correct plans. In the present research, relief logistics was utilized for reduction of loss of life and injury upon the occurrence of an earthquake, and a novel two-stage mathematical model was presented for this purpose. The shelter location for people's short-term primary residence, warehouse location, and the travelled distance were investigated at the first stage, and allocation of relief goods to people, idle vehicles at warehouses, and the number of voyages was addressed at the second stage. To validate the model, some small-sized examples were designed and to evaluate the proposed problem, a detailed problem was then suggested. Finally, the results were analyzed by an enumeration method. The following suggestions are made for future research:

- Using the proposed model for different regions considering relief routes with weight coefficients for the amount of urban fabric dilapidation,
- Prioritizing people for evacuation from the crisis area to shelters based on physical condition, etc.,
- Solving the model using meta-heuristic algorithms.

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