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Robust planning model for logistics relief warehouses locating based on Monte Carlo simulation model

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ABSTRACT

Thousands lose their lives due to natural disasters such as floods and earthquakes every year with huge material costs and moral damage inflicted to many of the region; so the presence of plans to respond such events seems crucial. The current paper represents the use of mathematical modeling and robustness approach in crisis management. Moreover, the problems may be caused by the crisis in the real world in relief offering that are evaluated in the form of scenarios. Scenarios are produced and chosen using Monte Carlo simulation robustness logic is used for dealing with the uncertainty problem due to the uncertain nature of scenarios. It seeks to determine the location of warehouses with respect to the range of warehouse coverage based on the vehicle. Given the cost of warehouses locating and drugs transportation in relief network, the problem seeks to minimize the costs of warehouses establishment and transportation costs in the region.The results of the model solving has been analyzed in the form of a numerical example, indicating the importance of locating problem.

KEYWORDS: crisis management, locating and allocation, robust optimization, mathematical programing, Monte Carlo simulation

1. INTRODUCTION

Accidents and natural and unnatural disasters causes loss of life and property in the world, and our country is no exception to this rule, but the loss of lives that are irreversible country's main assets is the worst part of the tragedy. The need for crisis management in order to reduce the impact of these events and the management of crisis situations increasingly increases. Crisis is an unstable condition in need of rapid and immediate relief. On the other hand, crisis management includes all activities to prevent and mitigate the effects of the crisis and the rapid return to normal conditions. Rapid and immediate relief after a natural disaster such as an earthquake, flood or hurricane to save the lives of accident victims is one of the most fundamentals addressed in the shadow of the right strategy selection, timely decisions and the ability to implement these decisions before, during and after the events, as a requirement and can reduce harmful and damaging effects of these events to an optimal level.

According to studies, Iran is one of the top 10 accident-prone countries of the world. Unfortunately Iran is at high risk of 31 types of realized disasters in the world out of the 40 ones and specifically earthquake, flood and drought disasters had inflicted more damages into our country. According to Earthquake Engineering Research Institute, nearly 83% of Iran population is living in areas with high and very high earthquake risk and 50% ate at flood risk [1].

Therefore the need for applied research in the field of relief logistics management during the crisis to minimize its damages is obvious. Obviously, applied research on issues related to the relief logistic in natural disasters causes increases in initiatives in projects and finding best policies and the most efficient methods and technologies considering the condition of the country. So far, various models were developed as utilities in crisis management decision-making process and locating problem is one of them. In fact, this type of research aims to provide a comprehensive model to locate the best relief spots before and after the crisis, both in terms of safety and efficiency of performance and desirable in terms of cost, as well. Facilities locating problem locates plethora of facilities (resources) in order to minimize the cost to satisfy some of the demands (from customers) given the constraints. Locating theory first was formally proposed in 1909, when Alfred Weber faced with the problem of location a warehouse in order to minimize the distance between the store and customers [2]. The current article tries to control the situations and appropriate decision making in crisis like the earthquake using locating problem. A number of warehouses are constructed in this article each equipped with four types of different equipments and all should completely cover all demand points and each point drug demand should be only and only satisfied by a

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warehouse and equipment which service may be on land or air. The current paper, using Monte Carlo simulation framework and scenarios definition assumes that it is possible that some of the land routes face with damages during accident with trouble in transportation thus it is intended to define the scenario model to get closer to the real world condition.

2- LITERATURE REVIEW

Evidence indicates that the number of accidents and natural disasters occurring annually around the world in need of efficient plan and management to reduce the damages. According to studies conducted by the Association of IFRC, world have witnessed 7184 incidents from 2000 and 2009, among them are attack on the World Trade Center in 2001, the tsunami in Indonesia in 2004, Katrina Hurricane in 2005, the earthquake in Haiti in 2010. The IFRC estimated economic losses caused by these events equal to 986691 million dollars as well as lives losses of 1,105,352 people and with 2,550,272,267 injured. Also, according to Mon Cheri incidents in 2010 caused more than 295 000 deaths and economic losses of more than 130 billion. These statistics reflect the high probability of crisis and the need to develop better strategies to reduce such losses [2].

Torgas studies conducted in 1971 is among the first activities to locate emergency equipment in which the coverage was modeled and a method of linear programming was developed for solving it [3]. Many studies on the relief logistic in the crisis (emergency chain) are focused on the implementation of logistic activities with the aim of optimizing inventory through the existing distribution networks. For example, Knott (1987) proposed a linear model considering food transportation problem with the aim of minimizing transportation costs and the maximum amount of food delivery to the affected areas [4]. He, in the subsequent investigation in 1988 proposed a linear model of planning for vehicles with the aim to maximize the delivery of food as a crisis management problem [5]. However, transport losses and their treatment compared to relief goods have been less of concern and focus. Brotcorne et al (2003) and proposed classified locating of emergency vehicles in the form of dynamic and queuing models. Akkihal (2006) studied warehouse optimal location for placing first aid before the crisis [6]. Stepanov (2007) proposed a definite multi objective model for the distribution in demand points with respect to cost, response time and coverage. The article discussed decisions making on where to evacuate victims and provide relief [7].

Many studies, such as Fiedrich et al. (2000) and Sakakibara et al.(2004) are conducted in the distribution of relief assistance through planning as to minimize response times and maximize coverage [8,9]. In most studies ideal goal programming, such as minimizing response time and maximizing coverage is used.

Planning for the management of relief in crisis situations often is faced with many uncertainties. In the overall classification, the uncertainties are of two kinds: 1) uncertainty in planning for the future and 2) uncertainties relating to the amount of input parameters of the problem.

Details of the categories are listed below.

Table 1. Uncertainty classification in crisis planning [1]

Uncertainty in planning for relief management	Details
Uncertainty in planning for future needs	Uncertainty associated with the input parameters
	Uncertainty of Events
	Different effects in different regions
Uncertainty associated with the input parameters	Crisis different characteristics (type, location, time, size)
	Uncertainty of providers
	The lack of definitive route

Login uncertainty parameters in mathematical models as follows:

1- Draw risk and possible values
2- Facilities distribution and uncertainty planning
3- Robust optimization
4- The simulated models
5- Fuzzy sets

Crisp programming methods certainly better than certain techniques but because of incomplete and uncertain data are often with different approach. Many scientists have done researches based on the crisis by means robust optimization. More articles on the problems of the crisis are focused on the flow of goods or the victims and further studies are available based on both assumptions intended.

Barbarosoglu & Arda (2004) developed a randomized two-step framework for transportation planning in responding phase on crisis situations under uncertainty. In this study, the researchers developed a model presented in the paper by (Oh and Haghani, 1996) as a definitive, multi-product and multi-type transport fleet. this study investigated, uncertainty in the estimation of resources needed for relief goods, vulnerability and potential supply sources as well as routes resistance [10].

Jia et al. (2007) proposed a single-purpose facility locating model without limited capacity for large emergency services such as ambulance or fire stations. The possibility of damage to facilities was considered zero and one.The model does not consider inventory level in the preparation phase and limited capacity of facilities [11]. Chang et al. (2007) studied more logistic planning for emergency preparedness in flood condition. In this study, flood emergency logistic problem is modeled as a random planning under demand uncertainty. So that four types of activities intended to support and all points on the network is divided into five groups.The five groups are: the rescue center base in charge of rescue operations in the all affected area and regional rescue centers are its subs that are developed to operate rescue on their executive authority and support of demands points in other regions. The third are local rescue group sites that are responsible for their implementation in the region. Two random planning models are proposed to determine the storage center and the amount of equipment needed in the rescue and rescue equipment distribution to help government agencies save resources so that the first model is to minimize the distance from the rescue equipment and the second model also aims to minimize the deployment cost and mean cost of rescue equipment [12].

Mete and Zabinsky(2009) proposed a randomized optimization models for planning for the storage and distribution of emergency medical supplies under the uncertainty of demand and costs. The main aim of model was to locate optimal storage and inventory needed items to stores before the crisis, and rreducing the risk of warehouses at risk of damage from earthquake crisis. After the start of a stimulated crisis, the algorithm and then paths to hospitals to reduce travel time were identified [13].

Salmeron and Apte (2010) proposed an optimization model for planning funding for the acquisition and positioning of relief assets. In this model, the decisions of the first stage consists of positioning relief supplies such as warehouses, medical facilities, rest areas and shelters. While the second stage decisions are to discuss logistics under uncertainty of demand and cost. What is not seen in the model is the relationship between relief center locations (back cover), and the possibility of failure of emergency stock of goods [14]. Rawls and Turnquist (2010) proposed a mixed integer random planning to determine the location and amount of different ordered emergency goods. Their model studied transport network access under the demand and cost uncertainty [15]. Jabbarzadeh et al., provided a dynamic model to determine the location of facilities and distribution of blood to hospitals in critical condition and used Robust planning model planning due to lack of uncertainty of demand in the modeling [16].

Camacho (2014) provided a two level model for the distribution of international assistance for the humanitarian logistics, the relief aid from international organizations and foreign countries is aimed at reducing the cost of the other countries affected by the crisis and was followed by the distribution of aid as effective and quickly as possible. In this paper, he used Stackelberg game to model two –level planning [17].

Jeonga et al. (2014) in his paper presented a model of integrated logistics services with robust, risk and efficacy parameters. This model is partially divided into two sub-strategic and operational models, and studies how to provide basic goods and their distribution [18].

3- Problem definition

Due to the geographic and strategic position of Iran and 90% of the territory being located on the fault, the earthquake disaster in our country has led to more losses. Tehran, as the strategic city of Iran has always been prone to such accidents; Tehran in terms of earthquake is considered among high risk areas (8 to 10 degrees Mercalli).

Figure 1 show that North Tehran fault is the largest fault placed in the south Alborz mountain range in the north of Tehran. This fault starts from Lashkarak and Sohanak to Farahzad and Hisarak and the West, as well. The fault in its path encompasses Niyavaran, Tajrish, Zafaranieh, Ellahiye and Farmaniyeh. The high risk of Tehran in the regions mentioned requires crisis management.

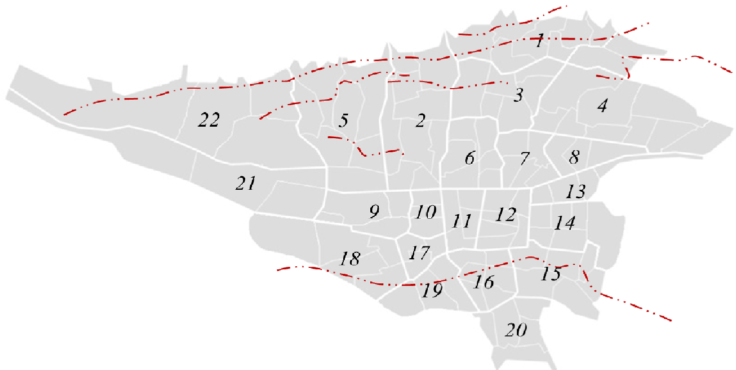

Figure (1). 22 districts of Tehran faults in the north and south of the city

As noted earlier in this paper is to develop a model to locate the area of crisis management to locate the securing locations with the aim of effective relief with minimal costs after the crisis. In fact, the safety requires several equipped points to meet drug demand. This model seeks to find a suitable location for the construction of relief logistics warehouses from the demand points. Each base contains at least four types of equipments in different numbers covering the demand points. Each type of equipment has a certain mean speed of each demand point should be satisfied in a certain time, because in the real world most of the time we do not have enough time to serve during the crisis and are to reach the desired point in a certain time period. After determining what equipment covers what demand point from which base, deterministic models shows the correctness of their performance; but given the uncertain nature of the crisis some of the routes used by the warehouse logistics to meet the demands are failed. The Monte Carlo simulation simulates the failed routes in Figure 2f flowchart . Robust planning model was used for uncertain condition modeling after elimination of the routes and the likelihood of any of these failures. The results of the model have been analyzed based on a numerical example of robust planning model planning.

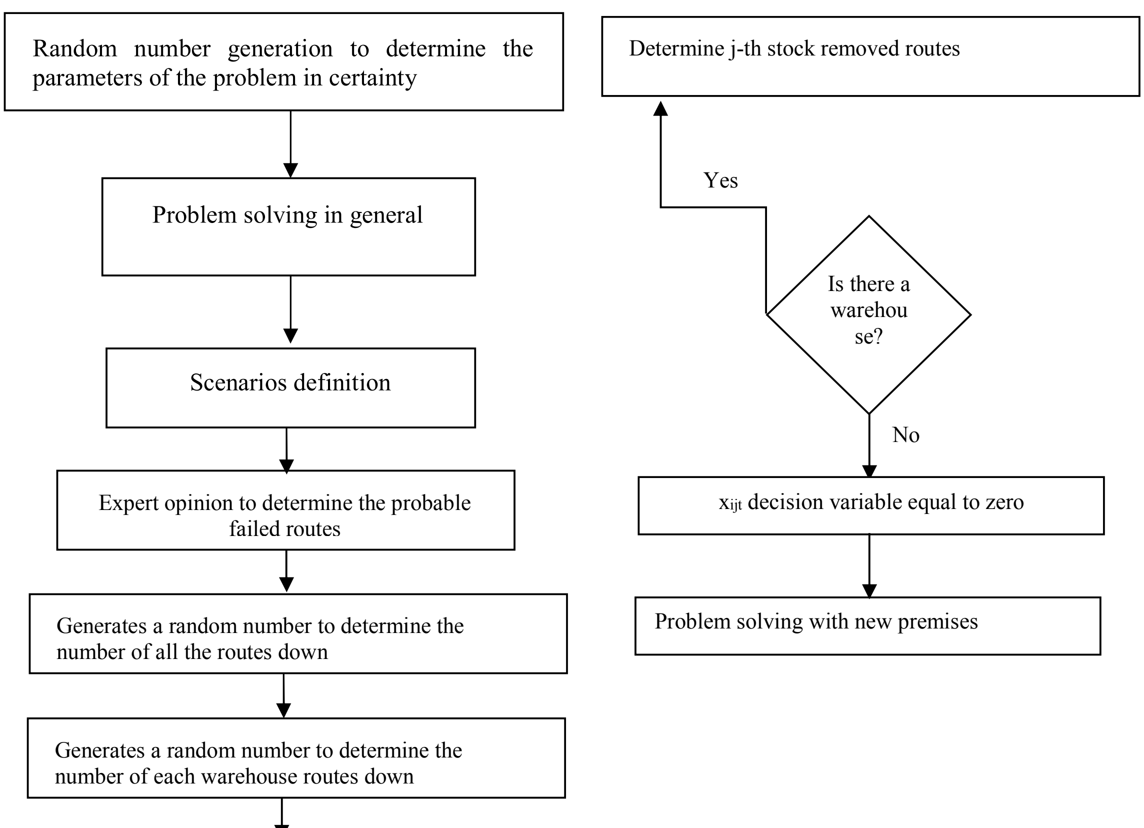

Figure 2. Remove route flowcharts using Monte Carlo simulation

4- Mathematical Model

The following is a mathematical linear model with its objective function to minimize the cost. The costs consist of three, first the cost of established base and the second relates to transportation vehicles and the third part is the cost of dealing with the deficit. A number of warehouses are selected among the demand points and the demand for a particular drug from a warehouse is satisfied only by one vehicle from one equipment and warehouse. More importantly is that meeting the needs should take place in a certain time span. A certain number of each type of equipment may be located in any base. Three of the equipments out of four can meet demands through the land and a type of equipment is done by air. Moreover, locating warehouses is determined based on the overall capacity of drugs and demand in the region. The decision variables parameters and deterministic mathematical model will be given in the following.

4.1. The decision variables

x_{ijtk} If the drug type k with equipment type t is taken from the base i to the point of demand j is one and otherwise zero.

y_i Is one when base i created and otherwise zero.

z_{ijtk} The type k drug amount that vehicle type t takes to from base i to the demand j.

s_{ik} Base i coverage radius for good k

k_{it} The number of type t vehicle at base i

Q_{jk} The amount of shortages drug type k in demand j

4.2. Parameters

F_i The cost of storage i establishment

Q'_{ik} The amount of the drug k stored in the base i

C_t Transportation cost per unit by the t vehicle

v_t Vehicle t mean speed

t_{jk} Time of service delivery to demand point j for drug k

B_{tk} Increase radius of coverage for drug k for each vehicle type t

d_{ij} The base point i to demand j

w_{jk} Penalties for drug k shortages to the point of demand j

U_{tk} Vehicle type t capacity for drug k

m The maximum budget available for dealing with the deficit

d'_{jk} Point j demand for drug type k

L_{ik} The maximum amount of the drug type k stored in the base i

e_k The total amount of drug type k

4.3. Deterministic model

$$Min \quad z = \sum_i f_i y_i + \sum_i \sum_j \sum_k \sum_t x_{ijkt} . d_{ij} . c_t + \sum_j \sum_k w_{jk} . Q_{jk} \qquad (14)$$

s.t:

$$\sum_i Q'_{ik} \le e_k \qquad \forall k \qquad (1)$$

$$\sum_j \sum_t z_{ijkt} \le Q'_{ik} \qquad \forall i,k \qquad (2)$$

$$\sum_j \sum_k w_{jk} . Q_{jk} \le m \qquad (3)$$

$$\sum_i \sum_t z_{ijkt} = d'_{jk} - Q_{jk} \qquad \forall j,k \qquad (4)$$

$$s_{ik} \le \sum_t B_{tk} . k_{it} \qquad \forall i,k \qquad (5)$$

$$Q'_{ik} \le L_{ik} . y_i \qquad \forall i,k \qquad (6)$$

$$M . x_{ijkt} \ge z_{ijkt} \qquad \forall i,j,k,t \qquad (7)$$

$$M . y_i \ge z_{ijkt} \qquad \forall i,j,k,t \qquad (8)$$

$$x_{ijkt} . d_{ij} \le s_{ik} \qquad \forall i,j,k,t \qquad (9)$$

$$\frac{d_{ij} . x_{ijkt}}{v_t} \le t_{jk} \qquad \forall i,j,k,t \qquad (10)$$

$$z_{ijkt} \le u_{tk} \qquad \forall i,j,k,t \qquad (11)$$

$$x_{ijkt}, y_i \in \{0,1\} \qquad \forall i,j,k,t \qquad (12)$$

Equation (1) represents to minimize construction and transportation costs objective function and the cost of dealing with the deficit to meet the needs in the areas of demand. Equation (2) represents restrictions related to the entire inventory in all relief warehouses for each type of drug. Equation (3) represents the storage capacity for each specific drug. Equation (4) represents restrictions on funding entirely taken into account for the deficit. Equation (5) represents the equilibrium equation of demand. Equation (6) represents limits to increase the radius of coverage for each unit increase in t type of vehicle. Equation (8) is constrains related to dependence x and z. Equation (9) shows the required construction of storage for the allocation of the vehicle to the depot. Equation (10) shows radius of warehouse coverage and the equation (11) shows the time limit for the average of each vehicle speed. Equation (12) expresses the capacity of vehicles and the last equation is about binary decision variables.

4.4. Scenario model

$$Min \quad z = \sum_i f_i y_i + \sum_i \sum_j \sum_k \sum_t x_{ijkts} . d_{ij} . c_t + \sum_j \sum_k w_{jk} . Q_{jks} \qquad (14)$$

s.t:

$$\sum_i Q'_{iks} \le e_k \qquad \forall k,s \qquad (15)$$

$$\sum_j \sum_t z_{ijkts} \le Q'_{iks} \qquad \forall i,k,s \qquad (16)$$

$$\sum_j \sum_k w_{jk} . Q_{jks} \le m \qquad \forall s \qquad (17)$$

$$\sum_i \sum_t z_{ijkts} = d'_{jks} - Q_{jks} \qquad \forall j,k,s \qquad (18)$$

$$s_{iks} \le \sum_t B_{tk} . k_{it} \qquad \forall i,k,s \qquad (19)$$

$$Q'_{iks} \le L_{ik} . y_i \qquad \forall i,k,s \qquad (20)$$

$$M . x_{ijkts} \ge z_{ijkts} \qquad \forall i,j,k,t,s \qquad (21)$$

$$M . y_i \ge z_{ijkts} \qquad \forall i,j,k,t,s \qquad (22)$$

$$x_{ijkts} . d_{ij} \le s_{iks} \qquad \forall i,j,k,t,s \qquad (23)$$

$$\frac{d_{ij} . x_{ijkts}}{v_t} \le t_{jk} \qquad \forall i,j,k,t,s \tag{24}$$

$$z_{ijkts} \le u_{tk} \qquad \forall i,j,k,t,s \tag{25}$$

$$x_{ijkts}, y_i \in \{0,1\} \qquad \forall i,j,k,t,s \tag{26}$$

Equations 14 to 26 act similar to equations 1 to 13 except that repeated as per the scenario and shown with s index. The model is executed for each scenario and the results for each scenario is saved at cs * and is used in the Robust planning model.

4.5. Robust model

$$Min \quad z = \sum_i f_i y_i + \sum_i \sum_j \sum_k \sum_t x_{ijkt0} . d_{ij} . c_t + \sum_j \sum_k w_{jk} . Q_{jk0} \tag{27}$$

s.t:

$$\sum_i f_i y_i + \sum_i \sum_j \sum_k \sum_t x_{ijkts} . d_{ij} . c_t + \sum_j \sum_k w_{jk} . Q_{jks} \le (1+p) c_s^* \tag{28}$$

$$\sum_i Q'_{iks} \le e_k \qquad \forall k,s \tag{29}$$

$$\sum_j \sum_t z_{ijkts} \le Q'_{iks} \qquad \forall i,k,s \tag{30}$$

$$\sum_j \sum_k w_{jk} . Q_{jks} \le m \qquad \forall s \tag{31}$$

$$\sum_i \sum_t z_{ijkts} = d'_{jks} - Q_{jks} \qquad \forall j,k,s \tag{32}$$

$$s_{iks} \le \sum_t B_{tk} . k_{it} \qquad \forall i,k,s \tag{33}$$

$$Q'_{iks} \le L_{ik} . y_i \qquad \forall i,k,s \tag{34}$$

$$M . x_{ijkts} \ge z_{ijkts} \qquad \forall i,j,k,t,s \tag{35}$$

$$M . y_i \ge z_{ijkts} \qquad \forall i,j,k,t,s \tag{36}$$

$$x_{ijkts} . d_{ij} \le s_{iks} \qquad \forall i,j,k,t,s \tag{37}$$

$$\frac{d_{ij} . x_{ijkts}}{v_t} \le t_{jk} \qquad \forall i,j,k,t,s \tag{38}$$

$$z_{ijkts} \le u_{tk} \qquad \forall i,j,k,t,s \tag{39}$$

$$x_{ijkts}, y_i \in \{0,1\} \qquad \forall i,j,k,t,s \tag{40}$$

Equation 28 represents a robust planning constraint that gives he decision maker the authority to have a pessimistic or optimistic view on the problem based on the parameter p. Other restrictions are similar to that of scenario limitations.

5. The numerical example

Ranges have been considered to various parameters in the model due to the lack of real examples in this regard shown in Table 1. The values of the parameters are determined by random value within this range for each solving of the model. The important point is the random values often make our problems lack the answer, so we generate a number of random values, so it is possible to solve the problem.

Table 2 and Table 3 provide some of the parameters related to the vehicles and the demand, as well.

Table 2. Range specified for some parameters

	Lower limit	Upper limit
F_i	4000	5000
T_j	7	14
d_{ij}	45	60

Table 3. Parameters considered for vehicles

Vehicle	Mean speed) km/h)	Transportation cost per unit	Vehicle capacity	β_{tk} : Increase the range of goods
Equip 1	70	10	3	1
Equip 2	65	100	5	1
Equip 3	60	120	10	1
Equip 4	250	500	13	1

Table 4. Parameters considered for the demand points

Node	The cost of storage facility	Demand
1	4300	10
2	3500	6
3	3900	13
4	5700	4
5	4500	2
6	4000	11
7	4700	9
8	5000	1
9	4500	7
10	4200	9

As already noted, Monte Carlo simulation approach has been used to produce scenarios which are in accordance with the flowchart in Figure 2, for example, a circulation in flowchart shows that after generating random values based on the steps listed in this flowchart six routes are destroyed during the event. These routes are intended for a specific scenario are $d_{17,}$ $d_{23\ 24}$, $d_{12\ 9}$, $d_{21\ 9}$, $d_{7\ 14}$, $d_{19\ 15}$.Table 3 gives the values of the scenario problem objective function for the four scenarios that these values are used as parameters on the first constrain of the Robust planning model; finally, the model objective function value is 28,243 currency unit and points 1, 4 and 8 are selected as crisis bases**.**

Table 5. Optimum solution for the 4 scenarios problems

	Cs*
Scenario 1	27405
Scenario 2	22301
Scenario 3	24124
Scenario 4	25344

6. Conclusion and Future Research

Crisis management and especially natural disasters need to consider several factors, many of which are associated with a high range of uncertainty. Every manager faces decision-making under uncertainty in the face of the crisis situation. These decisions often must be made as soon as possible and to minimize the lives and financial losses. Robust planning model optimization method on the allocation of resources can be a useful program used against uncertainty. In this paper, a single-purpose model for crisis situations of natural disaster such as earthquake is given that aims to minimize the costs of construction and equipment transportation and deal with the deficit on the network. Each base is equipped with four, each with its own average rate and certain transportation costs. Since the demand point should be met for the period specified in the real world, a time is taken into account as demand response time to approach the problem to the real world for each point. Robust approach is used in order to improve the performance of the model against unexpected event. The results of the Robust planning model compared to the scenario model results indicate better performance by Robust planning model that delivers more optimal objective function.

At the end three suggestions are proposed for future research as the following: using traditional methods has its own problems since real-world problems are large-scale, so finding heuristic and meta-heuristic innovative methods can greatly alleviate the problems of traditional methods. Given the multiple objective functions with different priorities, such as maximum coverage, reliability and minimizing the risk, time of service and etc. which brings the problem closer to reality. some points demand may not fully be covered due to problems in the real world, thus the use of certain models or Fuzzy theories, taking into account the partial coverage, can make the model more complete.

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