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Humanitarian Logistics Optimization Model in Natural Disasters and Emergencies under Uncertainty (Case Study: Istanbul)

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Abstract

Natural and abnormal disasters are on the rise all over the world and cause a lot of life and financial losses, so it is important to address these issues and challenges. Humanitarian logistics and disaster management planning can control critical situations and minimize losses, shortages, and injuries. An important logistical strategy for crisis management is to plan for crucial goods before and after the crisis. This paper focuses on credible suppliers, designing a multi-level supply chain with the scenario-based approach under uncertainty environments. The validity and reliability of the proposed model are examined by presenting an applied numerical example, in Istanbul and then sensitivity analysis of the model variables is performed. The results show that with increasing supply rates, shortages and shortage costs decrease, and with the increase of the capacity of shelters, the number of persons not transported from the accident area, and the cost of the non-transportation people decreases and the number of persons transported from the site increases.

Keywords: Supply Network; Humanitarian Logistics; Network Design; Mathematical Model; Disaster.

1. Introduction

Natural disasters are increasing day by day in our world due to factors such as population growth, changes in climate and environment, and the movement of layers of the earth. Because of these natural disasters, there are often many casualties and financial losses. According to surveys (as in the case of Istanbul, Turkey), it seems that current relief is not sufficiently effective. Furthermore, because of the critical nature of crises, they need to be addressed quickly. An appropriate tool at the time of the disaster is the use of efficient humanitarian aid through the supply-chain network (SCN) and humanitarian logistics. Humanitarian logistics is the process of planning, implementing, and monitoring the flow and proficient storage of goods and materials at a suitable cost (Bag, et al. 2020, Safaei 2020). It also includes a set of actions to deal with natural disasters in two phases of preparation and response.

Another important issue that has been addressed in recent years is "crisis management." Each crisis-management system comprises a cycle with four different phases of prevention, preparation, recovery (or mitigation) and response, with each phase performing specific operations (Figure 1).

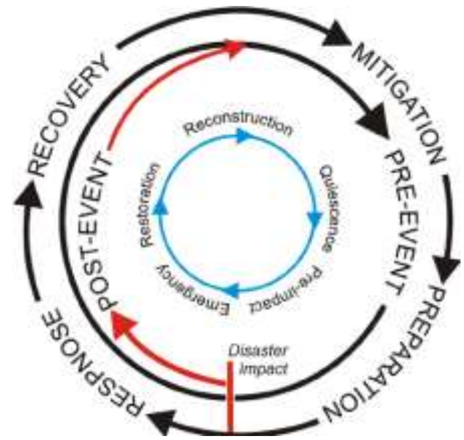

Figure 1 Crisis-management cycle (Ndlela 2018)

Given the distinctive nature of uncertainty in these problems, comprehensive crisis plans are needed to control and mitigate the risks and consequences thereof. In the event of natural disasters, response operations must be undertaken expeditiously, as well as an efficient and effective response to logistical problems. To achieve these goals, improved relief can produce efficacious results. In fact, humanitarian logistics management is the most important part of crisis management (Safaei 2020).

Following, given the uncertainty characteristic of this group of issues, a brief review of the literature on the allocation and distribution of goods in the humanitarian logistics network under uncertainty is briefly discussed.

Lin et al. (2011) developed a model to minimize costs and improve an emergency planning tool to determine the location and quantities of various types of emergency equipment prior to the disaster. Their approach had a long travel time, and this weakness was remedied in future research and the logistics efficiency of the rescue improved (Lin, et al. 2011).

(Bozorgi-Amiri, et al. 2012) presented a large-scale model in which demand, supplier capacity, shipping and purchasing costs are all considered uncertain. Their purpose was to distribute relief goods and to minimize the costs of providing relief to those affected by the accident.

In 2014, Kulshrestha et al. developed a nonlinear model aiming to minimize the total amount of time needed to evacuate people from an accident (Kulshrestha, Lou and Yin 2012). In the same year, Rezaei-Malek, and Tavakkoli-Moghaddam presented a two-objective non-linear model of time-based relief as well as cost minimization (Rezaei-Malek and Tavakkoli-Moghaddam 2014).

Bozorgi and Khorsi (2016) proposed a dynamic non-linear multi-objective model with facility location and routing of transport vehicle's objectives, and equitable distribution of relief goods for humanitarian logistics before and after the crisis (Bozorgi-Amiri and Khorsi 2016).

Zokaee et al. (2016), presented a single-objective nonlinear model, aiming to minimize total costs under allocation locating for three-tier supply chain design (Zokaee, Bozorgi-Amiri and Sadjadi 2016).

In the literature review, it is rarely seen as an integrated model that integrates all phases of a natural disaster and crisis-management decisions. Focusing and planning on suppliers has also been less considered in past research. Since it is important to ensure the supply of goods or, in other words, the assurance of reducing the shortage of goods in different crucial situations, in this study, a two-objective probabilistic model with the goal of minimizing all costs associated with the supplier, and not transporting healthy and injured persons affected by the accident, and minimizing shortages are considered, with a particular focus on suppliers. Moreover, in this model, it is attempting to control these suppliers, taking into account the specific reliability reserve and supply rate given the different critical conditions in the pre- and post-crisis periods. Considering an integrated model for events and their associated parameters in natural disasters is one of the cases whose gaps in its research literature still persist.

Section 2 of this article describes the full details of the research problem. Then in Section 3, the required parameters and variables for the problem are defined, and finally; the corresponding mathematical model is presented. In Section 4, a numerical example (with the assumption of Istanbul city) and sensitivity analysis and results are presented. Finally, Section 5 summarizes and concludes the horizons ahead.

ISSN- 2394-5125 VOL 7, ISSUE 15, 2020

2. Problem definition

The present article deals with the problem of designing a critical supply chain network in times of crisis and uncertainty. This paper deals with the issue of supply chain network design to supply "critical goods" in times of crisis and uncertainty. This involves a four-level supply network, consisting of suppliers, accident sites, hospitals, and shelters. Suppliers play an important role in this, and their inventory levels are planned before and after the crisis (Koushki Jahromi and Safaei 2020). The problem involves several operations such as transporting injured people to hospitals, transferring homeless people to shelters, and delivering and distributing vital goods to them in these centers. The objective functions of the model are to minimize the total cost of suppliers; costs are affected by non-displacement of survivors, as well as minimization of shortages. That is, in fact, the humanitarian goal of which the rescue of the wounded and displaced will be improved. In addition, the damage caused by such accidents will be minimized. In this issue, a mathematical model with a scenario-based approach is written.

2.1. Problem assumptions include

- The planning horizon is three periods (each period has 24 hours (72 hours))
- The two phases of "pre-crisis" and "post-crisis response" are discussed.
- The capacity and number of hospitals and shelters are known.
- The amount of need for each person is determined for each type of vital goods.
- Safety stock is a variable of "pre-crisis" decision.
- The individual needs for each type of product and the weight of each product and the cost of establishing shelters and the capacity of shelters and hospitals and vehicles and the cost of maintenance and shipping times are equal in all scenarios; as a result, changing the scenario does not affect them, and other data also depend on the scenario.
- There are three types of vehicles (trucks for transporting goods, buses for transporting healthy people, ambulances for transporting injured persons), which are limited in number of and capacity.

2.2. Material and method

This section presents a mixed-integer linear programming model for the problem with the symbols, parameters, and variables used.

Indexes

V_1: $Set\ of\ vehicles\ used\ to\ transport\ healthy\ people\ from\ the\ scene\ to\ the\ shelter.$

V_2: $Set\ of\ vehicles\ used\ to\ transport\ injured\ people\ from\ the\ scene\ to\ the\ hospital$

V_3: $Set\ of\ vehicles\ used\ to\ transport\ goods\ from\ supplier\ to\ accident\ and\ shelter\ locations$

$T: \{0, 1, 2, \dots, t\}$ $Set\ of\ periods$

$I: \{1, 2, 3, \dots, i\}$ $Suppliers$

$J: \{1, 2, 3, \dots, j\}$ $Set\ of\ accident\ scene\ locations$

$H: \{1, 2, 3, \dots, h\}$ $Set\ of\ hospitals$

$P: \{1, 2, 3, \dots, p\}$ $Set\ of\ shelters$

$V: \{V_1, V_2, V_3\}$ $Set\ of\ vehicles$

$K: \{1, 2, 3, \dots, k\}$ $Set\ of\ vital\ goods$

$S: \{1, 2, 3, \dots, s\}$ $Set\ of\ vital\ Set\ of\ scenarios$

Parameters

nh_{js}: $Number\ of\ healthy\ people\ at\ the\ scene\ of\ the\ accident\ j\ under\ scenario\ s$

ni_{js} : $Number\ of\ people\ injured\ at\ the\ scene\ of\ the\ accident\ j\ under\ scenario\ s$

qg_k: $The\ quantity\ needed\ for\ k - type\ goods\ per\ person$

w_k: $Weight\ of\ goods\ type\ k$

cbs_p: $The\ cost\ of\ building\ a\ shelter\ p$

ISSN- 2394-5125 VOL 7, ISSUE 15, 2020

cs_p : $Capacity\ of\ the\ shelter\ p$

ch_h: $Capacity\ of\ the\ hospital\ h$

cv_v: $Capacity\ of\ the\ vehicle\ v$

cpp_{ts}: $Penalty\ for\ non-transfer\ of\ persons\ in\ period\ t\ under\ scenario\ s$

cs_k: $Cost\ of\ storage\ of\ k\ type\ goods$

ps_s: $Scenario\ s\ likely$

srg_{kits}: $Supply\ type\ k\ good, by\ supplier\ i\ for\ period\ t\ under\ scenario\ s$

$ttss_{vip}$: $Time\ of\ transport\ type\ v\ from\ the\ supplier\ i\ to\ the\ shelter\ p$

$ttas_{vjp}$: $Time\ of\ transport\ type\ v\ from\ the\ scene\ of\ the\ accident\ j\ to\ the\ shelter\ p$

nva_{vj}: $Number\ of\ type\ v\ vehicles\ at\ accident\ point\ j\ at\ the\ beginning\ of\ planning$

nvs_{vi}: $Number\ of\ type\ v\ vehicles\ at\ supplier\ location\ i\ at\ the\ beginning\ of\ planning$

bgs_{ki}: $The\ binary\ parameter, if\ k-type\ goods\ are\ supplied\ by\ supplier\ i, will\ be\ one, otherwise\ zero.$

t_{max}: $Maximum\ coverage\ time$

bpn: $A\ big\ positive\ number$

bbs: $Budget\ available\ to\ build\ shelters$

Variables

dsg_{pkts}: $Demand\ of\ shelter\ p\ for\ type\ k\ goods\ in\ period\ t\ under\ scenario\ s$

dhg_{hkts}: $Demand\ of\ hospital\ h\ for\ type\ k\ goods\ in\ period\ t\ under\ scenario\ s$

ssg_{ki}: $Supplier\ i\ saftey\ stock\ for\ goods\ k$

Lgs_{pkts}: $Lack\ of\ k-type\ goods\ in\ shelter\ p\ in\ period\ t\ under\ scenario\ s$

Lgh_{hkts}: $Lack\ of\ k-type\ goods\ in\ hospital\ h\ in\ period\ t\ under\ scenario\ s$

Nht_{jpts}: $The\ number\ of\ healthy\ people\ transferred\ from\ the\ accident\ site\ j\ to\ the\ shelter\ p$ $in\ period\ t\ under\ scenario\ s$

$NhNt_{jts}$: $The\ number\ of\ healthy\ people\ not\ transferred\ from\ the\ accident\ site\ j\ in\ period\ t\ under$ $scenario\ s$

$NiNt_{jts}$: $The\ number\ of\ injured\ people\ not\ transferred\ from\ the\ accident\ site\ j\ in\ period\ t\ under$ $scenario\ s$

Nit_{jhts}: $The\ number\ of\ injured\ people\ transferred\ from\ the\ accident\ site\ j\ to\ the\ hospital\ h$ $in\ period\ t\ under\ scenario\ s$

y_{ikhts}: $The\ amount\ of\ goods\ of\ type\ k\ transferred\ from\ supplier\ i\ to\ hospital\ h\ in\ period\ t\ under$ $scenario\ s$

x_{ikpts}: $The\ amount\ of\ goods\ of\ type\ k\ transferred\ from\ supplier\ i\ to\ shelter\ p\ in\ period\ t\ under$ $scenario\ s$

$Nvss_{ipvts}$: $Number\ of\ vehicles\ of\ type\ v\ transferred\ from\ supplier\ i\ to\ shelter\ p\ in\ period\ t\ under\ scenario\ s$

$Nvsh_{ihvts}$: $Number\ of\ vehicles\ of\ type\ v\ transferred\ from\ supplier\ i\ to\ hospital\ h\ in\ period\ t\ under\ scenario\ s$

ISSN- 2394-5125 VOL 7, ISSUE 15, 2020

$Nvas_{jpvts}$
$: Number\ of\ vehicles\ of\ type\ v\ transferred\ from\ accident\ site\ j\ to\ shelter\ p\ in\ period\ t\ under\ scenario\ s$

$Nvah_{jhvts}$
$: Number\ of\ vehicles\ of\ type\ v\ transferred\ from\ accident\ site\ j\ to\ hospital\ h\ in\ period\ t\ under\ scenario\ s$

$Nva_{jvts}: Number\ of\ vehicles\ of\ type\ v\ at\ accident\ site\ j\ in\ period\ t\ under\ scenario\ s$

bs_{ps}: A binary variable is that if the shelter p is constructed under scenario s, its value will be one, otherwise it will be zero.

3. Model

$$\min z_1 = \sum_i \sum_k cs_k \times ssg_{ki} + \sum_s (ps_s (\sum_j \sum_t cpp_{ts} \times NiNt_{jts} + \sum_j \sum_t cpp_{ts} \times NhNt_{jts})) \quad (1)$$

$$\min z_2 = \sum_s ps_s (\sum_{t>1} \sum_p \sum_k Lgs_{pkts} + \sum_{t>1} \sum_h \sum_k Lgh_{hkts}) \quad (2)$$

S.t.

$$Lgs_{pkts} \geq dsg_{pkts} - \sum_i x_{ikpts} \qquad \forall k \epsilon K, \forall p \epsilon P, \forall s \epsilon S, \forall t \epsilon T \quad (3)$$

$$Lgh_{hkts} \geq dhg_{hkts} - \sum_i y_{ikhts} \qquad \forall k \epsilon K, \forall p \epsilon P, \forall s \epsilon S, \forall t \epsilon T \quad (4)$$

$$\sum_p x_{ikpts} + \sum_h y_{ikhts} \leq ssg_{ki} \qquad \forall k \epsilon K, \forall i \epsilon I, \forall s \epsilon S \quad (5)$$

$$\sum_p x_{ikpts} + \sum_h y_{ikhts} \leq srg_{kits} \qquad \forall k \epsilon K, \forall i \epsilon I, \forall s \epsilon S \quad (6)$$

$$\sum_j Nht_{jpts} \times qg_k = dsg_{pkts} \qquad \forall k \epsilon K, \forall p \epsilon P, \forall s \epsilon S, \forall t \epsilon T \quad (7)$$

$$\sum_j Nit_{jhts} \times qg_k = dhg_{hkts} \qquad \forall k \epsilon K, \forall h \epsilon H, \forall s \epsilon S, \forall t \epsilon T \quad (8)$$

$$\sum_j \sum_{t>0} Nht_{jpts} \leq cs_p \times bs_{ps} \qquad \forall p \epsilon P, \forall s \epsilon S \quad (9)$$

$$\sum_j \sum_{t>0} Nit_{jhts} \leq ch_h \qquad \forall h \epsilon H, \forall s \epsilon S \quad (10)$$

$$\sum_p \sum_{t>0} Nht_{jpts} \leq nh_{js} \qquad \forall j \epsilon J, \forall s \epsilon S \quad (11)$$

$$\sum_h \sum_{t>0} Nit_{jhts} \leq ni_{js} \qquad \forall j \epsilon J, \forall s \epsilon S \quad (12)$$

$$\sum_k w_k \times x_{ikpts} \leq cv_v \times Nvss_{ipvts} \qquad \forall i \epsilon I, \forall p \epsilon P, \forall s \epsilon S, \forall t \epsilon T, \forall v \epsilon V_3 \quad (13)$$

$$\sum_k w_k \times y_{ikhts} \leq cv_v \times Nvss_{ipvts} \qquad \forall i \epsilon I, \forall h \epsilon H, \forall s \epsilon S, \forall t \epsilon T, \forall v \epsilon V_3 \quad (14)$$

$$Nvss_{ipvts} \leq nvs_{vi} \times bs_{ps} \qquad \forall i \epsilon I, \forall p \epsilon P, \forall s \epsilon S, \forall t \epsilon T, \forall v \epsilon V_3 \quad (15)$$

$$Nht_{jpts} \leq cv_v \times Nvas_{jpvts} \quad \forall j\epsilon J, \forall p\epsilon P, \forall v\epsilon V, \forall s\epsilon S, \forall t\epsilon T, \forall v\epsilon V_1 \tag{16}$$

$$Nit_{jhts} \leq cv_v \times Nvas_{jpvts} \quad \forall j\epsilon J, \forall p\epsilon P, \forall v\epsilon V_2, \forall s\epsilon S, \forall t\epsilon T \tag{17}$$

$$ttss_{vip} \times Nvss_{ipvts} \leq t_{max} \quad \forall i\epsilon I, \forall p\epsilon P, \forall v\epsilon V_3, \forall s\epsilon S, \forall t\epsilon T \tag{18}$$

$$ttas_{vjp} \times Nvas_{jpvts} \leq t_{max} \quad \forall j\epsilon J, \forall p\epsilon P, \forall v\epsilon V_1, \forall s\epsilon S, \forall t\epsilon T \tag{19}$$

$$\sum_{p}\sum_{t>0} Nvss_{ipvts} + \sum_{h}\sum_{t} Nvsh_{ihvts} \leq nvs_{vi} \quad \forall i\epsilon I, \forall v\epsilon V_3 \tag{20}$$

$$\sum_{h}\sum_{t>0} Nvah_{jhvts} \leq nva_{vj} \quad \forall j\epsilon J, \forall v\epsilon V_2 \tag{21}$$

$$\sum_{p}\sum_{t>0} Nvas_{jpvts} \leq nva_{vj} \quad \forall j\epsilon J, \forall v\epsilon V_1 \tag{22}$$

$$\sum_{p} bs_{ps} \times cbs_p \leq bbs \quad \forall s\epsilon S \tag{23}$$

$$Nva_{jvts} = nva_{vj} \quad \forall j\epsilon J, \forall v\epsilon V_1, (t=0), \forall t\epsilon T \tag{24}$$

$$Nva_{jvts} = nva_{vj} \quad \forall j\epsilon J, \forall v\epsilon V_2, (t=0), \forall t\epsilon T \tag{25}$$

$$Nva_{jvts} = Nva_{jv(t1)s} - \sum Nvas_{jpvts} \quad \forall j\epsilon J, \forall v\epsilon V_1, \forall s\epsilon S, \forall t\epsilon T \tag{26}$$

$$Nva_{jvts} = Nva_{jv(t1)s} - \sum Nvah_{jhvts} \quad \forall j\epsilon J, \forall v\epsilon V_2, \forall s\epsilon S, \forall t\epsilon T \tag{27}$$

$$Nvas_{jpvts} \leq bs_{ps} \quad \forall j\epsilon J, \forall p\epsilon P, \forall v\epsilon V_2, \forall s\epsilon S, \forall t = 1,2,\dots,T \tag{28}$$

$$NiNt_{j1s} = ni_{js} - \sum_{h} Nit_{jh1s} \quad \forall j\epsilon J, \forall s\epsilon S \tag{29}$$

$$NiNt_{jts} = NiNt_{j(t-1)s} - \sum_{h} Nit_{jhts} \quad \forall j\epsilon J, \forall s\epsilon S, \forall (t \geq 2)\epsilon T \tag{30}$$

$$NhNt_{j1s} = nh_{js} - \sum_{p} Nht_{jp1s} \quad \forall j\epsilon J, \forall s\epsilon S \tag{31}$$

$$NhNt_{jts} = NhNt_{j(t-1)s} - \sum_{p} Nht_{jpts} \quad \forall j\epsilon J, \forall s\epsilon S, \forall (t \geq 2)\epsilon T \tag{32}$$

$$dsg_{pkts} \geq 0 \quad \forall p\epsilon P, \forall k\epsilon K, \forall s\epsilon S, \forall t\epsilon T \tag{33}$$

$$dhg_{hkts} \geq 0 \quad \forall h\epsilon H, \forall k\epsilon K, \forall s\epsilon S, \forall t\epsilon T \tag{34}$$

$$ssg_{ki} \geq 0 \quad \forall k\epsilon K, \forall i\epsilon I \tag{35}$$

$$Lgs_{pkts} \geq 0 \quad \forall p\epsilon P, \forall k\epsilon K, \forall s\epsilon S, \forall t\epsilon T \tag{36}$$

$$Lgh_{hkts} \geq 0 \quad \forall h\epsilon H, \forall k\epsilon K, \forall s\epsilon S, \forall t\epsilon T \tag{37}$$

$$Nht_{jpts} \geq 0 \quad \forall j\epsilon J, \forall p\epsilon P, \forall s\epsilon S, \forall t\epsilon T \tag{38}$$

$$NhNt_{jts} \geq 0 \quad \forall j\epsilon J, \forall s\epsilon S, \forall t\epsilon T \tag{39}$$

$$NiNt_{jts} \geq 0 \quad \forall j\epsilon J, \forall s\epsilon S, \forall t\epsilon T \tag{40}$$

$$Nit_{jhts} \geq 0 \quad \forall j\epsilon J, \forall h\epsilon H, \forall s\epsilon S, \forall t\epsilon T \tag{41}$$

ISSN- 2394-5125 VOL 7, ISSUE 15, 2020

$$y_{ikhts} \geq 0 \qquad \forall i\epsilon I, \forall k\epsilon K, \forall h\epsilon H, \forall s\epsilon S, \forall t\epsilon T \tag{42}$$

$$x_{ikpts} \geq 0 \qquad \forall i\epsilon I, \forall k\epsilon K, \forall p\epsilon P, \forall s\epsilon S, \forall t\epsilon T \tag{43}$$

$$Nvss_{ipvts} \geq 0 \qquad \forall i\epsilon I, \forall p\epsilon P, \forall v, \forall s\epsilon S, \forall t\epsilon T \tag{44}$$

$$Nvsh_{ihvts} \geq 0 \qquad \forall i\epsilon I, \forall h\epsilon H, \forall v, \forall s\epsilon S, \forall t\epsilon T \tag{45}$$

$$Nvas_{jpvts} \geq 0 \qquad \forall j\epsilon J, \forall p\epsilon P, \forall v, \forall s\epsilon S, \forall t\epsilon T \tag{46}$$

$$Nvah_{jhvts} \geq 0 \qquad \forall j\epsilon J, \forall h\epsilon H, \forall v, \forall s\epsilon S, \forall t\epsilon T \tag{47}$$

$$Nva_{jvts} \geq 0 \qquad \forall j\epsilon J, \forall v, \forall s\epsilon S, \forall t\epsilon T \tag{48}$$

$$bs_{ps} \epsilon \{0,1\} \qquad \forall p\epsilon P, \forall s\epsilon S \tag{49}$$

In the proposed model, the objective function (1) minimizes the total costs, including the cost of the safety stock and the cost of the fines (the fine for failing to transport healthy and injured persons to the shelter and hospital). Objective function (2) minimizes the whole shortage. Constraints (3) and (4) indicate the shortage in shelters and hospitals, respectively. Restriction (5) ensures that the amount of goods transferred from suppliers to shelters, and hospitals does not exceed the safety stock in the initial period. In addition, limitation (6) ensures that the amount of goods transferred from the supplier to shelters and hospitals in the periods after the first period is less than the supply rate for each supplier. Restrictions (7) and (8) indicate demand for hospitals and shelters. Restriction (9) states that the number of healthy persons transferred to a shelter shall not exceed the capacity of the shelter. Restriction (11) indicates that the number of injured persons transported from the scene of the accident to the shelter should not exceed the number of those injured at the scene. Constraint (12) indicates that the number of healthy people transported from the scene of the accident to the shelter should not exceed the number of healthy persons at the scene of the accident. Constraint (13) indicates that the quantity of goods transported from the supplier to shelter shall not exceed the capacity of the vehicles concerned. Additionally, limitation (14) indicates that the quantity of goods transferred from the supplier to the hospital should not exceed the capacity of the relevant vehicles. Restriction (15) guarantees that if a shelter is established, the respective vehicles will be allocated from the supplier's location. Restriction (16) states that the number of healthy persons transported from the scene of an accident to a shelter shall not exceed the capacity of the vehicle concerned. Limitation (17) also states that the number of injured persons transported from the scene of an accident to a hospital must not exceed the capacity of the vehicle concerned. Constraints (18) and (19) respectively indicate that the transition time from supplier to shelter, and from the accident point to shelter should not exceed the maximum coverage time. Restriction (21) states that the number of relevant vehicles transferred from the supplier to the hospital, and shelter should not exceed the number planned before the crisis. Constraints (21) and (22) respectively state that the number of relevant vehicles transported from the accident point to the hospital, and shelter shall not exceed the number planned before the crisis. Restriction (23) indicates that the cost of constructing a shelter should not exceed the planned pre-crisis cost. Constraints (24) to (27) also balance the number of vehicles at the accident scene. In addition, limitation (28) ensures that only if a shelter is built, the vehicle will be assigned to the shelter from the scene of the accident. Constraints (29) to (32) also balance the number of people being transferred and not transferred at different times. Finally, constraints (33) to (47) introduce decision variables.

4. Results and Discussion (Scenario and sensitivity analysis)

In this section, in order to evaluate the performance of the proposed model, a number of hypothetical numerical scenarios for Istanbul are investigated using the Normalized Weighted Sum Algorithm as well as using GAMZ software. In these cases, considering the problem of three time periods, two goods and two suppliers, two accident points, four candidate points for the construction of shelters, two hospitals, three types of vehicles, three difference scenarios are considered. In these cases, according to the research hypotheses, three time periods, two goods and two suppliers, two accident points, four candidate points for the construction of shelters, two hospitals, three types of vehicles, are considered for three different scenarios. In addition, values for the other data are taken as Monte-Carlo simulations.

In each case, the amount of hospital and shelter capacities and the supply rate of each supplier are different. In order to examine more precisely, the sensitivity of the model variables to changing some parameters has been investigated.

The results in Figure 2 shows, a decrease in the number of people without any services (healthy and injured) at the scene of the accident, due to the increased capacity of shelters and the number of hospitals, In addition, there has been a reduction in the cost of non-transportation people (healthy and injured). Therefore, if the capacity is adequate, all persons are transferred, and as such, the number of persons transported from the scene of the accident is increased. This trend is not sustainable, and due to the limited capacity and the number of vehicles, more and more people do not always transfer with the increasing capacity of shelters and hospitals. For this reason, the trend initially increased then decrease. To this end, to change this steady state of trend (first increase and then decrease), the number, and capacity of the vehicles must increase. This study was conducted for Scenario 1, and similar results were obtained for the other two scenarios. It can be seen in Figure 3, that as the supply rate of each supplier increase, the number of shelters and hospitals is reduced, and consequently, the costs of their shortages are reduced.

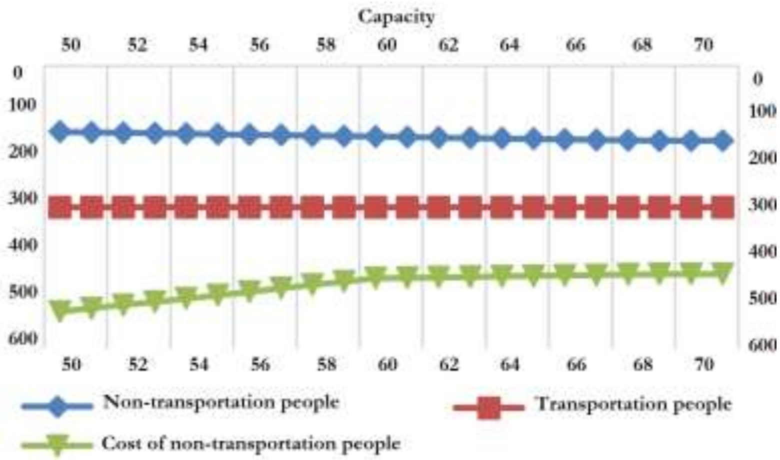

Figure 2 Changes in transfers and non-transfers, and costs of non-transfers based on capacity changes in shelters and hospitals

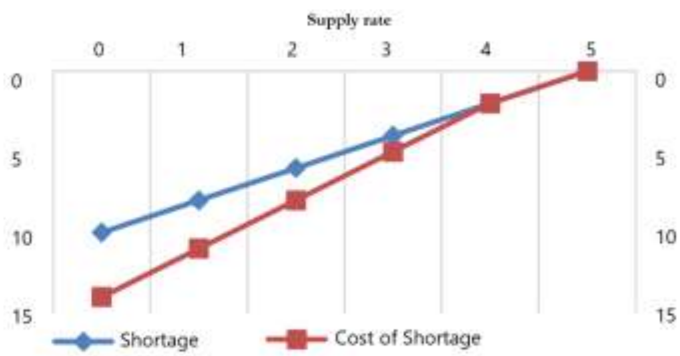

Figure 3 Sensitivity analysis of cost and amount of the shortage to the supply rate

5. Conclusion

Considering the need for crisis management, and humanitarian logistics, as well as the importance of pre- and post-crisis planning to minimize shortages at the time of the crisis and the importance of having credible suppliers as well as the transport of more disaster victims, the results of the presented mathematical model identify tenable pre-crisis suppliers and commit them to providing safety stock in their warehouses, and ensuring the ability to supply the vital goods needed in different scenarios.

The validity of the model was verified by presenting several numerical examples using exact solution. In addition, the sensitivity of the model variables to changing some parameters was investigated. It can be seen that as supply rates increase, the amount and cost of shortage's decrease. Subsequently, as a result of the increased capacity of shelters, the number of un-transported persons and the cost of non-transported persons decreased, and the number of transported persons increased.

Finally, future research can focus on supplier costs. As such, these costs are taken into account in more detail. Several levels can also be added to the supply chain under the guise of "public donors" and "international aid" for the supply of vital goods. Furthermore, by considering this model on a larger scale (at the city level or in the disaster-prone provinces) and by solving meta-heuristics, a good output can be achieved in the field of humanitarian relief.

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