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An integrated logistics model for emergency relief and rescue operation considering secondary disaster

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Abstract

In recent years, and after further studies on the effects of natural disasters and catastrophes that threaten human life, a new concept called secondary disasters has been proposed. The fact that all areas affected by natural disasters may be affected by secondary disasters is generally overlooked, and this has exacerbated the effects of disasters. Therefore, to reduce the human and economic effects of natural disasters, this article examines the issue of designing a supply chain for relief resources and providing optimal rescue operations, considering the possibility of primary and secondary disasters. Due to the dynamic nature of the secondary effects and the need for continuous updating of the relief management process, this paper presents a one-objective model of mixed nonlinear integer programming to meet the demand for relief items, rescue the injured and evacuate the affected peoples concerning the prioritization of demand points under the conditions of primary and secondary crises, minimizes transportation time, transportation costs and unsatisfied demand; also defines the priority of demand points based on the amount of unmet needs and duration of deprivation of relief items and services; in this view, demand points are prioritized and unmet needs is minimized. Since the problem of the current study falls into the category of Np-hard problems, in order to solve the model, a combined approach of genetic algorithm (GA) and rolling horizon planning is introduced, finally the proposed algorithm is based on a case study has been implemented on the existing data set, which shows the high quality of this solution method in terms of the quality of the solution and the computational time.

Keyword: Secondary disasters, emergency relief planning, rolling horizon planning, humanitarian supply chain

1- Introduction

Natural disasters occur at different spatial and temporal scales, these include earthquakes, volcanic eruptions, fires, hurricanes, tornadoes, floods, outbreaks of infectious diseases, and so on. Each of these sudden events could have catastrophic consequences, for example, the 7.6 magnitude earthquake in Pakistan in 2005, which killed 75,000 people and left 106,000 dead. They were injured in this incident (Iqbal et al., 2018). In the past decades, several natural disasters such as tsunamis, floods, earthquakes, etc. have occurred.

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Due to Deadly Earthquakes in Turkey (Izmit, 1999), Taiwan (Chichi, 1999), India (Gujurat, 2001), Iran (Manjil-Rudbar, 1990, Bam, 2003), Pakistan (Kashmir, 2004), China (Sichuan, 2008) and Haiti (2010), about 450,000 people lost their lives. The tsunami in Indonesia (2004), Hurricane Katrina in the United States (2005) and floods in Pakistan (2010), killed more than 300,000 people and lost billions of dollars in assets, leaving more than 20 million displaced. (Barzinpour and Esmaeili, 2014). Therefore, due to the high frequency of accidents and their significant impact, the development of effective strategies to reduce the risks and the impact of accidents and disasters is very important. So far, numerous studies have been conducted to examine the various dimensions of disaster response. Due to the importance of relief operations in the post-disaster situation, several studies have been conducted on disaster management in the community. When a disaster occurs, there is a huge need for items relief items and services, which requires a timely and appropriate response. Having a better access to more information resources, demand in different parts of the affected area is changing. Therefore, it is necessary to consider the dynamic changes in demand and the availability of the required resources after a disaster. Need for relief items is usually higher than available resources. Hence, deficiencies are inevitable in some areas. Given these explanations, in such complex situations it is vital to have a practical decision-making tool to support logistical efforts. Considering the demand and availability of resources in future periods. In this regard, the need for inventory management to meet the potential demand created in future periods may increase. At the same time, compensating for the possible shortage of relief items by not distributing the total inventory to ensure minimum welfare in future periods (demand management) can be done in several periods (Sakiani et al., 2019; Ghasemi and Babaeinesami, 2019). This highlights the need to take advantage of multi-period decision-making, which is one of the considerations of this article. Central warehouses with high storage capacity should be located in safe places. Distribution centers can be in public places such as schools, hospitals and mosques in the city. In humanitarian logistics, initial measures must be taken within the first 72 hours after an earthquake (Mitsotakis and Kassaras, 2010). The first 12 hours after any disaster are very important and are known as standard relief time (SRT). Any delay in taking the necessary action can lead to more deaths. Public and non-governmental organizations should immediately assess the situation and start sending relief items from local warehouses to the affected areas. An efficient humanitarian logistics network should minimize human casualties by delivering relief items such as food, water and medical equipment to affected areas (Ghasemi et al., 2021). One of the most used strategies in the event of a disaster is to deploy resources to distribute relief items among the affected population. It is important to note that there may be different priorities for allocating relief items among the affected population, for example, some people who have a higher priority for receiving relief items than others may be deprived of receiving services for a period of time. In this paper, we aim to present an optimization model for planning the distribution of relief items and rescuing injured and displaced people, in a planning horizon, taking into account the priority level of the affected population. In this study, we prioritize the demand points and model based on the priorities to provide rescue services in the event of primary and secondary crises. These priorities can be defined by considering the following items: (i) access to demand points, (ii) how long people have been waiting for relief items at demand points, and (ii) the importance of each type of relief items. Secondary disasters in the real-world account for a significant proportion of economic losses and casualties. However, most previous research focuses on the occurrence of a disaster, while in the real world, the occurrence of a secondary disaster is one of the main challenges in sustainable rescue operations. The data show that the damage caused by secondary disasters exacerbates the deplorable situation. Therefore, the risk of these disasters should not be ignored (Yun et al., 2012). In this research, the problem of designing a humanitarian relief logistics planning model in the event of primary and secondary disaster is investigated, and the various dimensions of the problem and its components are described. A mathematical model for the problem is presented that has the objective function of minimizing unsatisfied demand based on demand prioritization and consists of three parts: the first part is related to minimizing the unsatisfied demand of relief items, the second part is unsatisfied demand in the transfer of displaced people, and the third part is related to the unsatisfied demand in the transfer of the injured. Due to the non-linearity of the model, which makes the problem more difficult to solve, we try to linearize the mathematical relations and turn it into a mixed linear model with integers. Real-world rescue chain planning problems generally take place in a dynamic environment. The dynamics of the problem environment make static models incapable of solving the problem. Therefore, we use the rolling horizon approach. Since the problem of the current study is of Np-hard problems, so the combined solving method of the rolling horizon approach based on genetic algorithm (HRH-GA) is introduced to solve the problem.

2- Literature review

Natural disasters have always seriously threatened human life and seriously damaged their property. In the short term after a disaster, there is a significant demand for emergency resources, and rescue equipment must be moved to disaster areas within a specified time. Therefore, timely allocation of limited resources to disaster areas is critical (Wei et al., 2020). The study of disaster relief network design was initiated by Baumol and Wolfe (1958). They proposed an innovative method for the warehouse location model in single-source conditions. They only considered how to select warehouse locations with distribution of known demand. Subsequently, several different studies were introduced to address this issue. Most of these studies focus on deciding on inventory levels and the appropriate choice of locations. For example, Hu et al. (2017), considered a two-stage random problem to integrate pre-disaster and post-disaster inventory levels in humanitarian relief. Other recent studies have succeeded in considering more realistic considerations. For example, Zhang et al. (2019), considered secondary disasters with a conditional probability scenario. Pradhananga et al. (2016), proposed an integrated resource allocation and distribution model. They hypothesized that disasters would result in the loss of a portion of the pre-determined inventory. Distributing emergency aid from warehouses to relief centers is a complex problem because of the uncertainty and huge demand for the quick response. In order to provide an effective response and efficient use of resources, Moreno et al. (2018), proposed a mathematical model for optimizing decisions regarding location, transportation, and fleet size. They reused vehicles for multiple trips under different time periods (hours or days). In the early hours of the disaster, the transportation infrastructure is an unreliable channel for relief supply, which has attracted the attention of Barbarosoğlu and others (Barbarosoğlu et al., 2002). They modeled a rescue flight plan involving the use of helicopters. In another study, Özdamar et al. (2011), proposed a mathematical model for supply chain planning, including the use of helicopters that transport injured victims and medical equipment. In their model, helicopters are used to minimize the total time to meet the needs of victims. Walter and Gutjahr (2014), provided a routing and location model for disaster relief operations. They claimed that temporary intermediate warehouses should be set up to expedite relief efforts and provide basic items to those affected. Huang et al. (2010), used dynamic programming to solve the location problem in a large-scale emergency network and designed an effective algorithm for locating locations in the network. Lu and Sheu (2013) designed a p-center model to select the optimal location for the emergency relief and rescue distribution center from among the proposed sites. Alinaghian et al. (2019), presented a mathematical model for locating temporary relief centers, so that each affected area is covered by at least one temporary relief area. By dynamically designing the helicopter allocation route, they sought to improve service. Updating information can have a significant impact on the success of rescue plans. Liu et al. (2019), considered the location of the emergency medical service station. They used instantaneous information to describe the ambiguity in the demand distribution, the number of studies examining the distribution of relief items is greater than studies dealing with rescue operations. Iqbal et al. (2018) used a statistical model to investigate the location of relief centers and the distribution of relief items in natural disaster management. They use the PRISM search engine model to formulate and analyze the real-world scenario of locating and distributing relief items, taking into account some key factors such as the demand for medical equipment in hospitals, predetermined routes, warehouse capacity and shipping schedules. Najafi et al. (2014) focused on the issue of supply chain management for sending relief items to affected areas and transporting injured people to hospitals. Their model allows the information to be updated at any time to adjust the plan. The objective function of their model minimizes the total transportation time, including the time of transporting people to hospitals and the time of sending equipment to the affected areas. Liu et al. (2019), have jointly considered the supply chain of relief items and injured people to minimize unsatisfied demand in a multi-product, multi-period problem. They used a rolling horizon-based framework to adjust plans based on updated information in real time. Their model focuses on post-disaster operations. In many previous studies, humanitarian goals have been considered in disaster management. Rezaei-Malek, and Tavakkoli Moghaddam (2014), presented a two-objective MILP model for humanitarian procurement operational planning. The purpose of their model is to reduce the average response time and total operating costs (including fixed warehouse construction costs, maintenance costs of unused items and cost of unsatisfied demand) while ensuring optimal warehouse location policies, emergency inventory maintenance in each warehouse, and distribution plans. Recent research on humanitarian supply provides a variety of non-cost objective functions such as fairness and justice and measures to minimize the suffering of individuals (Tavana et al., 2017; Hu et al., 2017; Li et al., 2018). The objective function of the current study is determined by the weighted priority score based on the ratio of unsatisfied demand at each point of demand. In addition, the objective function is indirectly related to minimizing response time, because the priority score is a function of the waiting time for people to receive relief items and rescue services. Among the articles in the reviews, the articles that are most related to the objective function of our work include Afshar and Haghani (2012), Perez-Rodríguez and Holguín-Veras (2013), and Rivera-Royero et al. (2016). Afshar and Haghani (2012), developed a dynamic model that, similar to the current model, considers the relative urgency of demand points at the objective function. Such urgency depends on the type of relief good, the characteristics of the demand point and the response time. However, in the objective function, the authors use the total value of unsatisfied demand instead of the respective ratio. In addition, they did not set budget constraints for humanitarian action. In their study, Perez-Rodríguez and Holguín-Veras (2013) minimized social costs, which include logistics costs and deprivation. However, they also did not consider budget constraints. The study of Rivera-Royero et al. (2016), is the closest research to this paper in terms of type of modeling and objective function, but the main difference between the current research and the last three articles is that neither of them has a plan to save the injured and displaced people. The rolling horizon approach is a practical approach to real-time demand supply problems in distribution systems; especially in issues that require updating future demand information over a time horizon. Among them are Rivera-Royero et al. (2016) and most recently the article by Sakiani et al. (2019), on the allocation and distribution of relief items after the disaster. Zanganeh et al. (2019), have presented a two-objective model for the distribution of relief items after the disaster due to the change in the values of the parameters over time, they have used a planning approach in the rolling horizon. However, none of these studies have examined rescue planning (i.e., the distribution of relief items and the relocation of displaced persons) simultaneously. Zhang et al. (2012), examined the emergency response in the case of multiple sources and multiple warehouses, while considering secondary disasters. However, this study has only one objective and does not consider issues such as transportation and resource scarcity. Yun et al. (2012) developed a swarm-based dynamic disaster evacuation simulation model to deal with reduced evacuation efficiency after primary and secondary disasters. Zhang et al. (2014), presented a Two-echelon emergency resource distribution model in which minimization of maximum relief time was considered as a criterion for relief performance in the event of secondary disasters. Zhang et al. (2019), addressed the issue of emergency resource allocation by considering both primary and secondary disasters in order to improve the ability of sustainable rescue in emergency relief management. They used a conditional probability-based scenario tree to define the relationship between primary and secondary disasters, and presented a three-step, multi-objective stochastic planning model to minimize transportation time, transportation costs, and unsatisfied demand. They have used fuzzy auxiliary variables of membership to use multi-objective functions and convert them into a single-objective model. Recently, Li et al. (2020) proposed a three-tier stochastic planning model to investigate the relationship between primary and secondary disasters under uncertainty conditions. They used the Benders decomposition algorithm to solve the problem. The results of their research showed that by considering secondary disasters compared to the case where only the primary disasters are considered, the satisfaction of demand can be significantly improved. Ghasemi and Babaeinami (2020) have studied the simulation of fire station sources by considering the downtime time of machines.The aim of this study is the optimization of equipment use in the fire stations, minimization the time to arrive at the incident through management of referral call to 125 Sari fire station center so that the referral call to the nearest fire station do not remain unanswered as much as possible and there will be no need to refer to another station. In this research, the resources required at Sari's fire station were simulated using Enterprise Dynamic software. The input data of the simulation is based on the number and sequence of the time of people's phone calls. The result indicates an improvement of 20% in relief time by adding one source in Sari fire station center. In addition, Li et al. (2020) presented a robust, stochastic, three-stage, scenario-based hybrid model that effectively distributes relief items under uncertain combined scenarios of primary and secondary disasters. They introduced a customized progressive hedging algorithm based on the augmented Lagrangian relaxation to solve the problem. The results of one example showed that combining secondary disaster scenarios could help improve relief coverage. However, none of the above research has addressed the issue of designing a comprehensive rescue network, including the distribution of relief items and the rescue of injured and displaced people in the event of primary and secondary crises. According to the best information collected, for the first time in reviewing the literature of this research, the operation research approach is used to provide a robust mathematical model to deal with the above problem. Also, due to the dynamics of the environment and the need for continuous updating of information such as the priority level of demand points based on the amount of unsatisfied needs and the duration of deprivation of relief items and services, a combined method based on the rolling horizon approach and genetic algorithm is used to solve the problem.

2-1- Problem statement

In this research, we deal with the issue of designing a humanitarian relief logistics planning model in the event of primary and secondary crises. This includes both types of post-disaster relief and rescue logistics. In such a way that in the relief phase, the relief items have reached the demand points, and in the rescue phase, people who have been injured or displaced due to the occurrence of primary or secondary disasters have been transferred to the medical centers and shelters, respectively. In this study, we present a dynamic model for responding to the demand for relief items, rescuing the injured and relocating the displaced according to the prioritization of demand points under the conditions of primary and secondary crises in a planning horizon. The problem is explained through the conceptual diagram of figure (1). The way of functioning of relief and rescue network in secondary disaster conditions.

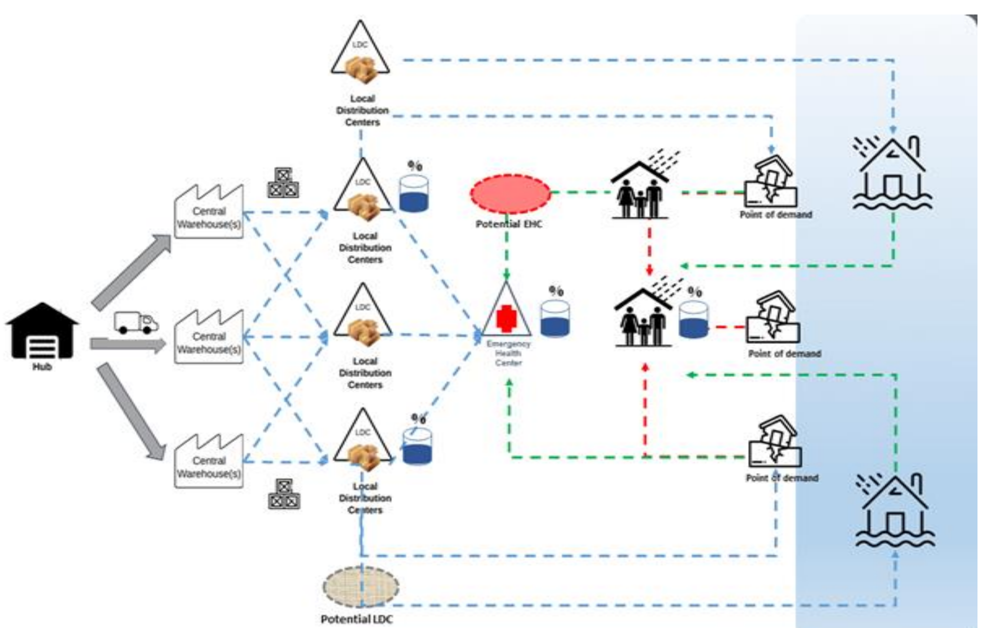

Fig 1. Conceptual diagram for the problem of relief and rescue in primary and secondary disaster

The purpose of this problem is to send relief items in the form of pallets to demand points that have been affected by primary disasters such as earthquakes and a possible secondary disaster such as fire or flood, as well as transporting the injured to medical centers and relocating displaced people to the shelters. Responding to the needs after the initial disaster takes place in a given time horizon as $t \in T = \{1,2, \dots, t, \dots, tr, \dots, t', \dots T1, \dots, T2, \dots, |T|\}$. Assume that the origin of the time horizon is equivalent to the initial disaster moment, t. Thus t = 1, and on the other hand, a secondary disaster occurs at time t'. The rescue and relief planning that has been proposed in the current research is affected by the time interval between the primary and secondary disasters. Considering this point, three cases can be assumed. In the first case, suppose that the time interval between t and t' is too short that a secondary disaster occurs before there is enough time to plan or act on the primary disaster and before any decision is made. In this case, it can be assumed that the primary disaster and the secondary disaster are both in the form of a single disaster and there is no difference in terms of planning and management between these two events. In the second case, suppose that the time interval between the occurrence of the primary and secondary disasters is large enough so that the planning done for the primary disaster during this period is fully implemented and all measures have been implemented. In other words, the secondary disaster occurs after the completion of essential operation in the primary disaster, in which case these two crises can be considered as two separate problems that do not necessarily have a relationship. However, in the third case, which is the subject of the current study, it is assumed that the time interval between the two primary and secondary disaster events is not too short that the two disasters can be considered as a larger disaster and not large enough to be able to separate primary and secondary crises into two independent crises. In other words, in this case, we assume that the interval between the occurrence of the primary and the secondary disaster is such that at the time of the secondary disaster, some decisions and allocations related to the planning of the primary disaster have been made and implemented, and on the other hand, a secondary disaster occurs before all the tasks assigned to the primary disaster planning are completed. In this case, the occurrence of a secondary disaster affects the implementation of the plan related to the primary disaster. The diagram in figure (2) shows the time of occurrence of primary and secondary disasters in the above three cases.

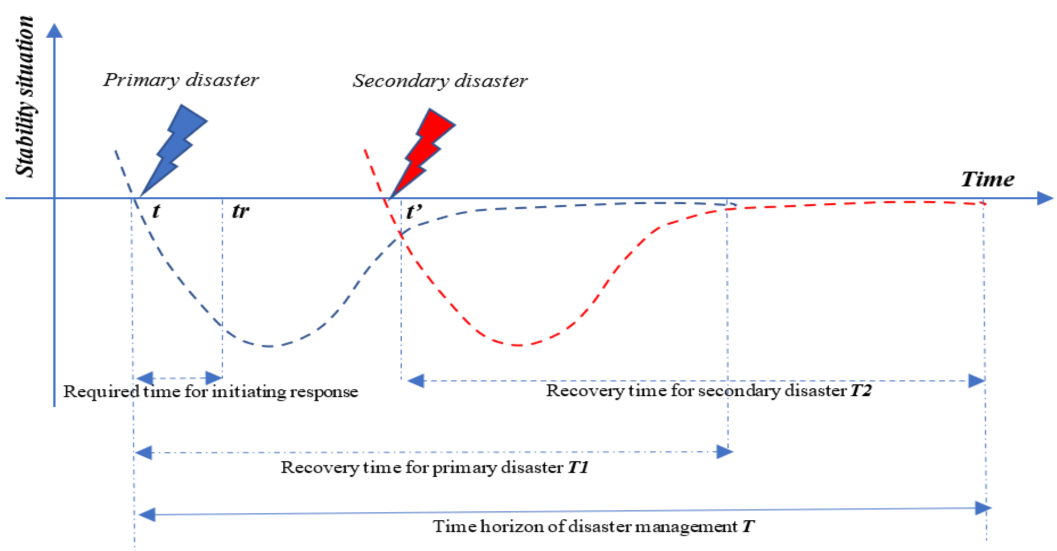

Fig 2. Diagram of return to steady state of operation over time after the onset of primary and secondary crises

As can be seen in figure (2), t is the moment of the primary disaster and by tr, no effective action has been taken to respond, and as a result, the operational stability situation in society is deteriorating. The reason for this delay could be the worsening of the disaster effects the disaster is still ongoing and it is not possible to send aid and items to the affected areas. On the other hand, it takes a while for the rescue team to be ready to dispatch the items, and they cannot be expected to be dispatched immediately after the disaster. This delay depends on the readiness of the rescue and disaster management team, which varies from community to community, but in none of them (even the most prepared communities) this interval is not zero. However, the interval between t and tr is the same interval that in case of a secondary disaster it can be managed together with the primary disaster. According to the explanations provided above in the subject of this research, the time of occurrence of the secondary disaster according to Equation (1) should be after the onset time of the primary disaster response so that they can be managed as two separate with interactive effects in the form of primary and secondary disaster.

$$t < tr < t' \qquad t \in T = \{1,2,\dots,t,\dots,tr,\dots,t',\dots T1,\dots,T2,\dots,|T|\} \tag{1}$$

On the other hand, before the end of the primary disaster response time and before completing the primary disaster planning tasks, a secondary disaster occurs so that the interaction of the two disasters in terms of rescue and relief logistics management is evident, so Equation (1) is completed to equation (2).

$$t < tr < t' < T1 \qquad t \in T = \{1,2,\dots,t,\dots,tr,\dots,t',\dots T1,\dots,T2,\dots,|T|\} \tag{2}$$

Therefore, if the condition in equation (2) is met, it can be said that the planning of primary and secondary disasters will be affected by each other. Pallets are used to facilitate the delivery of relief items. There are different types of pallets $f \in F$ that the type of each pallet depends on the kits in each pallet. Each kit is a combination of similar items such as canned food, personal hygiene items, first aid, clothing and so on. Therefore, we assume that a specific pallet contains the same relief kits of the same type. As a result, it can be said that different types of pallets have different weights and values, while the volume of all pallets is the same and standard. It is also assumed that each relief item kit meets the needs of a group of four. There are three levels in the proposed relief supply chain. At upstream level there are several central bases whose location pre-defined, and it is assumed that each $w \in W$ base can hold all types of relief items. At the middle level are Local Distribution Centers, which out of $|LD|$ potential points, they can be launched. The location of local distribution centers is done with consideration of budget constraints as well as the accelerating of distribution of relief items. There is a fixed cost to set up each local distribution centers$i \in LD$. If a LDC $i \in LD$ is established, it is possible to receive relief items and distribute them to demand points. Demand points need to receive relief items, and the demand of each point $j \in DP$ at the beginning of the planning horizon is a definite parameter that is obtained based on basic information. After the disaster and the initial estimation of demand in different points, the logistics mechanism of relief items is started, and first relief items are sent to LDCs and then from there they are allocated and sent to different points of demand. Considering the scope of the disaster, it may not be possible to supply all the items demanded by all points in the first visit, so during the time horizon, the unsatisfied demand of each of the demand points will be updated, so in order to bring the model of this research closer to real world problems, we consider meeting demand of different points in different time periods. Consequently, some points of demand may not be met at the beginning of the time after the disaster and may be postponed to later time periods. This will increase the priority degree of the demand point for those pallets in subsequent periods. Therefore, the proposed model should be a dynamic model that depends on the time as well as its past. In this model, the longer the passes through the occurrence of disaster, the higher the priority of demand point whose demand is not met. Therefore, demand points have different degrees of necessity and priority. In other words, if the demand point j has priority α in the time period t and its demand is not met in that period, the priority of that point in time t + 1 will be equal to α', which is $\alpha' > \alpha$.

As shown in figure (3), a set of demand points (DPs) is shown to represent areas affected by the disaster. These DPs indicate the population' need for essential items. In this figure, the points of demand where it is possible to transport relief items by normal vehicles in the affected areas are called Regular Demand Point

(RDP) and other points of demand that for reasons such as interruption of communication routes in remote areas it is not possible to send relief items by normal vehicles, are referred to as irregular demand point (IDP).

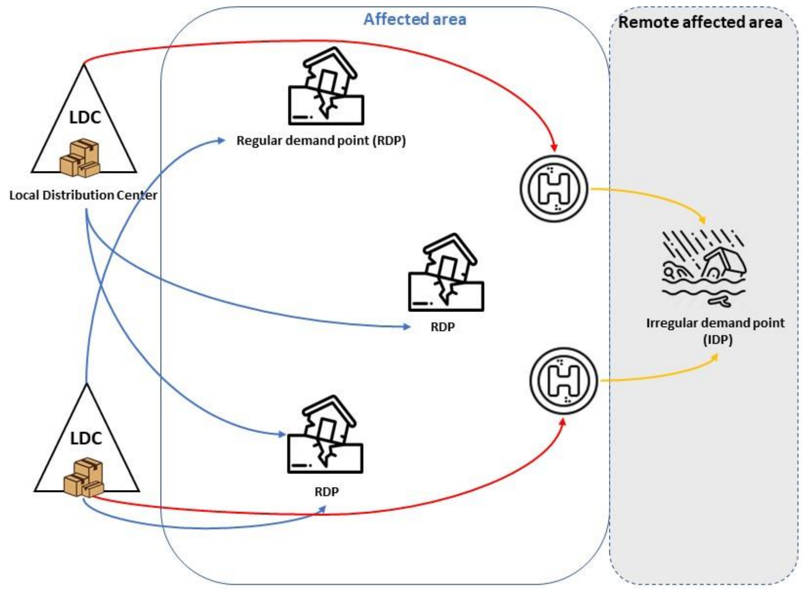

Fig 3. Conceptual diagram of relief items supply chain

A set of distribution centers (DC) of relief items is shown. A batch of pallets are sent by conventional vehicles to the located local distributor points, from where they are sent to RDPs. Another batch of pallets are sent to the Transmission Points (TP) with known locations, from where they are sent by special vehicles to those IDPs that were not accessible. Pallets have a certain weight and volume and each vehicle has a predefined capacity to carry pallets. In the rescue operation phase, it is assumed that there are several potential points for setting up a shelter, from which the optimal points are selected and set up considering budget constraints and humanitarian goals. Each $c \in C$ camp has the capacity to accommodate a limited number of displaced individuals. After the primary disaster, vehicles are sent to the affected sites and from there, they move the evacuees to the camps where the accommodation had been set up. For displaced people in RDPs where communication routes are not blocked, normal vehicles are sent, and special vehicles are sent to out-of-reach points. Both normal and special vehicles have a limited capacity to move displaced people. Similarly, there are several potential points for setting up health posts, from which the optimal points are selected and set up considering budget constraints and humanitarian goals. Each $h \in H$ clinic has the capacity to provide medical care to a limited number of casualties. It should be noted that for the three main operations, namely sending relief items, relocating displaced persons, and transporting the injured, separate vehicles are used. Therefore, all three major rescue and relief operations can be carried out in parallel and simultaneously. Due to restrictions on the use of vehicles, warehouses of relief items in distribution centers, accommodation camps, as well as health post, it is not possible to meet total demand in the DP at the same time. Thus, a multi-day planning is required for providing rescue services to all affected. These individuals that are scattered at DPs in a geographical area, as they are not at the same conditions in terms of confrontation with the disaster as well as need for items and services, have different emergency priorities. This means that some DPs needs more attention in rescue operations compared to others. In addition, it is assumed that emergency conditions of DPs for relief are dynamic. Thus, a DP that might not be considered emergency at time *t*, could turn into a DP with a high priority at time $t' | t' > t$ if it is neglected and its demand for relief and rescue is not met at due time. The important point is that the priority function is assigned to the users and any type of priority function can be defined according to the function of the problem with the fact that this is a non-decreasing function at time. The priority function should consider the following aspects:

A. The characteristics of a DP, these characteristics are different in terms of regulated or irregulated DP. Due to the acute and special circumstances in IDPs, they would have a higher service priority than RDPs.
B. The waiting time to receive rescue and relief services is another factor that affects the priority score of a DP. Long waiting times will increase the priority of a DP in receiving services.
C. The type of relief items or the rescue services required can be another important factor in determining the priority of a DP. For example, the DP with more casualties than other points can be treated with a higher priority function.

By passing the time, from the moment of the disaster, the threshold of human tolerance gradually decreases, so delivering rescue services as soon as possible is the most important point target. The proposed model is a dynamic model because the demand of each point in each period of time is determined based on the (un)met needs of that point in the previous period. Therefore, the model is presented in the rolling horizon approach. Also, considering that the demand of different points have been prioritized and this priority is determined based on the type and number of relief items requested as well as the time elapsed from the disaster (*the length of the disaster period until the demand is met*), so one of The most important decisions that the model should make are the amount and time of meeting each of the DPs according to the priority of the points and the existing constraints. This important decision is for minimizing objective function of the proposed mathematical model, i.e., minimizing unsatisfied demand of prioritized points. All symbols used in the mathematical model are described in table (1). The following assumptions are considered for the mathematical model:

- Prioritized demand points are based on the characteristics of DPs, the type of relief items and the length of waiting time to receive relief kits.
- Demand for relief items, number of injured and number of displaced individuals are known parameters.
- Parameters of travel time from distribution centers to DPs and from DPs to health posts or shelters are known.
- The delivery of relief items is considered as all at once and in the form of standard kits.
- Budget constraints are considered for relief and rescue operations.
- Due to the lack of access to some routes after the disaster, in each category of rescue operations, we consider two types of vehicles (ordinary and special vehicles) that special vehicles (such as helicopters, boats, etc.) are used for access to points where normal communication routes (such as bridges, underpasses, etc.) have been lost due to a disaster.
- Locating local distribution centers as well as shelters and health posts will be conducted among potential points that have already been identified.
- The number and location of supply points (central warehouses) are definite.
- Local distribution centers have a certain capacity to receive and send relief packages.
- Health posts have a specific capacity to provide services to the injured.
- Shelters have a certain capacity to hold and accommodate displaced people.
- There are different types of relief items which delivers in standard kits and are packed in pallets. Each pallet contains a certain number of identical kits.
- Different types of pallets have different weights and values, but the volume of all pallets is the.
- It is assumed that each relief item kit meets the needs of a group of four during a day.
- Each vehicle has a specific capacity to carry cargo / people / injured

Table1. Definition of sets and indices

T	A set of all disaster management time units, $\boldsymbol{t} \in \boldsymbol{T}$.
DP	Set of all demand points, $j \in DP$.
RDP	Set of regulated demand points $\in RDP \mid RDP \subset DP$.
IDP	Set of irregulated demand points ، $\in IDP \mid IDP \subset DP$.
TP	Set of midpoints to transfer to irregulated demand points ، $\in TP$.
LD	Set of potential points for setting up a local distribution center ، $\in LD$.
H	A set of potential points for setting up a field medical center ، $h \in H$.
C	Set of potential points for setting up accommodation camps ، $\in C$.
W	Set of central warehouses of relief items ، $\in W$.
VR	Set of ordinary vehicles to send relief items ، $\in VR$.
VE	Set of special vehicles for sending relief items ، $\in VE$.
VT	Set of ordinary vehicles for transferring displaced people, $\in VT$.
VS	Set of special vehicles for transferring displaced people ، $\in VS$.
AR	Set of ordinary vehicles for transferring the injured ، $\in AR$.
AE	Set of special vehicles for transferring the injured ، $\in AE$.
F	Set of pallets ، $\in F$.
N	Levels of severity of primary disaster ، $\in N$.

Table 2. Definitions of parameters

d_{fj}	Initial demand of the $j \in DP$ node for the $f \in F$ palette at the beginning of the time horizon (origin of the time of the primary disaster).
L_j	Number of people applying for locating in the $j \in DP$ node at the beginning of the time horizon (origin of the time of the primary disaster).
O_j	Number of the injured in the $j \in DP$ node at the beginning of the time horizon (origin of the time of the initial disaster).
P_{ljt}	The probability of a secondary disaster occurring with $l \in N$ severity at the demand point $j \in DP$ at time $t \in T$
θ^2_{fljt}	The amount of added demand for the $f \in F$ palette in the $j \in DP$ node due to the occurrence of a secondary disaster with $l \in N$ severity at time $t \in T$
θ'^2_{jlt}	The number of applicants for housing added to the $j \in DP$ node due to the occurrence of a secondary disaster with $l \in N$ severity at time $t \in T$
θ''^2_{jlt}	Number of health care applicants added to the $j \in DP$ node due to the occurrence of a secondary disaster with $l \in N$ severity at time $t \in T$.
Γ_{wf}	Inventory of the $f \in F$ pallet at the $w \in W$ warehouse at the beginning of the plan.
φ_{fk}	Inventory of the $f \in F$ pallet at the midpoint of $k \in TP$ at the beginning of the plan
η_{ijl}	Delay time added to the return time from the $i \in LD$ node to the $j \in RDP$ demand point if a secondary disaster of $l \in N$ severity occurs.
ζ_{kjl}	Delay time added to the return time for transporting relief items from the $k \in TP$ node to the $j \in IDP$ demand point if a secondary disaster of $l \in N$ severity occurs.
Ω_{cjl}	Delay time added to the return time from the $c \in C$ node to the $j \in IDP$demand point if a secondary disaster of $l \in N$ severity occurs.
$Ч_{kjl}$	Delay time added to the return time for the transfer of displaced persons from the $k \in TP$ node to the $j \in IDP$ demand point if a secondary disaster of $l \in N$ severity occurs.
$\mathfrak{Q}_{hjl}$	Delay time added to the return time from the $h \in H$ node to the $j \in RDP$ demand point if a secondary disaster of $l \in N$ severity occurs.
$\mathfrak{I}_{kjl}$	Delay time added to the return time for transfer of the injured from the $k \in TP$ node to the $j \in IDP$ demand point if a secondary disaster of $l \in N$ severity occurs.
τ_{wi}	The return time from $w \in W$ warehouse to local distribution center of $i \in LD$ node in each time period.
ξ_{ij}	The return time from the $i \in LD$ node to the $j \in RDP$ demand point in each time period.
ε_{wk}	Round time from node $w \in W$ to intermediate node $k \in TP$ in each time period.
ϱ_{kj}	The return time from $k \in TP$ intermediate node to $j \in IDP$ demand point for items in each time period.
$\mathfrak{E}_{wc}$	The return time from $w \in W$ warehouse to $c \in C$ camp in each time period.
$\mathfrak{A}_{cj}$	The return time from $c \in C$ camp to $j \in RDP$ demand point in each time period.

Table 2. Continued

$\mathfrak{M}_{ck}$	The return time from c ∈ C camp to k ∈ TP intermediate node in each time period.
$\mathfrak{K}_{kj}$	The return time from k ∈ TP intermediate node to j ∈ IDP demand point for displaced people in each time period.
$\mathfrak{N}_{wh}$	The return from w ∈ W warehouse to h ∈ H field hospital in each time period.
$\mathfrak{P}_{hj}$	The return time from h ∈ H field hospital to j ∈ RDP demand point in each time period
$\mathfrak{O}_{hk}$	The return time from h ∈ H field hospital to k ∈ TP intermediate node in each time period
$\mathfrak{X}_{kj}$	The return time from k ∈ TP node to j ∈ IDP demand point for the injured in each time period
$WCap_r$	Weight capacity of regular vehicle r.
$VCap_r$	Volume capacity of regular vehicle r
$WCap_e$	Weight capacity of special vehicle e
$VCap_e$	Volume capacity of special vehicle e
Cap_g	Capacity of regular vehicle for transfer of displaced people g .
Cap_m	Capacity of special vehicle for transfer of displaced people m
Cap_a	Capacity of regular vehicle for transfer of displaced people a
Cap_u	Capacity of special vehicle for transfer of displaced people u
Π_t	Time available in any time period t.
$DCap_i$	Capacity of distributor i
$HCap_c$	Capacity of camp c
$VCap_h$	Medical capacity of hospital h
$rDCap_{il}$	Decrease in capacity of distributor i if a secondary disaster of severity l occurs at time t.
$rHCap_{cl}$	Decrease in capacity of camp c if a secondary disaster of severity l occurs at time t.
$rVCap_{hl}$	Decrease in capacity of hospital h if a secondary disaster of severity l occurs at time t.
M	The number is large enough.
ρ_f	Volume of pallet f ∈ F.
Ψ_f	Capacity of number of relief kits per f ∈ F pallet.
PW_f	Weight of pallet f ∈ F .
$I0_{fw}$	Inventory of pallet f ∈ F . In warehouse w ∈ W at time t
TCA_{rwi}	The cost of r ∈ VR vehicle traffic between the w ∈ W warehouse and the i ∈ LD distributor.
TCA_{rij}	The cost of r ∈ VR vehicle traffic between r ∈ VR station and the j ∈ RDP demand point
TCA_{rwk}	The cost of r ∈ VR vehicle traffic between the w ∈ W station and the k ∈ TP intermediate point
TCA_{ekj}	The cost of e ∈ VE vehicle traffic between the k ∈ TP intermediate point and the j ∈ IDP demand point
TCB_{gwc}	The cost of g ∈ VTvehicle traffic between the w ∈ W station and the c ∈ C camp
TCB_{gcj}	The cost of g ∈ VTvehicle traffic between the c ∈ C camp and j ∈ RDP demand point
TCB_{gck}	The cost of g ∈ VTvehicle traffic between the c ∈ C camp and the k ∈ TP intermediate point
TCB_{mkj}	The cost of m ∈ VS vehicle traffic between the k ∈ TP intermediate point and the j ∈ IDP demand point
TCC_{awh}	The cost of a ∈ AR vehicle traffic between the w ∈ W station and the h ∈ H hospital
TCC_{ahj}	The cost of a ∈ AR vehicle traffic between the h ∈ H hospital and j ∈ RDP demand point
TCC_{ack}	The cost of a ∈ AR vehicle traffic between the c ∈ C camp and the k ∈ TP intermediate point
TCC_{ukj}	The cost of u ∈ AE vehicle traffic between the k ∈ TP intermediate point and j ∈ IDP demand point
FD_i	Cost of establishment of distributor i ∈ LD
FC_c	Cost of establishment of camp c ∈ C
FH_h	Cost of establishment of field hospital h ∈ H
B0	Budget available for disaster management plan costs at the beginning of the plan.
ω (j, t, f)	Priority score of nodes j ∈ DP for pallet f ∈ F at time t.
ϖ (j, t)	Priority score of nodes j ∈ DP in terms of status of the displaced at time t.
$\mathfrak{Z}$ (j, t)	Priority score of nodes j ∈ DP in terms of status of the injured at time t.

Table 3. Definitions of variables

x_{rwit}	Number of trips made by the vehicle $r \in VR$ from node $w \in W$ to node $i \in LD$ at time t
q_{rfwit}	Number of pallets sent by the vehicle $r \in VR$ from node $w \in W$ to node $i \in LD$ at time t
X_{rijt}	Number of trips made by the vehicle $r \in VR$ from node $i \in LD$ to node $j \in RDP$ at time t
Q_{rfijt}	Number of pallets sent by the vehicle $r \in VR$ from node $i \in LD$ to node $j \in RDP$ at time t
β_{rwkt}	Number of trips made by the vehicle $r \in VR$ from node $w \in W$ to node $k \in TP$ at time t
Q'_{rfwkt}	Number of pallets sent by the vehicle $r \in VR$ from node $w \in W$ to node $k \in TP$ at time t
$\ni_{ekjt}$	Number of trips made by the vehicle $e \in VE$ from node $k \in TP$ to node $j \in IDP$ at time t
$Q"_{efkjt}$	Number of pallets sent by the vehicle $e \in VE$ from node $k \in TP$ to node $j \in IDP$ at time t
U_{gcjt}	Number of trips made by the vehicle $g \in VT$ between nodes $c \in C$ and $j \in RDP$ at time t
U'_{gcjt}	Number of people transferred by the vehicle $g \in VT$ between nodes $c \in C$ and $j \in RDP$ at time t
γ_{gckt}	Number of trips made by the vehicle $g \in VT$ between nodes $c \in C$ and $k \in TP$ at time t
γ'_{gckt}	Number of people transferred by the vehicle $g \in VT$ between nodes $c \in C$ and $k \in TP$ at time t
R_{mkjt}	Number of trips made by the vehicle $m \in VS$ between nodes $k \in TP$ and $j \in IDP$ at time t
R'_{mkjt}	Number of people transferred by the vehicle $m \in VS$ between nodes $k \in TP$ and $j \in IDP$ at time t
Ɔ_{ahjt}	Number of trips made by the vehicle $a \in AR$ between nodes $h \in H$ and $j \in RDP$ at time t
$\text{Ɔ}'_{ahjt}$	Number of the injured transferred by the vehicle $a \in AR$ between nodes $h \in H$ and $j \in RDP$ at time t
□_{ahkt}	Number of trips made by the vehicle $a \in AR$ between nodes $h \in H$ and $k \in TP$ at time t
$\text{□}'_{ahkt}$	Number of the injured transferred by the vehicle $a \in AR$ between nodes $h \in H$ and $k \in TP$ at time t
Ƨ_{ukjt}	Number of trips made by the vehicle $u \in AE$ between nodes $k \in TP$ and $j \in IDP$ at time t
$\text{Ƨ}'_{ukjt}$	Number of the injured transferred by the vehicle $u \in AE$ between nodes $k \in TP$ and $j \in IDP$ at time t
θ_{fjt}	Unsatisfied demand at node $j \in DP$ for pallet $f \in F$ at time t
θ'_{jt}	Number of the displaced at node $j \in DP$ at time t
$\theta"_{jt}$	Number of the injured at node $j \in DP$ at time t
I_{fwt}	Inventory of pallet $f \in F$ in warehouse $w \in W$ at time t
$\mathrm{B_t}$	Budget available at time t
ʅ_{gwc}	If the vehicle $g \in VT$ is assigned from warehouse $w \in W$ to the camp c∈C it is 1; otherwise 0.
Ƹ_{awh}	If the vehicle $a \in AR$is assigned from warehouse $w \in W$ to the field hospital $h \in H$ it is 1; otherwise 0.
Δ_{ij}	If the demand point $j \in RDP$ is assigned to the distribution center $i \in LD$ to receive relief items, it is 1; otherwise 0.
δ_{kj}	If the intermediate point $k \in TP$ is assigned for the rescue and relief operation to the demand point $j \in IDP$, it is 1; otherwise 0.
Ж_{cj}	If the demand point $j \in IDP$ is assigned to camp $\in C$, it is 1; otherwise 0.
λ_{ck}	If the intermediate point $k \in TP$ is assigned to camp $\in C$, it is 1; otherwise 0.
σ_{hj}	If the demand point $j \in RDP$ is assigned to the field hospital $h \in H$, it is 1; otherwise 0.
μ_{hk}	If the intermediate point $k \in TP$ is assigned to the field hospital $h \in H$, it is 1; otherwise 0.
ɷ_{i}	If local distribution center $i \in LD$ is established, it is 1; otherwise 0.
ƕ_{c}	If camp $c \in C$ is established, it is 1; otherwise 0.
ɥ_{h}	If field hospital $h \in H$ is established, it is 1; otherwise 0.

3- Mathematical model

Updating the data in each time unit helps decision makers get new and more accurate information about the remaining budget available, the remaining demand at each point and, consequently, the priority score of each demand point The current model has the objective function of minimizing unmet demand based on demand prioritization and consists of three parts: the first part is related to minimizing the unmet needs of relief items, the second part is related to the unmet needs in transportation of displaced people and the third part is related to unmet needs in the transfer of the injured. As mentioned earlier, in this study, the objective function is of the humanitarian objective type, which is defined based on the level of emergency priority of unsatisfied demand. More precisely, in the model of this research, higher priority is given to people who have more emergencies, so that the points of demand with the highest priority receive rescue services as soon as possible. Given the provision of three important types of services in the rescue chain, the priority score of each type of service provided at one point of demand should be considered separately. The first type is the services that the affected areas in a disaster need, i.e., receiving essential relief items such as food, clothing and medical supplies. Therefore, the PD's weigh equal to ω (j, t, f) based on the priority situation related to receiving relief items. This priority function is a discrete function for determining weight based on population size at the DP, time of receipt of items, and type of items needed. The second type of demanded services is the transfer of the displaced people to shelters, the priority of which is a weight equal to ϖ (j, t) in the objective function. This priority score relates to discrete duration of waiting, as well as the type of DP (presence of the elderly, infirm, or children at that point). In the last part of the objective function, the third type of services demanded in the disaster, i.e., transferring the injured to the health posts, is weighted with the discrete priority score function $\mathfrak{Z}\,(j,t)$. This priority score is also a discrete function of the waiting time for transferring the injured as well as the type of demand point (based on the severity of the injuries and the number of severely injured persons). Given the high importance of saving human lives in real-world disasters, which are also considered in humanitarian models, it can be said that the weight of transporting the injured at a demand point will be higher than the weight given to transferring displaced people. According to the explanations provided, the mathematical model presented in this research is a one-objective MINLP model, which is introduced below.

$$Min\ z = \sum_{\substack{j\epsilon DP\\ f\epsilon F\\ t\epsilon T\\ l\in N}} \omega(j,t,f)\left(\frac{\theta_{fjt}}{d_{fj}+\theta^2_{fjlt}}\right) + \sum_{\substack{j\epsilon DP\\ t\epsilon T\\ l\in N}} \varpi\,(j,t)\left(\frac{\theta'_{jt}}{L_j+\theta'^2_{jlt}}\right) + \sum_{\substack{j\epsilon DP\\ t\epsilon T\\ l\in N}} \mathfrak{Z}\,(j,t)\left(\frac{\theta''_{jt}}{O_j+\theta''^2_{jlt}}\right) \tag{3}$$

Subject To:

$$B_0 = B0 - \sum_{i\epsilon LD} \square_i\, FD_i - \sum_{c\epsilon C} \square_c\, FC_c - \sum_{h\epsilon H} \square_h\, FH_h \tag{4}$$

$$\begin{aligned} B_t = B_{t-1} &- \sum_{\substack{r\epsilon VR\\ w\epsilon W\\ i\epsilon LD}} TCA_{rwi}\,\tau_{wi}x_{rwit} - \sum_{\substack{r\epsilon VR\\ i\epsilon LD\\ j\epsilon RDP}} TCA_{rij}\,\xi_{ij}X_{rijt} - \sum_{\substack{r\epsilon VR\\ w\epsilon W\\ k\epsilon TP}} TCA_{rwk}\,\varepsilon_{wk}\,\beta_{rwkt} \\ &- \sum_{\substack{e\epsilon VE\\ k\epsilon TP\\ j\epsilon IDP}} TCA_{ekj}\varrho_{kj}\backepsilon_{ekjt} - \sum_{\substack{g\epsilon VT\\ w\epsilon W\\ c\epsilon C}} TCB_{gwc}\mathfrak{E}_{wc}\mathfrak{l}_{gwc} - \sum_{\substack{g\epsilon VT\\ c\epsilon C\\ j\epsilon RDP}} TCB_{gcj}\,\mathfrak{A}_{cj}U_{gcjt} \\ &- \sum_{\substack{g\epsilon VT\\ c\epsilon C\\ k\epsilon TP}} TCB_{gck}\,\mathfrak{M}_{ck}\,\gamma_{gckt} - \sum_{\substack{m\epsilon VS\\ k\epsilon TP\\ j\epsilon IDP}} TCB_{mkj}\,\mathfrak{K}_{kj}\,R_{mkjt} - \sum_{\substack{a\epsilon AR\\ w\epsilon W\\ h\epsilon H}} TCC_{awh}\,\mathfrak{N}_{wh}\,\mathcal{E}_{awh} \\ &- \sum_{\substack{a\epsilon AR\\ h\epsilon H\\ j\epsilon RDP}} TCC_{ahj}\,\mathfrak{P}_{hj}\,\mathfrak{I}_{ahjt} - \sum_{\substack{a\epsilon AR\\ h\epsilon H\\ k\epsilon TP}} TCC_{ahk}\,\mathfrak{D}_{hk}\square_{ahkt} - \sum_{\substack{u\epsilon AE\\ k\epsilon TP\\ j\epsilon IDP}} TCC_{ukj}\;\mathfrak{X}_{kj}\,\mathfrak{Z}_{ukjt} \end{aligned}$$

$$\forall t \in T \tag{5}$$

$$\sum_{f\in F} q_{rfwit}PW_f \le \mathrm{WCap}_r x_{rwit} \qquad \forall\, r\epsilon VR, w\epsilon W, i\epsilon LD\,, t\,\epsilon\, T \tag{6}$$

$$\sum_{f\in F} Q_{rfijt}PW_f \le \mathrm{WCap}_r X_{rijt} \qquad \forall\, r\epsilon VR, i\epsilon LD, j\epsilon RDP\,, t\,\epsilon\, T \tag{7}$$

$$\sum_{f\in F} Q'_{rfwkt}PW_f \le \mathrm{WCap}_r \beta_{rwkt} \qquad \forall\, r\epsilon VR, w\epsilon W, k\epsilon TP\,, t\,\epsilon\, T \tag{8}$$

$$\sum_{f\in F} Q"_{efkjt} PW_f \leq \text{WCap}_e \ni_{ekjt} \quad \forall\, e\epsilon VE, \quad k\epsilon TP, \quad j\epsilon IDP\,, t\in T \tag{9}$$

$$\sum_{f\in F} q_{rfwit}\, \rho_f \leq \text{VCap}_r x_{rwit} \quad \forall\, r\epsilon VR, w\epsilon W, i\epsilon LD\,, t\in T \tag{10}$$

$$\sum_{f\in F} Q_{rfijt}\, \rho_f \leq \text{VCap}_r X_{rijt} \quad \forall\, r\epsilon VR, i\epsilon LD, j\epsilon RDP\,, t\in T \tag{11}$$

$$\sum_{f\in F} Q'_{rfwkt}\, \rho_f \leq \text{VCap}_r \beta_{rwkt} \quad \forall\, r\epsilon VR, w\epsilon W, k\epsilon TP\,, t\in T \tag{12}$$

$$\sum_{f\in F} Q"_{efkjt}\, \rho_f \leq \text{VCap}_e \ni_{ekjt} \quad \forall\, e\epsilon VE, \quad k\epsilon TP, \quad j\epsilon IDP\,, t\in T \tag{13}$$

$$\sum_{\substack{w\epsilon W\\ f\epsilon F\\ r\epsilon VR}} q_{rfwit} \leq \left(D\text{Cap}_i - P_{ljt-1}\, rDCap_{il}\right) ▯_i \quad \forall\; i\epsilon LD\;, t\in T\,, l\in N \tag{14}$$

$$I_{fw0} = I0_{fw} \quad \forall\, f\epsilon F, \quad w\epsilon W \tag{15}$$

$$I_{fwt} = I_{fwt-1} - \sum_{\substack{r\epsilon VR\\ i\epsilon LD}} q_{rfwit} - \sum_{\substack{r\epsilon VR\\ k\epsilon TP}} Q'_{rfwkt} \quad \forall\, f\epsilon F, \quad w\epsilon W, t\in T \tag{16}$$

$$\sum_{\substack{r\epsilon VR\\ w\epsilon W}} q_{rfwit} - \sum_{\substack{r\epsilon VR\\ j\epsilon RDP}} Q_{rfijt} = 0 \quad \forall\, f\epsilon F, \quad i\epsilon LD, t\in T \tag{17}$$

$$\sum_{\substack{r\epsilon VR\\ w\epsilon W}} Q'_{rfwkt} - \sum_{\substack{e\epsilon VE\\ j\epsilon IDP}} Q"_{efkjt} = 0 \quad \forall\, f\epsilon F, \quad k\epsilon TP, t\in T \tag{18}$$

$$\theta_{fj0} = d_{fj} \quad \forall\, f\in F, j\in DP \tag{19}$$

$$\theta_{fjt} = \theta_{fjt-1} - \sum_{\substack{r\epsilon VR\\ i\in LD}} Q_{rfijt}\Delta_{ij} + P_{ljt-1}\, \theta^2_{fjlt-1} \quad \forall f\in F, t\in T, j\in RDP, l\in N \tag{20}$$

$$\theta_{fjt} = \theta_{fjt-1} - \sum_{\substack{e\in VE\\ k\in TP}} Q"_{efkjt}\, \delta_{kj} + P_{ljt-1}\, \theta^2_{fjlt-1} \quad \forall f\in F, t\in T, j\in IDP, l\in N \tag{21}$$

$$\theta_{fj(t-1)} \geq \sum_{\substack{r\epsilon VR\\ i\in LD}} Q_{rfijt}\Delta_{ij} \quad \forall f\in F, t\in T, j\in RDP \tag{22}$$

$$\theta_{fj(t-1)} \geq \sum_{\substack{e\in VE\\ k\in TP}} Q"_{efkjt}\, \delta_{kj} \quad \forall f\in F, t\in T, j\in IDP \tag{23}$$

$$x_{rwit} \leq \sum_{f\in F} q_{rfwit} \quad \forall\, r\epsilon VR, w\in W, i\in LD\,, t\in T \tag{24}$$

$$X_{rijt} \leq \sum_{f\in F} Q_{rfijt}\; \Delta_{ij} \quad \forall\, r\epsilon VR, i\in LD\,, j\in RDP\,, t\in T \tag{25}$$

$$\beta_{rwkt} \leq \sum_{f\in F} Q'_{rfwkt} \quad \forall\, r\epsilon VR, w\in W\,, k\in TP\,, t\in T \tag{26}$$

$$\text{Э}_{ekjt} \leq \sum_{f\in F} Q"_{efkjt}\, \delta_{kj} \qquad \forall\, e\epsilon VE, k \in TP\,, \quad j \in IDP, t \in T \tag{27}$$

$$\sum_{i\in LD} x_{rwit}\tau_{wi} + \sum_{k\in TP} \beta_{rwkt}\varepsilon_{wk} \leq \Pi_t \qquad \forall\, r\epsilon VR, w \in W\,, t \in T \tag{28}$$

$$\sum_{j\in RDP} X_{rijt}\left(\xi_{ij} + P_{ljt-1}\,\eta_{ijl}\right) \leq \Pi_t \qquad \forall\, r\epsilon VR, i \in LD\,, t \in T, l \in N \tag{29}$$

$$\sum_{j\in IDP} \text{Э}_{ekjt}\left(\varrho_{kj} + P_{ljt-1}\,\zeta_{kjl}\right) \leq \Pi_t \qquad \forall\, r\epsilon VR, k \in TP\ \ , t \in T, l \in N \tag{30}$$

$$U'_{gcjt} \leq \mathrm{Cap}_g U_{gcjt} \qquad \forall\, g\epsilon VT, c\epsilon C, j \in RDP\,, t\,\epsilon\, T \tag{31}$$

$$\gamma'_{gckt} \leq \mathrm{Cap}_g \gamma_{gckt} \qquad \forall\, g\epsilon VT, c\epsilon C, k \in TP\,, t\,\epsilon\, T \tag{32}$$

$$R'_{mkjt} \leq \mathrm{Cap}_m R_{mkjt} \qquad \forall\, m\epsilon VS, \quad k \in TP\,, j \in IDP, \quad t\,\epsilon\, T \tag{33}$$

$$\sum_{\substack{g\epsilon VT\\ j\in RDP}} U'_{gcjt} + \sum_{\substack{g\epsilon VT\\ k\in TP}} \gamma'_{gckt} \leq \left(H\mathrm{Cap}_c - P_{ljt-1}\, rHCap_{cl}\right) \square_c \qquad \forall\, c\epsilon C, t\,\epsilon\, T, l\,\epsilon\, N \tag{34}$$

$$\theta'_{j0} = L_j \qquad \forall\, j \in DP \tag{35}$$

$$\theta'_{jt} = \theta'_{jt-1} - \sum_{\substack{g\epsilon VT\\ c\epsilon C}} U'_{gcjt}\, \text{Ж}_{cj} + P_{ljt}\, \theta'^{2}_{jlt} \qquad \forall\, t \in T, j \in RDP, l \in N \tag{36}$$

$$\theta'_{jt} = \theta'_{jt-1} - \sum_{\substack{m\in VS\\ k\in TP}} R'_{mkjt}\, \delta_{kj} + P_{ljt}\, \theta'^{2}_{jlt} \qquad \forall\, t \in T, j \in IDP, l \in N \tag{37}$$

$$\sum_{\substack{m\epsilon VS\\ j\in IDP}} R'_{mkjt} - \sum_{\substack{g\epsilon VT\\ c\epsilon C}} \gamma'_{gckt} = 0 \qquad \forall\, k \in TP, t \in T \tag{38}$$

$$\theta'_{j(t-1)} \geq \sum_{\substack{g\epsilon VT\\ c\epsilon C}} U'_{gcjt}\, \text{Ж}_{cj} \qquad \forall\, t \in T, j \in RDP \tag{39}$$

$$\theta'_{j(t-1)} \geq \sum_{\substack{m\in VS\\ k\in TP}} R'_{mkjt}\, \delta_{kj} \qquad \forall\, t \in T, j \in IDP \tag{40}$$

$$U_{gcjt} \leq U'_{gcjt} \qquad \forall\, g\epsilon VT, c\epsilon C, j \in RDP\,, t\,\epsilon\, T \tag{41}$$

$$\gamma_{gckt} \leq \gamma'_{gckt}\ \lambda_{ck} \qquad \forall\, g\epsilon VT, c\epsilon C, k \in TP\,, t\,\epsilon\, T \tag{42}$$

$$R_{mkjt} \leq R'_{mkjt} \qquad \forall\, m\epsilon VS, \quad k \in TP\,, j \in IDP, \quad t\,\epsilon\, T \tag{43}$$

$$\text{ʅ}_{gwc} \leq \square_c \qquad \forall\, g\epsilon VT, \quad w\epsilon W\ , c\epsilon C \tag{44}$$

$$\text{ʅ}_{gwc}\mathfrak{E}_{wc} + \sum_{j\in RDP} U_{gcjt}\left(\mathfrak{A}_{cj} + P_{ljt-1}\,\Omega_{cjl}\right) + \sum_{k\in TP} \gamma_{gckt}\mathfrak{M}_{ck} \leq \Pi_t \qquad \forall\, g\epsilon VT, c\epsilon C, w\epsilon W\,, t \in T, l \in N \tag{45}$$

$$\sum_{j\in IDP} R_{mkjt}\left(\mathfrak{K}_{kj} + P_{ljt-1}\, \text{Ч}_{kjl}\right) \leq \Pi_t \qquad \forall m\epsilon VS, k \in TP\ \ , t \in T, l \in N \tag{46}$$

$$\text{Ɔ}'_{ahjt} \leq \mathrm{Cap}_a \text{Ɔ}_{ahjt} \qquad \forall\, a\epsilon AR, h\epsilon H, j \in RDP\,, t\,\epsilon\, T \tag{47}$$

$$□'_{ahkt} \le \text{Cap}_a □_{ahkt} \qquad \forall\, a\epsilon AR, h\epsilon H, k \in TP, t \epsilon T \tag{48}$$

$$\text{Ƨ}'_{ukjt} \le \text{Cap}_u \text{Ƨ}_{ukjt} \qquad \forall\, u\epsilon AE, \quad k \in TP, j \in IDP, \quad t \epsilon T \tag{49}$$

$$\sum_{\substack{a\epsilon AR\\ j\in RDP}} \text{Ɔ}'_{ahjt} + \sum_{\substack{a\epsilon AR\\ k\in TP}} □'_{ahkt} \le (V\text{Cap}_h - P_{ljt-1}\, rVCap_{hl})\, □_h \qquad \forall\, h\epsilon H, t \epsilon T, l \epsilon N \tag{50}$$

$$\theta"_{j0} = O_j \qquad \forall\, j \in DP \tag{51}$$

$$\theta"_{jt} = \theta"_{jt-1} - \sum_{\substack{a\epsilon AR\\ h\epsilon H}} \text{Ɔ}'_{ahjt}\sigma_{hj} + P_{ljt}\, \theta"^{2}_{jlt} \qquad \forall\, t \in T, j \in RDP, l \epsilon N \tag{52}$$

$$\theta"_{jt} = \theta"_{jt-1} - \sum_{\substack{u\in AE\\ k\in TP}} \text{Ƨ}'_{ukjt}\, \delta_{kj} + P_{ljt}\, \theta"^{2}_{jlt} \qquad \forall\, t \in T, j \in IDP, l \epsilon N \tag{53}$$

$$\sum_{\substack{u\in AE\\ j\in RDP}} \text{Ƨ}'_{ukjt} - \sum_{\substack{a\epsilon AR\\ h\epsilon H}} □'_{ahkt} = 0 \qquad \forall\, k \in TP, t \in T \tag{54}$$

$$\theta"_{j(t-1)} \ge \sum_{\substack{a\epsilon AR\\ h\epsilon H}} \text{Ɔ}'_{ahjt}\sigma_{hj} \qquad \forall\, t \in T, j \in RDP \tag{55}$$

$$\theta"_{j(t-1)} \ge \sum_{\substack{u\in AE\\ k\in TP}} \text{Ƨ}'_{ukjt}\, \delta_{kj} \qquad \forall\, t \in T, j \in IDP \tag{56}$$

$$\text{Ɔ}_{ahjt} \le \text{Ɔ}'_{ahjt} \qquad \forall\, a\epsilon AR, h\epsilon H, j \in RDP, t \epsilon T \tag{57}$$

$$□_{ahkt} \le □'_{ahkt}\, \mu_{hk} \qquad \forall\, a\epsilon AR, h\epsilon H, k \in TP, t \epsilon T \tag{58}$$

$$\text{Ƨ}_{ukjt} \le \text{Ƨ}'_{ukjt} \qquad \forall\, u \in AE, \quad k \in TP, j \in IDP, \quad t \epsilon T \tag{59}$$

$$\text{Ɛ}_{awh} \le □_h \qquad \forall\, a\epsilon AR, h\epsilon H, w\epsilon W \tag{60}$$

$$\text{Ɛ}_{awh}\mathfrak{N}_{wh} + \sum_{j\in RDP} \text{Ɔ}_{ahjt}\left(\mathfrak{P}_{hj} + P_{ljt-1}\, \mathfrak{Q}_{hjl}\right) + \sum_{k\in TP} □_{ahkt}\, \mathfrak{O}_{hk} \le \Pi_t \qquad \forall\, a\epsilon AR, h\epsilon H, w\epsilon W, t \in T, l \in N \tag{62}$$

$$\sum_{j\in IDP} R_{mkjt}\left(\mathfrak{X}_{kj} + P_{ljt-1}\, \mathfrak{I}_{kjl}\right) \le \Pi_t \qquad \forall m\epsilon VS, k \in TP, t \in T, l \in N \tag{63}$$

$$x_{rwit}, q_{rfwit}, X_{rijt}, Q_{rfijt}, \beta_{rwkt}, Q'_{rfwkt}, \text{Ə}_{ekjt}, Q"_{efkjt}, U_{gcjt}, U'_{gcjt}, \gamma_{gckt}, \gamma'_{gckt} = \{0,1,2,3,\ldots\}$$

$$R_{mkjt}, R'_{mkjt}, \text{Ɔ}_{ahjt}, \text{Ɔ}'_{ahjt}, □_{ahkt}, □'_{ahkt}, \text{Ƨ}_{ukjt}, \text{Ƨ}'_{ukjt}, \theta_{fjt}, \theta'_{jt}, \theta"_{jt}, I_{fwt}, \mathrm{B}_t = \{0,1,2,3,\ldots\}$$

$$\text{Ɩ}_{gwc}, \text{Ɛ}_{awh}, \Delta_{ij}, \delta_{kj}, \text{Ӝ}_{cj}, \lambda_{ck}, \sigma_{hj}, \mu_{hk}, □_i, □_c, □_h = \{0,1\}$$

Equation (3) is the objective function of the model that minimizes unsatisfied needs for relief items, accommodation of displaced people, and transfer of the injured to regulated and irregulated DPs. Constraint (4) shows the amount of available budget after deducting of the respective expenditures for establishment of distribution centers, shelters, and health posts from the initial budget at the beginning of the planning horizon. Constraint (5) is related to budget updates during the planning days. Every day, operating expenses, including the distribution of relief items, transfer of displaced people and rescue of the injured, are deducted from the remaining budget and the budget balance is updated. Constraints (6) to (9) are related to the weight capacity of regulated and irregulated vehicles in carrying relief items between network nodes and Constraints (10) to (13) are also related to the capacity of vehicles. Constraint (14) states that if a distribution center is established until a secondary disaster has occurred, a maximum of the initial storage capacity of that center can be shipped. While the secondary disaster reduces the storage capacity of items in that center. Otherwise, if no center is established at point i, no items can be sent to point *i*. Constraint (15) quantifies the initial inventory at the beginning of the planning horizon, while the Constraint (16) updates the inventory of relief items in each warehouse *w* for each type of relief items at the end of each period. Constraint (17) is known as node balance and states that all relief items that arrive at a distribution center on the same day must be removed on the same day and shipped to DP. Constraint (18) expresses the same node balance for the intermediate points in the network. Constraint (19) quantifies initial demand at the beginning of the planning horizon just after the primary disaster. Constraints (20) and (21), respectively, update the amount of demand for relief items at regulated and irregulated DPs. In fact, these two constraints determine the remaining unsatisfied demand at the end of each day at any DP. Constraints (22) and (23) ensure that the number of relief items delivered to each regulated and irregulated DP, respectively, is equal to the maximum amount of unsatisfied demand for those DPs. Constraints (24) to (27) are the dependencies between the travel and the number of pallets moved. In other words, if no pallets are sent between the two nodes, naturally there will be no need to travel. Clearly, it can be said that these constraints prevent the unnecessary shipment in the network. Constraints (28) to (30) are related to the restrictions for the availability time of vehicles in each shift. The sum of the multiple travel times made by each vehicle in one day cannot be more than a certain limit of availability time. Constraints (31) to (33) show the dependency between the travels made and transferred people. the number of displaced people who moved to the shelters is at most equal to the capacity of the vehicles. Constraint (34) states that displaced people can be transferred to point *c* if the shelter has been established at that point. And if a secondary disaster has not occurred, displaced people can be sent to that point as much as the certain capacity of that shelter, and in the event of a secondary disaster, the capacity of the shelter will be reduced. Constraint (35) determines the initial needs for movement of displaced people at the onset of the primary disaster. Constraints (36) and (37) update the amount of unsatisfied demand from displaced people at regulated and irregulated DPs each day, respectively. Constraint (38) is the node balance in the intermediate point for the displaced people every day. Constraints (39) and (40) state that as much as the displaced applicant number, displacement takes place in regulated and irregulated points. Constraints (41) to (44) indicate the dependency between the variables related to the transfer of displaced people. Constraints (41) to (43) prevent useless shipments in the relief network, while constraint (44) states that a point of displaced demand can be assigned to point *c* if a shelter has been created there. Constraints (45) and (46) express the need for non-disruption of the available time of vehicles to move people in regulated and irregulated DPs. Constraint (47) states that the injured transported in the network must not exceed the capacity limit of vehicles. Constraints (48) and (49) also indicate the limitation of the capacity of regulated and irregulated vehicles. Constraint (50) states that the number of the injured transferred to a health posts is a maximum of the initial capacity of that health post in the absence of a secondary disaster or the reduced capacity of that health post in the event of a secondary disaster if a health post has been established at point *h*. Otherwise it will be equal to zero. Constraint (51) determines the initial demand for shipment of the injured of DP *j* at the beginning of the planning horizon on the moment of the primary disaster. Constraints (52) and (53) update the transportation of the injured from regulated and irregulated DPs on a daily basis. Constraint (54) is the node balance related to the injured in the intermediate point. Constraints (55) and (56) state, respectively, that the number of the injured moved from each regulated and irregulated DP will be equal to the number of needs in those points. Constraints (57) to (59) prevent unnecessary travels. Constraint (60) states that a point *h* can be assigned to transfer of the injured if a health post is established at that point. Restrictions (61) and (62) state that the total time allotted for transporting the injured cannot exceed the total available time for that vehicle. Constraint (63) indicates the range of acceptable interval for variables' value.

3-1- Linearization

The current model is a mixed integer nonlinear programming model (MINLP) due to the existence of nonlinear constraints of (20) to (23), (25), (27), (32), (37), (39), (40), (42), (52), (53), (55), (56) and (58). In all these constraints, multiplying a binary variable by another variable of integer or real number makes a nonlinear model. Since solving nonlinear models is much more complicated than linear types, we try to linearize the mathematical model. To linearize the relationships of the above constraints, the following dependency constraints are added to the model.

$$Q_{rfijt} \leq M\Delta_{ij} \qquad \forall r \epsilon VR, f \in F, i \in LD, j \in RDP, t \in T \tag{64}$$

$$Q"_{efkjt} \leq M\,\delta_{kj} \qquad \forall e \in VE, f \in F, k \in TP,, j \in IDP, t \in T \tag{65}$$

$$U'_{gcjt} \leq M\,\text{Ж}_{cj} \qquad \forall g \epsilon VT, c \epsilon C, j \in RDP, t \in T \tag{66}$$

$$R'_{mkjt} \leq M\,\delta_{kj} \qquad \forall m \in VS, k \in TP, j \in IDP, t \in T \tag{67}$$

$$\gamma'_{gckt} \leq M\,\lambda_{ck} \qquad \forall\, g \epsilon VT, c \epsilon C, k \in TP\,, t \,\epsilon\, T \tag{68}$$

$$\text{Ɔ}'_{ahjt} \leq M\,\sigma_{hj} \qquad \forall a \epsilon AR, h \epsilon H, j \in RDP, t \in T \tag{69}$$

$$\text{Ƨ}'_{ukjt} \leq M\,\delta_{kj} \qquad \forall u \in AE, k \in TP, j \in IDP, t \in T \tag{70}$$

$$\text{□}'_{ahkt} \leq \mu_{hk} \qquad \forall\, a \epsilon AR, h \epsilon H, k \in TP\,, t \,\epsilon\, T \tag{71}$$

Constraints (20), (21), (22), (23), (25), (27), (36), (37), (39), (40), (42), (52), (53), (55), (56) and (58) are also replaced by Constraints (72) to (87), respectively.

$$\theta_{fjt} + \text{ȣ}^{3}_{fjt} = \theta_{fjt-1} - \sum_{\substack{r \epsilon VR \\ i \in LD}} Q_{rfijt} + P_{ljt-1}\,\theta^{2}_{fjlt-1} \qquad \forall f \in F, t \in T, j \in RDP, l \in N \tag{72}$$

$$\theta_{fjt} + \text{ȣ}^{4}_{fjt} = \theta_{fjt-1} - \sum_{\substack{e \in VE \\ k \in TP}} Q"_{efkjt} + P_{ljt-1}\,\theta^{2}_{fjlt-1} \qquad \forall f \in F, t \in T, j \in IDP, l \in N \tag{73}$$

$$\theta_{fj(t-1)} \geq \sum_{\substack{r \epsilon VR \\ i \in LD}} Q_{rfijt} \qquad \forall f \in F, t \in T, j \in RDP \tag{74}$$

$$\theta_{fj(t-1)} \geq \sum_{\substack{e \in VE \\ k \in TP}} Q"_{efkjt} \qquad \forall f \in F, t \in T, j \in IDP \tag{75}$$

$$X_{rijt} \leq \sum_{f \in F} Q_{rfijts} \qquad \forall\, r \epsilon VR, i \in LD\,, j \in RDP\,, t \in T \tag{76}$$

$$\text{Э}_{ekjt} \leq \sum_{f \in F} Q"_{efkjt} \qquad \forall\, e \epsilon VE, k \in TP\,, \quad j \in IDP, t \in T \tag{77}$$

$$\theta'_{jt} + \text{ȣ}^{5}_{jts} = \theta'_{jt-1} - \sum_{\substack{g \epsilon VT \\ c \epsilon C}} U'_{gcjt} + P_{ljt}\,\theta'^{2}_{jlt} \qquad \forall\, t \in T, j \in RDP, l \in N \tag{78}$$

$$\theta'_{jt} + \text{ȣ}^{6}_{jt} = \theta'_{jt-1} - \sum_{\substack{m \in VS \\ k \in TP}} R'_{mkjt} + P_{ljt}\,\theta'^{2}_{jlt} \qquad \forall\, t \in T, j \in IDP, l \in N \tag{79}$$

$$\theta'_{j(t-1)} \geq \sum_{\substack{g\epsilon VT \\ c\epsilon C}} U'_{gcjt} \qquad \forall\, t \in T, j \in RDP \qquad (80)$$

$$\theta'_{j(t-1)} \geq \sum_{\substack{m\in VS \\ k\in TP}} R'_{mkjt} \qquad \forall\, t \in T, j \in IDP \qquad (81)$$

$$\gamma_{gckt} \leq \gamma'_{gckt} \qquad \forall\, g\epsilon VT, c\epsilon C, k \in TP\,, t\, \epsilon\, T \qquad (82)$$

$$\theta"_{jt} + \text{ȣ}^{7}_{jt} = \theta"_{jt-1} - \sum_{\substack{a\epsilon AR \\ h\epsilon H}} \text{Ɔ}'_{ahjt} + P_{ljt}\, \theta"^{2}_{jlt} \qquad \forall\, t \in T, j \in RDP, l\, \epsilon\, N \qquad (83)$$

$$\theta"_{jt} + \text{ȣ}^{8}_{jt} = \theta"_{jt-1} - \sum_{\substack{u\in AE \\ k\in TP}} \text{Ƨ}'_{ukjt} + P_{ljt}\, \theta"^{2}_{jlt} \qquad \forall\, t \in T, j \in IDP, l\, \epsilon\, N \qquad (84)$$

$$\theta"_{j(t-1)} \geq \sum_{\substack{a\epsilon AR \\ h\epsilon H}} \text{Ɔ}'_{ahjt} \qquad \forall\, t \in T, j \in RDP \qquad (85)$$

$$\theta"_{j(t-1)} \geq \sum_{\substack{u\in AE \\ k\in TP}} \text{Ƨ}'_{ukjt} \qquad \forall\, t \in T, j \in IDP \qquad (86)$$

$$\square_{ahkt} \leq \square'_{ahkt} \qquad \forall\, a\epsilon AR, h\epsilon H, k \in TP\,, t\, \epsilon\, T \qquad (87)$$

Therefore, the final mathematical model that is presented for problem solving in this research includes relations (3) to (19), constraints (24), (26), (28) to (35), (38), (41), (43) to (51), (54), (57) and (59) to (87).

4- Solution approach

In dealing with dynamic models, it is necessary to update the model information in different time periods over a time horizon, using the rolling horizon approach is one of the robust approaches. In this method, the time horizon consists of several equal time periods. The values of all or some of the model parameters are updated at the beginning of each period. In this method, in the time period t_0, the model is solved, and the output obtained is actually the input for the time period t_1. Then the model is solved in period t_1 and the output obtained will be the input of the model for period t_2 and so on until time period $t_{|T|}$ to be continued. So, the model is divided into |T| number of sub-problems. The diagram of how the rolling planning method works in the time horizon is shown in figure (4).

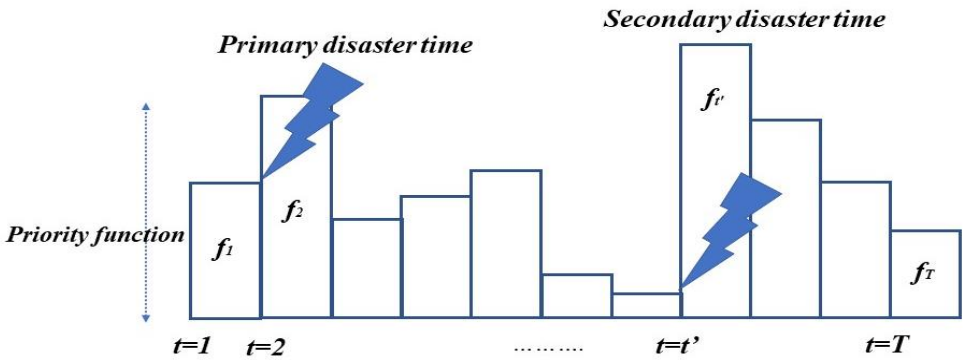

Fig 4. Rolling planning in the time horizon.

As shown in figure (4), at the beginning of the time horizon, i.e., the time of the primary disaster, the problem is solved with the input data. In addition to budget and demand parameters, this input data also includes the priority score of each demand point. Variables of Residual budget $B_{t-1,s}$, end-of-period inventory $I_{fwt-1,s}$, as well as satisfied demand including residual demand for relief items $\theta_{fjt-1,s}$, demand for transfer of displaced people$\theta'_{jt-1,s}$, and the demand for the transfer of the injured $\theta"_{jt-1,s}$ are obtained at the end of each period and after their values are determined, they are used as the parameters for next periods. In other words, after solving the variables in each period, they turn into parameters B_0 ، $I0_{fw}$ ، d_{fjs} ، L_{js} and O_{js} for the next period. On the other hand, the priority of DPs needing rescue and relief operation may according to the conditions mentioned earlier, and in the diagram in figure (4), the f_t function is related to the priority of the DPs in receiving rescue operations, so at the beginning of the time horizon, priority in receiving rescue and relief is as f_1 . Then, at the end of the first period, the input data f_2 is obtained for the second period and the model is solved again. Considering the constraints on capacity, distribution, and transfer and inadequate facilities in providing services to all DPs, it may add to the priority of many points where their demand is not fully satisfied. However, over time, as the remaining needs is satisfied, the priority scores of the DP gradually decrease. This process of rolling solving continues until a secondary disaster occurs. With the occurrence of the secondary disaster at time t' and increasing the resulting demand, the priority function $f_{t'}$ also increases during period t'. Then, according to the previous procedure, the demand of the points is gradually met again and the priority score of the demand point is reduced. It should be noted that each time roll is considered equal to 18 hours. To solve the main problem using the rolling horizon approach, it is broken down into sub problems to reduce the complexity. The sub-problems include distribution of relief items and rescue operations for displaced people and the injured ones, decisions to transport relief items from central warehouses to LDCs, transport of relief items from LDCs to DPs directly or through intermediate points, transfer of displaced people to the shelters, including the transfer of the injured from the disaster sites to the health posts, the control of the pallet inventory, in addition to the decisions to establish LDCs, shelters and health posts, as well as the allocation of these points to DPs. Each problem can be reduced to a Warehouse Ordering Problem that falls into the Np-hard category. For example, Sakiani et al. (2019), used a combined method of rolling approach based on simulated annealing (SA) algorithm to solve the inventory-routing problem and distribution of post-disaster relief items. In this research, we use a combined approach of genetic algorithm (GA) and rolling horizon planning. In the proposed solving method, the problem is first decomposed into specific periods then, the sub-problem is solved in each period using the genetic algorithm and the variables mentioned above are fixed as the updated parameters of the next period and used as the inputs of the next period. This procedure continues in each iteration to achieve the results of the problem. The flow diagram of the combined solving method of the rolling horizon approach based on genetic algorithm (HRH-GA) is shown in figure (5).

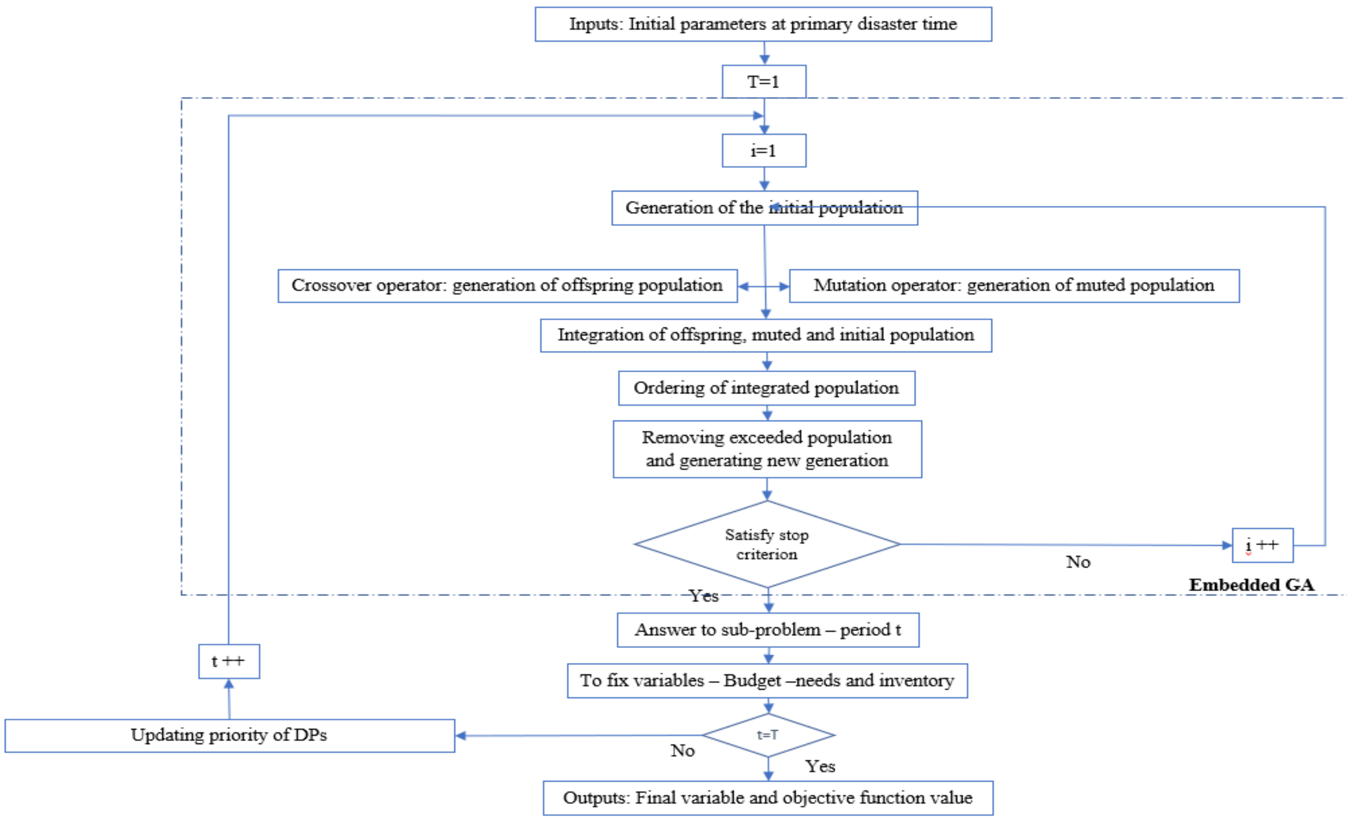

Fig 5. Flow diagram of the combined solving method of the rolling approach based on genetic algorithm

4-1- Representation of solution

The suitable chromosome for representing a valid solution to each of the following problems is as a vector. Each vector is a slice of the problem over a period, and since the genetic algorithm is recalled once in each period of the rolling horizon, the distribution variables in the humanitarian rescue logistics fleet are quantified in the chromosome vector genes. The number of the solution vector elements is equal to the multiplication of the values of the indices of the variables on the chromosome. An example of a proposed chromosome to show the solution to the following problem is shown in figure (6).

q_{rfwi}	Q_{rfij}	Q'_{rfwk}	Q''_{efkj}	U'_{gcj}	γ'_{gck}	R'_{mkj}	$Ↄ'_{ahj}$	$И'_{ahk}$	$Ƨ'_{ukj}$
$q_{1111} \cdots q_{3529}$	$Q_{1111} \cdots Q_{559,20}$	$Q'_{1111} \cdots Q'_{3526}$	$Q''_{1111} \cdots Q''_{356,10}$	$U'_{111} \cdots U'_{54,20}$	$\gamma'_{111} \cdots \gamma'_{546}$	$R'_{111} \cdots R'_{36,10}$	$Ↄ'_{111} \cdots Ↄ'_{10,10,20}$	$И'_{111} \cdots И'_{10,10,6}$	$Ƨ'_{111} \cdots Ƨ'_{56,10}$

Fig 6. Chromosome genotype of an example solution

Figure (6) is an example solution for the sub-problem. The ten variables presented on the chromosome are related to rescue logistics, including the number of pallets of relief items sent from central warehouses to LDCs, the number of pallets of relief items sent from LDCs to affected regulated points, and the number of pallets of relief items sent from central warehouses to intermediate points, number of pallets of relief items sent from intermediate points to irregulated points, number of displaced people transferred from regulated points to shelters, number of displaced people transferred from intermediate points to shelters, the number of displaced persons transferred from the irregulated demand points to the middle points, the number of the injured transferred from the disaster points to the health post, the number of the injured transferred from the intermediate points to the health posts, and the number of the injured transferred from the irregulated demand points to intermediate points. Given that the genetic algorithm is applied to a sub-problem of the main problem, the time index is not included in the above variables because GA is executed independently in each period. The values taken by the variables on the chromosome reflect the satisfied needs and residual demand for rescue and relief. All variables that show the number of trips made by different types of vehicles in the rescue fleet can be calculated from the variables of chromosome, capacity, and weight of vehicles. Variables such as residual demand, residual budget and inventory can also be easily calculated using the relationships in the model. In the case of binary variables, the quantitative genetic dependency method is applied, for example, if all the genes representing the number of pallets sent from the central warehouse to distribution center *i* is zero, then it can be concluded that distribution center *i* has not been established; or as another example, if there is no pallet of relief items sent from the local DP *i* to the demand point *j*, it can be concluded that the value of the binary variable representing the assignment of point *i* to point *j* is zero.

4-2- Initial population

To produce the initial population, the Allowable Responses Heuristic Method is used. In this method, node balance constraints and some other model constraints at the time of chromosome generation are considered. For example, we know that the sum of f-type pallets imported by different vehicles from central warehouses to a LDC must be directed to the DPs, and there is no warehouse to store them in distribution center *i*. As a result, balance at node *i* must be considered. Other operational constraints that are considered to justify the solution are capacity constraints. For example, in the generated solution, the injured beyond the service capacity of a health post cannot be transferred to that. Considering these constraints at the time of generating the initial response to prevent the production of impossible solutions increases the efficiency of the algorithm.

4-3- Crossover operator

In a two-point crossover operator, the cut points are randomly selected to represent the chromosome, which creates impossible response. Therefore, in this study, the Relative Two-Point Crossover is applied to generate the offspring population. In this operator, random cut points are applied between variables on the chromosome. In other words, the randomness of the cut site results in high-quality offspring and a variety of solutions. However, random cut points can only be selected between chromosome variables. In a Relative Two-Point Crossover, the cut point operator is applied to any of the subtractions in the chromosome vector. Figure 7 shows an example of a Relative Two-Point Crossover on a parent chromosome vector to generate new offspring as a genotype.

4-4- Mutation operator

The mutation operator is used to diversify the solutions and further search the solution space, preventing them from getting caught in the local optima trap. The mutation operator allows the solution algorithm to search for new parts of the solution space to find near-optimal solutions; for this purpose, the Change in Assignment (CIA) operator is applied to the parent chromosome vector, which generates the mutated chromosome. The mutation operator is basically changing the binary variables and assignments of the parent chromosome.

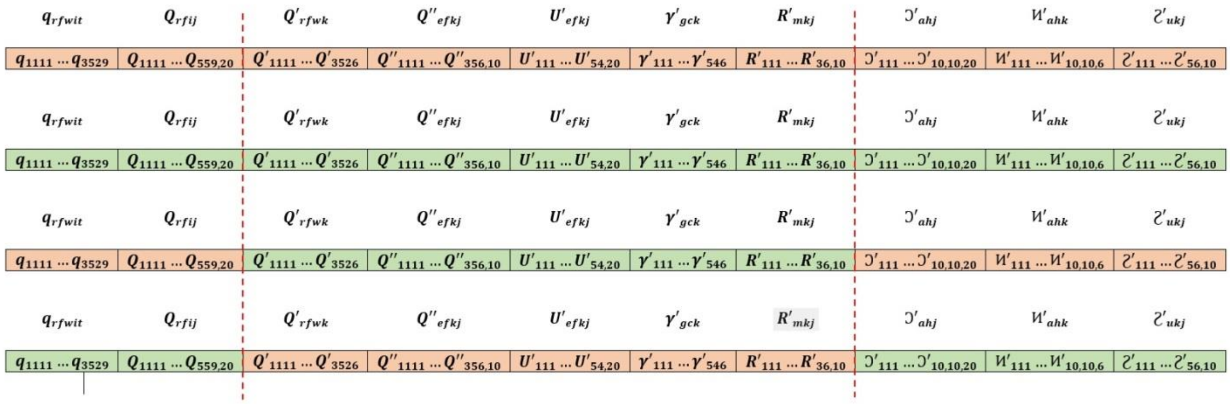

Fig 7. Applying a relative two-point crossover

In this mutation operator, an example of which can be seen in figure (8), the assignment of displaced people to a shelter has been mutated. As can be seen in the parent chromosome, shelter No. 1, 2 and 3 have been established and allocated to accommodate displaced people in different affected points, and company shelters have not been established in node 4, so no transfer is assigned to the shelter 4, while the application of the CIA operator to the parent chromosome has changed the allocation of displaced people to camps. As can be seen in the chromosome of the mutant offspring, it was not possible to allocate people to shelter No. 2 due to non-establishment of a camp in that node, and displaced people in different DPS have been allocated to shelter 1, 3 and 4. It should be noted that each time a mutation operator procedure is recalled, different variables are randomly selected to apply the CIA mutation operator to the assignment. This random selection of variables to change in assignments of the mutant chromosome ensures a wide variety of mutant solutions.

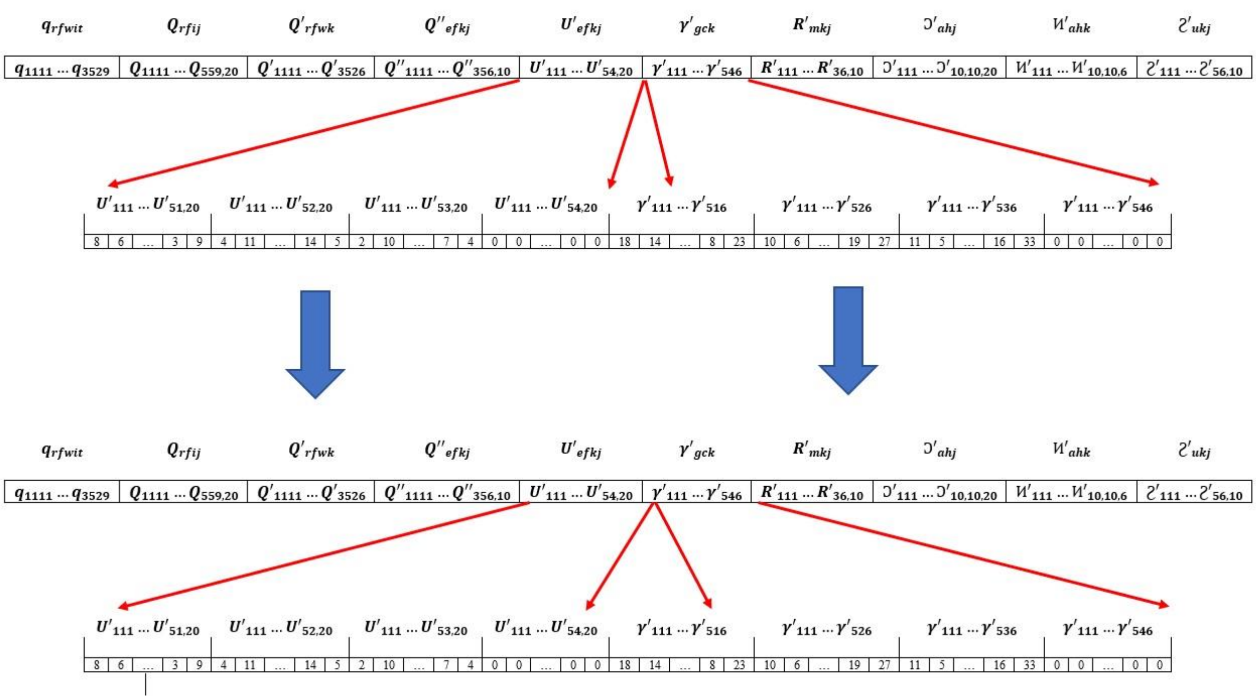

Fig 8. Applying the CIA mutation operator in the assignment.

4.5 Computational results

Since the proposed model is MILP, CPLEX solver is used to solve the model. The design of a humanitarian relief logistics planning model in the event of primary and secondary crises is an NP-hard problem. Large-scale examples of this problem cannot be solved with precise methods in a reasonable time. Therefore, first, 10 experimental examples including the occurrence of a disaster in a relatively small geographical area, and the humanitarian rescue chain under the conditions of primary and secondary crises were defined and solved by both algorithms. The parameters of the experimental problem, such as the needs at DPs and the travel time between the points of the transport network, in a time horizon of maximum 5 days are presented in tables (A2) to (A7).

Table 4. Parameter of DPs for relief items under different scenarios

		Pallet	DP1	DP2	DP3	DP4	IDP5	IDP6	DP7	DP8	DP9	DP10	DP11	DP12	IDP13	IDP14
Needs (Primary disaster)		f1	12	9	14	7	5	6	15	9	14	7	5	12	5	6
		f2	14	12	9	17	10	9	8	12	9	17	10	14	10	9
		f3	17	15	11	20	13	12	10	14	13	22	11	17	13	12
Needs (Secondary disaster)	*I=1*	f1	0	2	0	1	1	2	0	2	1	0	0	1	0	1
		f2	1	2	0	2	1	3	0	3	0	1	0	2	0	1
		f3	1	3	0	3	2	3	0	4	0	3	0	2	0	1
	I=2	f1	1	3	2	2	1	3	0	2	2	1	0	1	1	1
		f2	2	3	0	4	2	4	1	4	1	3	0	2	1	2
		f3	3	3	2	7	3	4	2	4	1	5	0	2	2	2
	I=3	f1	3	4	3	3	2	3	1	3	2	3	0	3	2	2
		f2	3	5	1	5	4	5	3	5	3	6	0	4	3	5
		f3	4	6	2	9	5	6	4	6	3	9	0	5	5	6

Table 5. Parameter of DPs for rescue operations of displaced people under different scenarios

		DP1	DP2	DP3	DP4	IDP5	IDP6	DP7	DP8	DP9	DP10	DP11	DP12	IDP13	IDP14
Needs (Primary disaster)		38	36	32	41	34	33	31	35	34	43	32	38	34	43
Needs (Secondary disaster)	*I=1*	8	3	0	7	5	6	0	7	4	8	0	6	0	7
	I=2	11	6	2	9	7	8	0	9	6	10	0	8	2	9
	I=3	14	8	2	12	8	11	1	12	7	13	0	10	3	12

Table 6. Parameter of DPs for rescue operations of the injured under different scenarios

		DP1	DP2	DP3	DP4	IDP5	IDP6	DP7	DP8	DP9	DP10	DP11	DP12	IDP13	IDP14
Needs (Primary disaster)		14	12	9	17	10	9	8	12	9	17	10	14	10	9
Needs (Secondary disaster)	*I=1*	3	2	0	3	2	1	0	3	2	3	0	2	1	3
	I=2	3	3	2	4	2	1	0	4	2	4	0	3	1	3
	I=3	5	5	2	5	3	2	2	6	3	5	0	3	2	4

Table (7) also shows the travel time parameter from distribution centers *i* as well as from intermediate points *k* to DPs. In the experimental examples, there are a maximum of three distribution centers *i* and three intermediate points *k*. In table (7), it is not possible to send relief aid from DCs to irregulated demand points such as *j5*, *j6*, *j13* and *j14*, which is indicated by an *X* sign. It is also possible to travel from intermediate point to all DPs, and even though travel time by special vehicles such as helicopters is much shorter than travel time by ordinary vehicles, due to the high cost of using special vehicles and the limited number of their models, it does not allow the delivery of relief aid to regulated demand points by special vehicles.

Table (8) shows the travel time parameter from the shelters as well as from the intermediate point's *k* to DPs. In the experimental examples provided, there are a maximum of four shelters c. In addition, table (9) shows the travel time parameter from health posts *h* as well as from intermediate point's *k* to DPs. There is a maximum of 6 health posts in the experimental examples provided. Occurrence of secondary disaster with weak, medium, and strong intensity can add 10, 20, and 30% to the travel times in tables (7) to (9), respectively.

Table 7. Parameter of travel time between network points for sending relief items

DC/TP	Vehicle	DP1	DP2	DP3	DP4	IDP5	IDP6	DP7	DP8	DP9	DP10	DP11	DP12	IDP13	IDP14
1	R	2	2	3	2	X	X	6	6	5	9	10	8	X	X
	E	4	0.3	0.5	0.2	2	2	0.3	0.2	0.2	0.7	0.9	0.6	4	4
2	R	4	5	6	6	X	X	2	1	2	7	6	6	X	X
	E	0.3	0.3	0.4	0.4	2	1	0.3	0.3	0.4	0.5	0.4	0.4	3	3
3	R	7	6	7	7	X	X	7	5	5	2	2	2	X	X
	E	0.3	0.4	0.5	04	4	4	0.5	0.4	0.4	0.3	0.2	0.3	2	2

Table 8. Parameter of travel time between network points for transfer of displaced people

Shelter/TP	Vehicle	DP1	DP2	DP3	DP4	IDP5	IDP6	DP7	DP8	DP9	DP10	DP11	DP12	IDP13	IDP14
1	G	2	2	3	2	X	X	6	6	5	9	10	8	X	X
	M	0.4	0.3	0.5	0.2	2	2	0.3	0.2	0.2	0.7	0.9	0.6	4	4
2	G	4	5	6	6	X	X	2	1	2	7	6	6	X	X
	M	0.3	0.3	0.4	0.4	2	1	0.3	0.3	0.4	0.5	0.4	0.4	3	3
3	G	7	6	7	7	X	X	7	5	5	2	2	2	X	X
	M	0.3	0.4	0.5	0.4	4	4	0.5	0.4	0.4	0.3	0.2	0.3	2	2
4	G	5	4	3	2	X	X	3	3	4	5	5	4	X	X
	M	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Table 9. Parameter of travel time between network points for transfer of the injured

DC/TP	Vehicle	DP1	DP2	DP3	DP4	IDP5	IDP6	DP7	DP8	DP9	DP10	DP11	DP12	IDP13	IDP14
1	A	2	2	3	2	X	X	6	6	5	9	10	8	X	X
	U	0.4	0.3	0.5	0.2	2	2	0.3	0.2	0.2	0.7	0.9	0.6	4	4
2	A	4	5	6	6	X	X	2	1	2	7	6	6	X	X
	U	0.3	0.3	0.4	0.4	2	1	0.3	0.3	0.4	0.5	0.4	0.4	3	3
3	A	7	6	7	7	X	X	7	5	5	2	2	2	X	X
	U	0.3	0.4	0.5	0.4	4	4	0.5	0.4	0.4	0.3	0.2	0.3	2	2
4	A	5	4	3	2	X	X	3	3	4	5	5	4	X	X
	U	X	X	X	X	X	X	X	X	X	X	X	X	X	X
5	A	2	3	2	2	X	X	4	3	4	4	5	4	X	X
	U	X	X	X	X	X	X	X	X	X	X	X	X	X	X
6	A	2	2	2	1	X	X	4	3	4	4	5	3	X	X
	U	X	X	X	X	X	X	X	X	X	X	X	X	X	X

In addition to the data in tables (4) to (9), it is assumed that the initial budget is one billion units of currency and the cost of using pallets is 1,500, 2,500, and 1,000 for different types of pallets f1, f2, and f3. Also, the fixed cost of building a local distribution center, shelter and health post is equal to 100,000, 150,000 and 200,000 units of currency, respectively, in this respect, 10 experimental examples are defined that are presented in table (10).

Table 10. Design of experimental examples

Example #	# Regular DP	# Intermediate points	# Irregular DP	# Days in time horizon
1	5	1	2	2
2	6	1	2	2
3	7	2	2	3
4	8	2	2	3
5	9	2	2	4
6	9	2	3	4
7	10	2	3	4
8	10	2	3	4
9	10	3	3	5
10	10	3	4	5

Since each sub-problem is solved by the exact method, the optimal solution of each sub-problem is guaranteed, however, the number of times the problem is solved increases with increasing number of time periods, which reduces the efficiency of the algorithm. Therefore, we use the combined method of rolling horizon based on genetic algorithm (HRH-GA) to solve large-scale problems. To evaluate the performance of HRH-GA, small-scale experimental examples are solved by both exact and meta-heuristic methods, and after confirming the efficiency of the combined method, HRH-GA method will be applied to solve the real problem in large scale problem. The obtained results from solving the experimental examples by both algorithms are compared as shown in table (11) to evaluate the performance of the proposed combined method. Both algorithms run on a PC with a 2.16GHz CPU as well as memory of 2GB of RAM with the same parameters.

Table 11. Comparison of the results for solving experimental examples

Example #	GAMS		HRH-GA	
	Objective function value	Solution time (Min)	Objective function value	Solution time (Min)
1	50.29	11	51.33	6
2	58.1	16	60.16	7
3	67.64	27	69.79	7
4	76.996	39	78.111	10
5	89.5	56	90.64	10
6	100.32	79	100.4	11
7	111.015	124	113.21	12
8	118.345	202	119.49	12
9	XXX	XXX	127.811	17
10	XXX	XXX	142.94	18

The purpose of table (11) is to compare the results obtained from the two algorithms based on two criteria of solving time and values of the solutions. However, table (11) does not show the problem solving in detail. For this purpose, one of the experimental examples (example 5) was selected as and its solving process is shown in more detail in figure (9). As shown in figure (9), the 4-day time horizon is divided into 6-hour periods. Relief items are distributed in three types of pallets in the relief network and are available to DPs based on the respective priority. The logistical and capacity constraints must be considered, for example, the constraint for transportation of different types of pallets after the primary disaster is equal to 40 pallets, since type 1 and 2 have a higher priority in terms of necessity, so the model first distributes this type of pallets and then distributes type 3 pallets. Among DPs, points 1, 4 and 6 have the highest priority for both pallets 1 and 2, therefore, the distribution of relief items with type 1 and 2 pallets for these points will begin in the first time period. In addition, the distribution of relief items of pallet type 1 to DP 10 and also type 2 pallets to DP 2 and 3 has started in the first period with high priority. The rest of the demand points are satisfied based on the priority of their demand. Rescue of the injured as well as the displaced people from the DPs is performed in the same way and they are serviced according to the priority. At the beginning of the third period (T = 18h), a secondary disaster occurs with an intensity of $I = 2$, which creates new demand in some DPs. This newly created demand is added with the already remaining demand that has not yet been satisfied and forms a new demand for each point. Therefore, the dynamic behavior of the model, in addition to updating the parameter related to the priority of demand points in receiving relief items and rescue services, can also handle the increased demand due to the occurrence of a secondary disaster. In addition, the analysis of the results shows that the priority score has a significant impact on the decision-making process to meet the demand of different points.

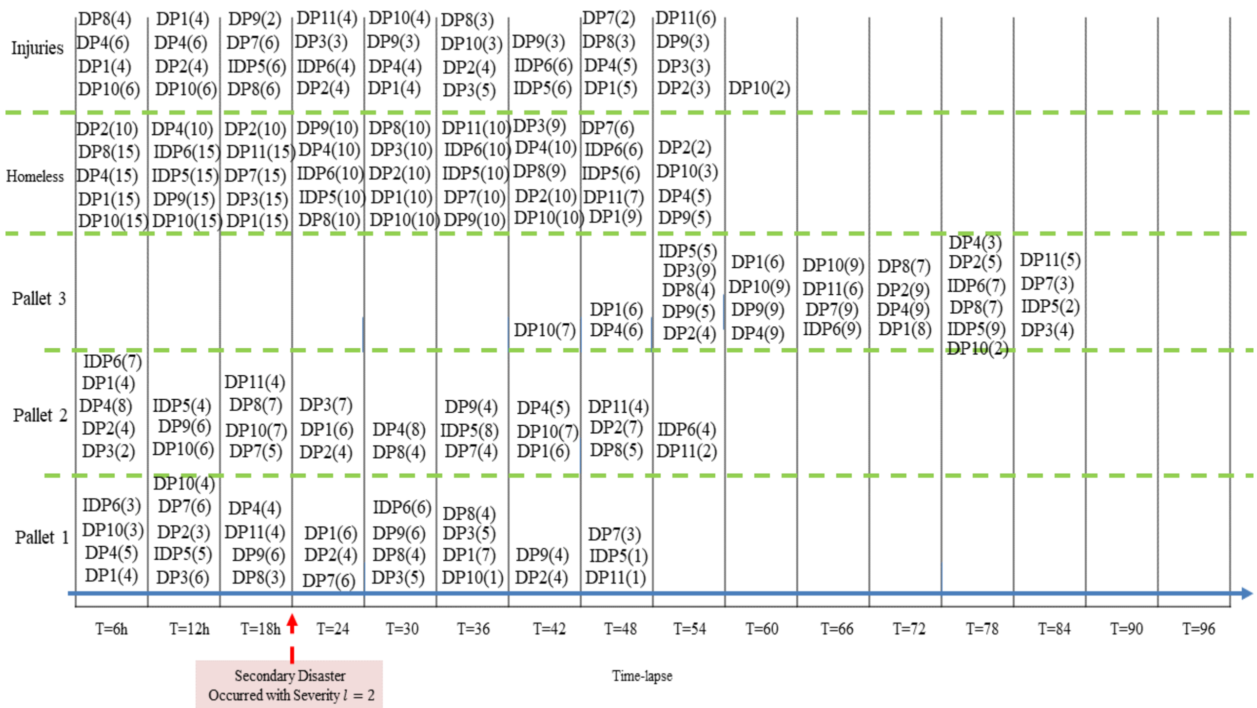

Fig 9. Time lapse to meet demands under primary and secondary disaster conditions

It should be noted that the priority of each DP is updated at the beginning of each time period and the model distributes relief items or rescues the injured and displaced people based on the new priority demand. The time lapse in figure (9), which is related to the solution of experimental example No. 5, shows that the current dynamic model presented in this study has been able to model the changes of parameters over time as well as in the event of a secondary disaster, and respond to all rescue and relief needs in the network within the defined time horizon (4 days). As can be seen, at the end of the fourteenth period (T = 84h), the entire demand and service supply tasks have been completed. Regarding the reduction of the capacity of the facilities due to the occurrence of the secondary disaster, it is also observed that the capacity of the facilities for the distribution of relief items reduced from 40 units to 33 units in total, the service facilities for the displaced people was from 70 units to 50 units and the rescue facilities for the injured reduced from 20 units to 15 units. This indicates the realism of the model presented in this study in the event of a secondary disaster, because the previous models, which considered only the primary disaster, could not deal properly in the event of a secondary disaster.

4-6- Case study

In this section, to investigate the solvability of the model and the dynamic algorithm presented, a large case study will be investigated, the case study is related to the occurrence of various natural disasters in North Khorasan province of Iran in 2016. In the early morning of the 3th of November 2016, an earthquake with a magnitude of 4 happened, the next day, due to heavy rains, there was a large flood on connection roads. Occurrence of floods, landslides as well as successive thunderstorms caused fires in different parts of Shirvan and Quchan counties and around Bojnourd the capital of the province. In addition, a storm with a speed of about 108 kilometers per hour hit the villages and towns of Bojnourd and the central part of the city. Thus, four natural disasters occurred simultaneously at a short interval, the earthquake did not cause any casualties due to the low intensity of the earthquake. The fire did not cause any casualties, except for a few minor injuries. The floods wreaked havoc, destroying homes and infrastructure, and left a significant number of dead, injured and displaced persons. There were also reports of people being injured and destruction of buildings by the storm, therefore, flood as a primary disaster and storm as a secondary disaster are studied in this research. The death toll from the floods, centered in Shirvan and Bojnourd, was announced at 19, according the official figures 4,388 people were injured and about 10,700 people became displaced. The number of damaged points in this primary disaster was 4 cities and 1,620 villages. However, the number of affected points was determined as a total of 271 rural centers and 4 cities as rescue and relief points. out of these number, 39 were determined as IDPs due to the destroying of communication routes, which could only be reached by special vehicles (helicopters and boats)., 7 heliports' runway located in Bojnourd and Shirvan, as the intermediate points, were used to send relief items and transport the injured and displaced people to and from IDPs. In addition, the storm, which is considered as the secondary disaster, injured 723 people, and destroyed the homes of some villagers in rural areas, leaving 396 people displaced. Also, 29 new DPs (26 RDPs and 3 IDPs) were created due to the secondary disaster and were added to the previous DPs. The secondary disaster happened about 12 hours after the primary disaster, and since 6-hour time periods are considered, it can be said that the secondary disaster occurred in a two time periods after the primary disaster. The studied parameters such as the DPs, the travel time between the points of the transport network, in a time horizon of maximum 10 days are presented in table (A-1) to (A-6) in Annex A. In this problem, 18 potential points for establishment of LDCs for relief items, 10 shelters, and 12 health posts are considered, and 7 intermediate points are located as intermediate points in the network. Table (12) shows the demand of each *j* points for each type of pallet *f* as well as the rescue operations for the transfer of the displaced and injured, respectively. In addition, tables (13) to (15) show the parameter of travel time between network nodes for the distribution of relief items, travel time for displaced people, and travel time for transporting the injured, respectively. Tables (13) to (15) do not allow ordinary vehicles to travel to IDPs, which are indicated by an X. It is assumed that the initial budget is 31 billion units of money and the cost of using pallets is 85,000, 122,000, 35,000, 245,000, 180,000, 14,000, 59,000 for pallets of f1, f2, f3, f4, f5 and f6 respectively, the averages fixed cost for establishment of a shelter is 105,000,000 and the averages cost of establishing a health post is 1.8 million. The solution results indicated in tables (A-3) and (A-4) Annex A.

Table 18. Results of meeting the demand of demand points for relief items

		% unmet needs at the first day of time horizon	# RDPs which demands will not be met by the end of time horizon	# IDPs which demands will not be met by end of time horizon
Distribution of relief items	Current research methodology	9	21	%71
	Best practice methodology	18	64	%91
Transportation of displaced persons	Current research methodology	15	51	%80
	Best practice methodology	21	94	%94
Transportation of injured persons	Current research methodology	5	15	%59
	Best practice methodology	14	48	%86

As can be seen in table (18), in the current research, in average 29% of relief item needs for the affected points is met on the first day of the time horizon, and there are a total of 21 RDPs and 9 IDPs which respective needs will not be met by end of the 10-day time horizon. Also, in average, 20% of the needs for affected areas for transportation of displaced persons is met on the first day of the time horizon, and there are a total of 51 RDPs and 15 IDPs whose demands are not met by the end of the 10-day time horizon. In addition, it is observed that in the current research, in average, 41% of the needs of the affected points for the transfer of the injured is met on the first day of the time horizon, and there are a total of 15 RDPs and 5 IDPs whose demand are not met by the end of the 10-day time horizon. It is noteworthy that out of 18 potential points for the establishment of LDCs, 12 LDCs were established, which indicates that no local LDC will be established in the remaining 6 potential points. The reason for this could be the high fixed cost of constructing a DC in those areas or the long distance from that DP, thus establishment of LDC in those areas as not economical. Facilitation capacity constraint is another factor because sending relief items to DCs which have limited capacity to receive relief items renders the relief logistics network inefficient. Similarly, out of 10 potential points for the construction of shelters, 8 camps were established and out of 12 potential points for health posts 11 have been set up.

4-7- Tuning the parameters of the genetic algorithm

Solving problems in larger scale would create more challenges for meta-heuristic algorithms as well as the proposed genetic algorithm. One of the most important factors affecting the performance of the genetic algorithm is the tuning GA parameters including the number of people in the population (population size), the number of repetitions of the algorithm (number of generations), the percentage of intersection operator applications and the percentage of mutation operator applications. For this purpose, various methods such as sensitivity analysis, pilot experiments and Taguchi method have been used to adjust the parameters of the genetic algorithm in the literature review. Properly tuning the parameters of the genetic algorithm will have a significant impact on the runtime of the algorithm as well as achieving near-optimal solutions. In this research, we will use Taguchi method to tune GA parameters. Taguchi method uses experimental design analysis for parameter tuning. Three levels were considered for each parameter and the Minitab software was used to design experiments and analyze the results obtained from solving a medium-sized problem. The algorithm parameters as well as the test levels designed for the GA algorithm parameters are shown in table (19). Levels of experiments designed for the parameters are obtained based on consultation with experts as well as reference to historical data. Figure (10) shows the results obtained from the Taguchi method.

Table 19. Experimental design for genetic algorithm parameters

# Level	Population size	Number of generations	% Intersection operator	% Mutation operator applications
1	50	50	0.3	0.3
2	75	100	0.5	0.5
3	100	200	0.7	0.7

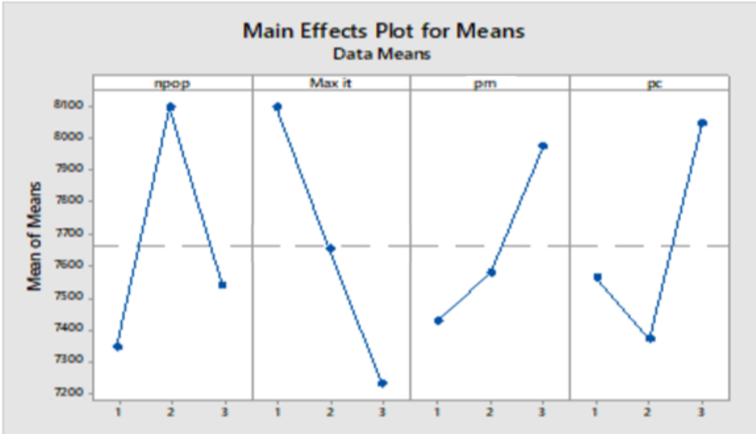

Fig 10. Adjustment of GA parameters using Taguchi method

Therefore, according to the results obtained from Taguchi method, the proposed values for population size, number of generations, percentage of mutation operator and percentage of intersection operator are equal to 50, 200, 0.3 and 0.5 respectively.

4-8- Sensitivity analysis

To test the efficiency of the proposed approach, using a case study data set, the effect of various assumptions and parameters of the model was investigated through sensitivity analysis. In this method, the values of the key parameter are changed while the values of other parameters of the model are fixed to determine the effects of this change on the model and the objective function, and if the changes and behavior of the model are in line with experts' expectations, it can be concluded that the model has the necessary efficiency. Among the key and influential parameters in the issue are the number of vehicles available as well as the allocated budget. Therefore, in the sensitivity analysis of the model, parameters such as the number of vehicles available and the budget have been changed to examine the effect of these changes on the performance of the model. In each case, only one parameter is changed, and the other parameters are considered fixed. Figures (11) and (12) show the results of the sensitivity analysis of the model parameters.

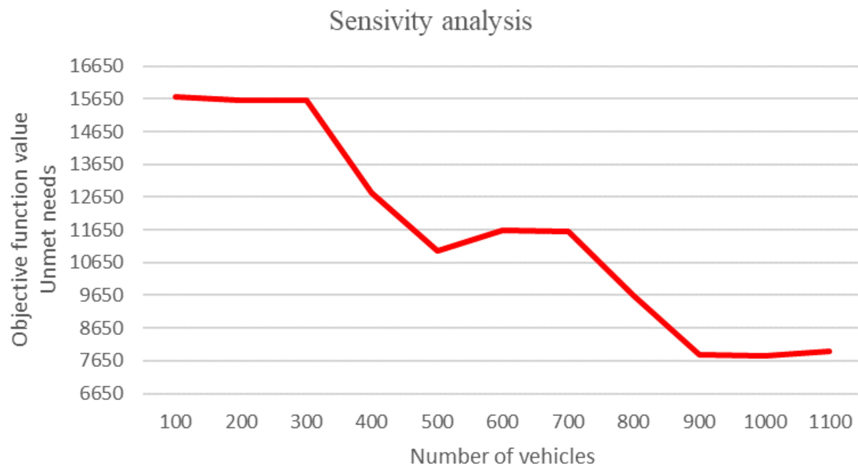

Fig 11. Sensitivity analysis of the objective function to the number of available vehicles parameter

As shown in figure (11), with increasing the total number of vehicles (ordinary vehicles available in DCs plus special vehicles in the middle points) the amount of objective function is significantly reduced. In fact, the reason for this is that with the increase of vehicles, which is the most important factor in the operation of a logistics distribution network, the ability of the rescue chain network to send higher amount of relief items as well as rescue services to the affected areas has increased. As a result, the amount of unsatisfied demand (objective function) decreases that is consistent with experts' expectations of real-world model behavior. The noteworthy point in figure (11) is that the downward trend of decreasing the of the objective function occurs up to 900 vehicles with a steep slope, while after that the downward trend is slight and tends to be almost a constant value. There are two main reasons for that, first, increasing the number of vehicles, despite its great importance, is not the only limitation of the current model, in fact, the amount of budget, supply of relief items, limited capacity of facilities, time constraints and also the limited number of pallets are other deterrents that affect the objective function and increasing the number of vehicles from one point later does not anymore accelerates rescue operations, and as a result, the objective function is not improved. In this case, there seems to be enough vehicles to distribute relief items, while no kits or pallets are available for distribution. Therefore, as a management solution, it is suggested that the number of vehicles for carrying out rescue operations is selected in proportion to the magnitude of the primary and secondary crises and the amount of demand created by the occurrence of crises. The results of sensitivity analysis show that if the primary and secondary crises in the real world occur as much as the floods and storms studied in this study, i.e. North Khorasan province, and the demand is similar to the study, a maximum of 900 vehicles of different types is enough to provide the best rescue services. Therefore, allocating more than this number of vehicles will not be optimal. On the other hand, by increasing the size and severity of the disaster, in other cases, the optimal number of vehicles required can be estimated. Another important point in figure (15) is that at least 100 vehicles are required for the initial launch of the rescue chain, and less than this will make the model impossible. In other words, the lower limit of the number of vehicles required to provide a minimum of services in the present study is 100 vehicles, as the upper limit was set at 900.

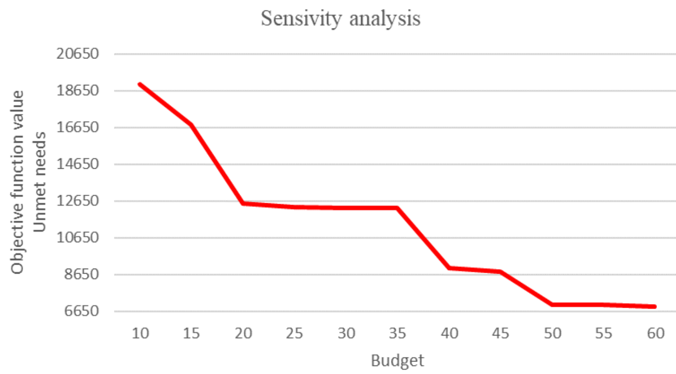

Fig 12. Sensitivity analysis of objective function of model versus the budget parameter

As shown in figure (12), the amount of the objective function decreases significantly with increasing budget. In fact, the reason for this is that with increasing budget, the ability of the rescue chain network to provide services to the affected areas increases and as a result, the amount of unsatisfied demand (objective function) decreases. This finding is also consistent with experts' expectations of model behavior in the real world. The noteworthy point in figure (12) is that this trend is this declining trend in the amount of the objective function to 50 billion is with a steep slope, while after that the downward trend is negligible and tends to almost a constant value. This, like previous sensitivity analysis, is due to other operational constraints on the issue. In this case, it seems that there is enough budget to distribute relief items, while the operational capacity of the rescue network is not enough. Therefore, according to the analysis of sensitivities, the behavior of the model is expected by experts and as a result, the efficiency of the model is guaranteed. Another parameter that can have a significant impact on the results is the severity of the secondary disaster. The sensitivity analysis of the amount of residual demand in each period to changes in the severity of the secondary disaster is shown in figure (13).

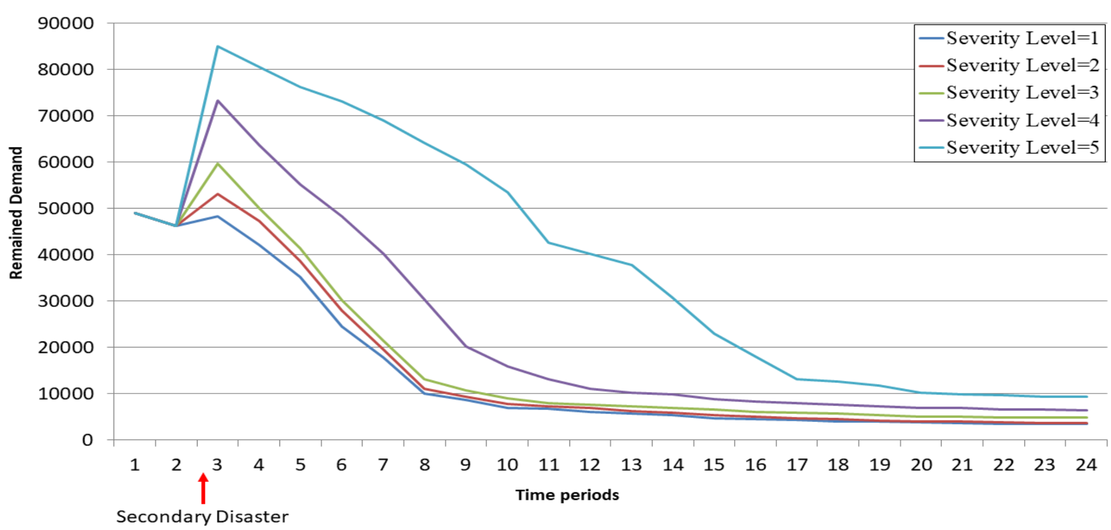

Fig 13. Graph of residual demand sensitivity analysis to changes in the severity of the secondary disaster

As can be seen in figure (13), increasing the severity of the secondary disaster can worsen the service situation to the demand points. The severity of the disaster at levels 1, 2, and 3, although it adds a different amount of demand to the unsatisfied demand at the onset of the disaster, due to the small difference in demand, all three graphs show similar behavior and converge in the ninth time period. While the occurrence of a disaster at levels 4 and 5 has a major impact on the performance of the rescue network, so that more time (from the thirteenth period for the occurrence of a disaster of magnitude 4 and the nineteenth period) to reach a relatively favorable situation in demand response is required. Regarding the demand for transporting the injured and transporting the displaced people, the model has a similar behavior, which is consistent with the expectations of the system experts and shows the efficiency of the proposed model.

5- Conclusion and future recommendations

In this study, after stating the problem of designing a humanitarian aid logistics planning model in the event of primary and secondary disaster and explaining the various dimensions of the problem and its components, a mathematical model was presented. As this problem is an Np-hard, so an innovative solution method, rolling horizon approach based on the genetic algorithm called HRH-GA, was introduced to solve the problem. To evaluate the presented approach, numerous numerical examples in small sizes and a real-world example in large scale were solved and the results were analyzed. Finally, the efficiency of the model was evaluated using the sensitivity analysis method. Based on the results from tables (18), decision makers and managers can take an appropriate approach to managing the rescue chain in the face of a natural disaster. In the traditional approach, which has already taken place in practice, on average, only 9% of the demand of affected areas for relief items was met on the first day of the time horizon, and in the whole time horizon period, 64 RDPs (i.e., about 21 % of total RDPs) and 18 IDPs (about 43% of total IDPs) until the end of their 10-day time horizon, respective needs were not met at all. Also, in average, only 6% of total needs for the displacement of displaced people on the first day was met from the time horizon, and in the whole time horizon period, 94 RDP (i.e., about 31% of total RDPs) and 21 IDPs (about 50% of the total IDPs) were not met until the end of the 10-day time horizon at all. In addition to that, in average, only 14% of needs for transfer of the injured was met on the first day from the time horizon, and in the whole time horizon period, 48 RDPs (i.e., about 16% of the total RDPs) and 14 IDPs (about 33% of the total IDPs) were not met at all by the end of 10-day time horizon. As a result, in terms of satisfying all three types of needs in the rescue and relief network, the approach presented in this research outperforms the manual approach. Considering traffic restrictions, the impact of public aid, etc. it would open a window to future research. Using mathematical models with more than one objective to model this complex problem and using multi-objective optimization methods in problem solving can be in line with getting closer to real-world problems. It is suggested that in future research, uncertain parameters be considered, and to deal with uncertainty, methods such as fuzzy planning, robust optimization and probabilistic planning, etc. are used and the results are compared with the present study. Finally, in the present study, a combined method of rolling horizon approach based on genetic algorithm for large-scale problem solving was introduced. It is suggested that other innovative and meta-heuristic methods be used to solve the problem and compare the results with the present study.

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Appendix A (Case study data)

Table A-1. Parameter of DPs for relief items

Pallets	j_1	j_2	j_3	j_4	j_5	…..	J_{302}	J_{303}	J_{304}
Need for f1	47	21	38	20	58	…..	20	24	13
Need for f2	33	17	10	24	28	…..	10	20	23
Need for f3	41	17	19	28	30	…..	14	10	18
Need for f4	14	19	25	44	9	…..	20	33	5
Need for f5	26	18	15	11	18	…..	48	13	11
Need for f6	30	27	16	19	11	…..	5	22	6
Number of displaced persons	66	62	24	149	23	…..	9	93	118
Number of injured	20	18	15	23	16	…..	20	16	15

Table A-2. Parameter of travel time between network points to send relief items

DC/TP	Vehicle	j_1	j_2	j_3	j_4	j_5	J_6	J_7	….	J_{301}	J_{302}	J_{303}	J_{304}
1	R	2	3	3	1	2	3	3	….	3	X	X	2
	E	0.1	0.2	0.3	0.2	0.1	0.1	0.3	….	0.3	3	5	1
2	R	6	4	5	6	3	4	9	….	3	X	X	4
	E	0.4	0.4	0.5	0.3	0.5	0.8	0.5	….	0.4	5	4	0.6
3	R	4	4	4	3	3	6	2	….	5	X	X	3
	E	0.2	0.3	0.4	0.3	0.2	0.3	0.5	….	0.5	2	3	11

Table A-3. Parameter of travel time between network points for the transfer of displaced people

Shelter/TP	Vehicle	j_1	j_2	j_3	j_4	j_5	J_6	J_7	….	J_{301}	J_{302}	J_{303}	J_{304}
1	G	2	2	3	2	X	X	6	…	10	8	X	X
	M	0.4	0.3	0.5	0.2	2	2	0.3	…	0.9	0.6	4	4
2	G	4	5	6	6	X	X	2	…	6	6	X	X
	M	0.3	0.3	0.4	0.4	2	1	0.3	…	0.4	0.4	3	3
3	G	7	6	7	7	X	X	7	…	2	2	X	X
	M	0.3	0.4	0.5	0.4	4	4	0.5	…	0.2	0.3	2	2

Table A-4. Parameter of travel time between network points to transfer the injured

Shelter/TP	Vehicle	j_1	j_2	j_3	j_4	j_5	J_6	J_7	….	J_{301}	J_{302}	J_{303}	J_{304}
1	A	2	2	3	2	X	X	6	…	10	8	X	X
	U	0.4	0.3	0.5	0.2	2	2	0.3	…	0.9	0.6	4	4
2	A	4	5	6	6	X	X	2	…	6	6	X	X
	U	0.3	0.3	0.4	0.4	2	1	0.3	…	0.4	0.4	3	3
3	A	7	6	7	7	X	X	7	…	2	2	X	X
	U	0.3	0.4	0.5	0.4	4	4	0.5	…	0.2	0.3	2	2

Table A-5. Total number of travels and pallets sent from each of the distribution centers

	i_1	i_2	i_3	i_4	i_5	i_6	i_7	i_8	i_9	i_{10}	i_{11}	i_{12}
# Travels for distribution of relief items	18	48	199	107	70	74	30	20	18	101	57	66
# Distributed pallets	53	131	529	298	188	192	83	55	53	276	164	170
# Travels for transportation of displaced persons	60	91	170	150	113	117	73	63	59	144	154	103
# of displaced persons who resettled	603	682	1274	850	742	750	633	605	603	826	1033	739
# Travels for transportation of injured persons	48	132	291	129	98	132	88	49	47	187	227	119
# of injured persons who rescued	53	417	933	298	188	440	283	55	53	577	674	374

Table A-6. Total number of travels and pallets sent from each of the intermediate

	K_1	K_2	K_3	K_4	K_5	K_6	K_7
# Travels for distribution of relief	10	31	14	12	6	8	2
# Distributed pallets	15	41	19	17	10	13	8
# Travels for transportation of displaced persons	15	20	12	10	9	10	2
# of displaced persons who resettled	96	122	69	62	55	73	14
# Travels for transportation of injured persons	15	11	10	10	13	9	3
# of injured persons who rescued	64	40	37	41	55	29	11