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A humanitarian reconfiguration and rehabilitation model for preparedness and response to earthquakes using a scheduled reopening of links

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Abstract

This study proposes a novel mathematical model for redesigning existing relief logistics network including suppliers, distribution centers and demand nodes along with integrating the measures in preparedness and response phases, simultaneously. In order to improve the accessibility and connectivity, certain precautionary measures for strengthening and rehabilitation of the links have been taken into account in the preparedness phase. In addition, a new debris clearance scheduling model for blocked links is modeled in accordance with the rehabilitation strategies. To overcome the uncertainty in a predefined destruction scenario tree, a multi-stage stochastic programming has been applied in a real case study. The results obtained in the proposed model indicate that the redesigned network leads to better performance in dealing with evacuees' requested relief as compared to the results obtained by the existing network. Moreover, the results clearly demonstrate the significant value of solutions determined by multi-stage stochastic programming.

Keywords: Relief logistics reconfiguration, preparedness and response, multi-stage stochastic programming, rehabilitation, Debris Clearance Scheduling Model (DCSM), Geographic Information System (GIS).

1-Introduction

A disaster is a set of potential hazardous events that may trigger a range of catastrophic demolitions and damage in terms of human life, infrastructures, and natural resources as well as intangible harm such as social or psychological trauma. According to literature of disaster management, disasters have been classified as either natural (e.g. earthquakes, floods, hurricanes, tsunamis) or man-made (war, political/tribal disturbances). The calamitous consequences of disasters are the main reasons that disaster mangers and decision makers are always seeking new approaches and plans in order to lessen these implications and after effects. In this regard, these time-based plans and measures include four phases that have been classified as mitigation, preparedness, response and recovery phases. In brief, mitigation decisions draw attention to the long-term decisions before disasters and at a strategic level. For example,

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the gradual transfer of residents from a region with dangerous potential to a safe area, or investment in rehabilitation and preventive maintenance of infrastructures are some cases in point (Peeta et al., 2010). The preparedness phase considers the strategic decisions including location of suppliers, shelters and disaster management support bases, the predetermined capacity of roads, facilities and other strategic decisions before a disaster. Scientific findings demonstrate that preparedness plans play a fundamental and crucial role in alleviating a large portion of catastrophic consequences. In this regard, Kunz et al. (2014) have studied a dynamic system approach to determine the effects of preparedness plans on unsatisfied demands as well as empowering plans for capabilities before a disaster. The results emphasize the necessity of the preparedness phase although costs are oftentimes prohibitive. They have emphasized the considerable effect of applying the disaster management capabilities (DMC) (staff training, experiences learned from past disasters and etc.) as well as preparedness strategies versus lack of strategies for addressing the problems in dealing with response phase, principally in the first 72 h.

In addition to mitigation and preparedness, two other phases are considered after a disaster, namely, the responses phase and recovery phase. Although both response and recovery phases are implemented after disaster occurrence, the recovery phase is commonly initiated after the response phase and includes restoration of failed links and facilities in an effort to return the affected area to normal conditions (Cavdaroglu et al., 2013). Also, the response phase deals with decision-making actions for the procurement and shipment of relief goods from suppliers to distribution centers and finally to evacuees and the wounded. To emphasize the role of consideration of preparedness and response phase, it can be learned from the previous disasters that there is a large gap between demand and supply occurring in the first 72 h after the disaster and the better design for network in the preparedness phase will lead to better performance (less unmet demands) in the response phase (Stepanov and Smith, 2009; Hobeika and Kim, 1998).

This study aims to focus on the preparedness and response phases due to their great importance in providing disaster relief. The proposed redesigned model considers some facts like changes in population distribution and infrastructure deterioration that consequently lead to changes in demands and link status during the disaster. In such circumstances, the redesigned network based on the new situation should effectively conduct the decision-making process. In this regard, disaster managers seek models and approaches that can reduce the gap between current logistics networks and the optimal configuration of relief networks before disaster occurrence. Albeit, a significant number research studies have been carried out on the design and establishment of humanitarian relief logistics (HRL), however, the present study proposes a reconfiguration model simultaneously considering current entities and facilities and eligible ones. This study not only couples a rehabilitation strategy plan for preparedness phase with a debris clearance schedule in the response phase, but also it integrates the roads and link decisions with facility reconfiguration model in order to propose an agile and effective relief network.

The remainder of this study is structured as follows. A review of literature related to the preparedness and response phases for disaster management dealing with relief logistics is presented in section 2. In the third section, the proposed mathematical model as well as it's extended version in a multi-stage stochastic programming structure are presented. Section 4 evaluates the performance and also analyzes the results of implementation of the proposed model and problem-solving approach on a real case study. Finally, the paper concludes in section 5 with some suggestions for future studies.

2-Literature survey

As mentioned previously, the preparedness phase and quick response before and after a disaster, leads to indisputable results for relieving the crisis level. Accordingly, review papers such as Hoyos et al. (2015) indicate that most of the literature (74%) is dedicated to these two phases (see figure 1). Also, Boonmee et al. (2017) reviewed and classified some cases, models and solution methods of disaster management that were studied in the relevant published investigations.

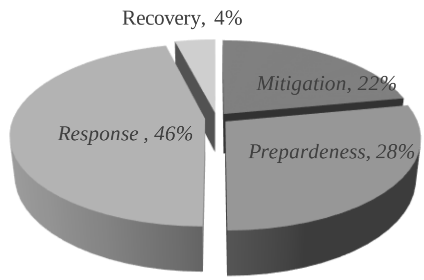

Fig 1. Distribution of research studies based on phase of disasters, derived from study of Hoyos et al. (2015)

In this section the researches relevant to preparedness and response phases have been considered. Rawls and Turnquist (2010) have solved a two- stage stochastic programming for a large-scale problem by using lagrangian method. Their study is associated with development of a pre-positioning planning tool for hurricane threats in an uncertain environment. Later, Rawls and Turnquist (2012) considered reliability constraints in their subsequent research as well as timely needs of the evacuees. They extended the prior model in research of Rawls and Turnquist (2010) to make it dynamic for the arrival of evacuees at shelters. Moreover, Noyan (2012) proposed a novel extension of the Rawls and Turnquist (2010) model by considering conditional value at risk (CVaR) as a risk approach for the total estimated cost. Vargas-Florez et al. (2015) proposed a supply chain in case of crisis that can provide the relief goods. The authors have considered the determination of warehouse location based on the crisis level situation between regions in order to evaluate the crisis scenario. They also drew up models for the fair distribution of relief goods as well as threshold determinants for regional shortages. Ahmadi et al. (2015) proposed a location-routing model by concentrating on last mile distribution after earthquake. To overcome the random time of transportation as uncertainty, they applied a two-stage stochastic programming. Also, they have taken some considerations such as multi-depot location-routing, vehicle planning and standard travel time into account in their study. Rezaei-Malek et al. (2016a) proposed a multi-objective approach to consider simultaneously the efficiency, efficacy and balance as objectives of the Location with Relief Distribution and Stock Pre-positioning (LRDSP). They proposed an integrated separable programming-augmented ε -constraint approach for solving a non-linear model with multiple objectives including total cost, expected time, priority, and demand-weighted utility levels of the delivered relief commodities. Gutjahr and Nolz (2016) reviewed some different combinations for evaluation of HRL efficacy evaluation including response time, travel distance, coverage, reliability and security. Rodriguez-Espindola and Gaytan (2014) contributed to LRDSP literature through location determination of emergency shelters and DCs as well as the allocation of relief centers (RCs) to DCs. Even though the aforementioned studies and others have focused on network design of the preparedness and response phases including locations, capacity determination, storage, flow quantities and various objectives, the necessity of modeling a reconfiguration model as a basic platform that would be able to analyze and comprise the current configuration versus an optimal one is undeniable. The proposed model aims to take into consideration the failure, rehabilitation and restoration of the links simultaneously; however, to the best of authors' knowledge, other studies have considered the rehabilitation in the preparedness phase and restoration in the response phase separately without consideration of their interaction. In this regard, Aksu and Ozdamar (2014) proposed a crisp restoration model of roads in the response phase. Their contributions to literature highlighted the tactical resource planning of the DCSM and the proposed DCSM's objective function. Their approach in modeling is more efficient in terms of complexity reduction for problem solving than link-based restoration models proposed in literature (e.g., Feng and Wang, 2003; Chen and Tzeng, 2000; Yan and Shih, 2009, Yan and Shih 2012). The present study differs from that of Aksu and Ozdmar, briefly taking in to account in terms of modeling in uncertain situation, in the proposal of a redesigned and reconfiguration model before the response phase and integration of rehabilitation and DCSM so that all these factors perform harmoniously. Also, Shuwen et al. (2017) proposed a resource allocation for rescue under deterministic situation in response phase. They considered team allocation and related repairs for opening the routes in a multi-objective problem as a part of response phase whereas our proposed model concentrates on simultaneous integration of preparedness phase (reconfiguration and rehabilitation model) and response phase (DSCM) under uncertainty. Also, redesigning strategies obtained by the present study can enhance a potential capacity and infrastructure for more appropriate performance in response phase.

Also, Verma and Gukler (2015) have taken endogenous failure into account in a prepositioning model. They have addressed the uncertainty in the magnitude of damages caused by a large-scale disaster via the definition of a distance-damage function. Moreover, Salman and Yucel (2015) have provided another joint link failure approach based on reliability and proximity ordering of the existing link in the junctions. Their focus is on the effect of a closed link on its vicinity, not modeling the restoration and rehabilitation or redesigning a new relief logistic network. The main contributions of this paper which differentiate our efforts from the other studies dedicated to the LRDSP investigations are briefly expressed as follows:

i. Developing of novel mathematical model for redesigning existing relief logistics network.
ii. Consideration of an integrated model for link rehabilitation in preparedness phase and reopening decisions (DCSM).
iii. Modeling the main shock, aftershocks and related demands thorough a scenario tree.
iv. Overcoming uncertainty associated with demands and disaster affected zones through a multi-stage stochastic programming.
v. Implementation of the proposed model in a real case study in Tehran.
vi.

Table 1 illustrates the contributions of the present study.

Table 1. The characteristics of some existing researches related to the LRDSP

References	*Model Characteristics*																*Stochastic Solving Approach*				
	Main contribution (Phase)		*Configuration(C)/ Reconfiguration(RC)*	*Uncertainty*		*Multi- or bi-objective*	*Multi-period*	*Strategies for Facilities*			*Rehabilitation*	*Standard time*	*DCSM*	*Multiple stages (Main and after shock)*	*Storage*	*Case study*	*Multi stage stochastic programming*	*Chance programming*	*Two stage stochastic programming*	*Deterministic equivalent*	*Risk averse*
	Preparedness	*Response*		*Demand*	*Link destruction*			*Establishment*	*Phase out*	*Consolidation*											
Rawls & Turnquist (2010)	✔	✔	*C*	✔	✔			✔								✔			✔		
Peeta et al (2010)	✔	✔			✔						✔					✔			✔		
Rawls & Turnquist (2012)		✔	*C*	✔			✔	✔							✔	✔		✔	✔		
Noyan (2012)	✔	✔	*C*	✔	✔			✔											✔		✔
Afshar & Haghani (2012)	✔	✔	*C*				✔	✔							✔						
Galindo & Batta (2013)	✔		*C*		✔			✔								✔				✔	
Rodriguez-Espindola & Gaytan (2014)	✔	✔	*C*			✔		✔								✔					
Aksu & Ozdamar (2014)		✔	*C*	✔	✔	✔	✔	✔					✔			✔					✔
Vargas-Florez et al. (2015)	✔		*C*	✔	✔			✔								✔				✔	
Ahmadi et al. (2015)	✔	✔	*C*	✔	✔		✔	✔				✔			✔	✔			✔		
Verma & Gukler (2015)	✔		*C*		✔			✔							✔				✔		
Salman & Yucel (2015)	✔		*C*	✔	✔			✔								✔					
Rath et al. (2016)		✔	*C*		✔	✔		✔											✔		
Rezaei-Malek et al. (2016a)	✔	✔	*C*	✔	✔	✔		✔								✔			✔		✔
Al Theeb & Murray (2017)		✔					✔					✔									
Shuwen et al. (2017)		✔				✔	✔					✔	✔			✔					
Condeixa et al. (2017)	✔	✔	*C*	✔				✔							✔						✔
Present investigation	✔	✔	***RC***	✔	✔		✔	✔	✔	✔	✔		✔	✔	✔	✔	✔				

3- Mathematical formulation

This section is divided into three subsections including problem description (section 3-1), details about pre-assumptions (section 3-2), and finally, notations and mathematical model (section 3-3).

3-1- Problem description

As mentioned above, a network comprising three echelons (supplier, DCs and demand points) has been considered. Suppliers provide the relief network for the DCs before and after disasters. By tracing the lessons learned from previous earthquakes, evacuees tend to turn to certain locations such as schools, health care centers and parks as a shelters or places to receive relief goods, particularly within the first 72h. Most of their demands can be categorized in to four groups, including: a) Package containing tents and the sleeping bags, b) Heating or cooling equipment package (such as blankets, clothing, fans, etc.), c) Health and emergency kits, and d) Food and drinks. Figure 2 illustrates 3 external suppliers, 13 DCs (9 existing and 4 candidate DCs) and 82 demand points.

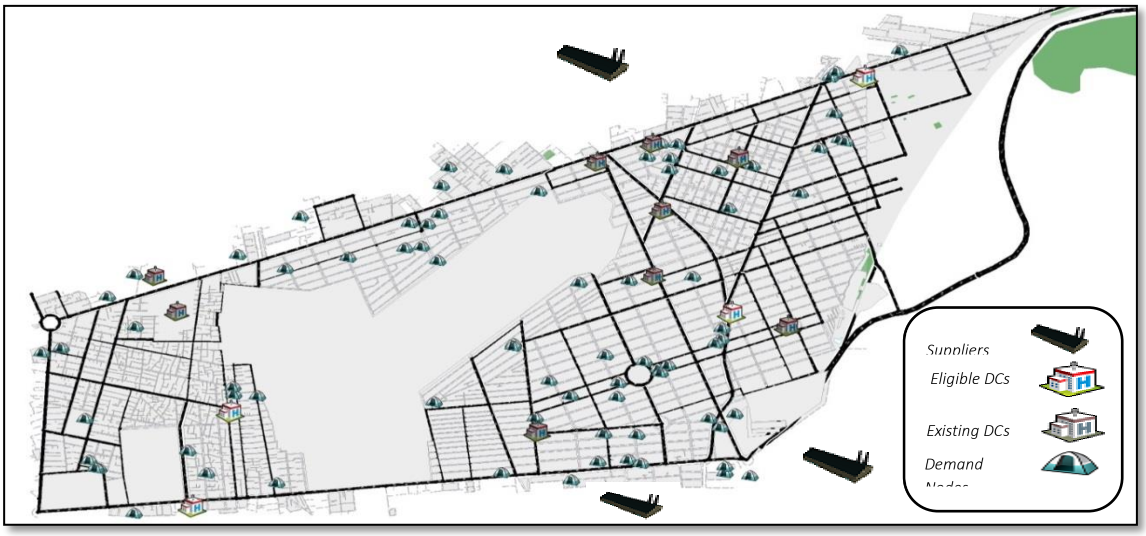

Fig 2. Three-echelon supply chain for relief network

The proposed model must propose new configurations and then revise relations between echelons. Also, the following questions should be addressed:

Which existing DCs are redundant and which ones should remain? Which eligible DCs should be established? To what extent can consolidation of the redundant DCs to other DCs improve overall performance? What are the new relations between suppliers and DCs? Which links must be rehabilitated in the preparedness phase and how this rehabilitation can affect DCSM. To emphasize the effects of a preventive plan for infrastructure as a part of proposed model before a disaster and its consequences on post-disaster responsiveness, Figure 3 illustrates possible conditions that could be encountered such as a longer route between DC and a demand node due to failure of the links (such as roads, bridges, etc.) around the illustrated DC. If it is possible to recognize, rehabilitate and reinforce only one link of determined high-risk links before the disaster, the results can be clearly observed in figure 3 (right side) which indicates less distance for the supply of relief goods.

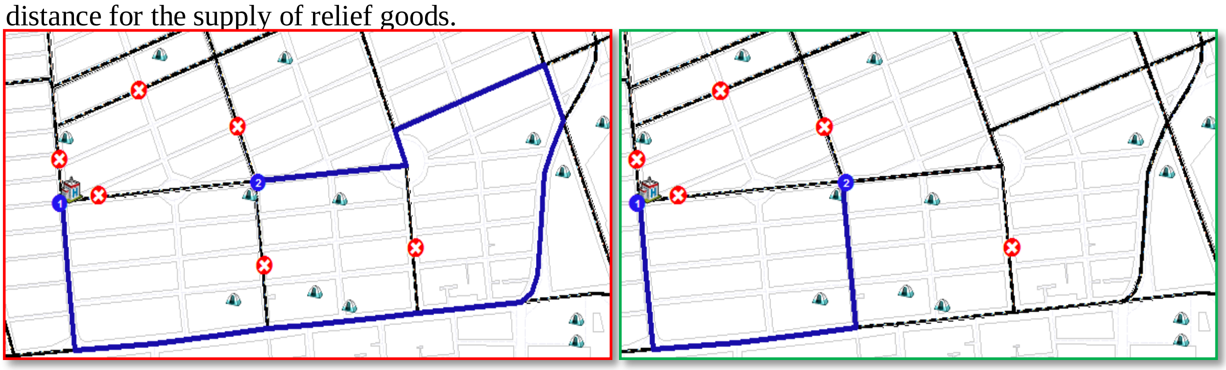

Fig 3. The effect of failed links on responsiveness after a disaster (a hypothetical example)

Hence, the present study models the high risk links to be selected for rehabilitation before disaster and considers rehabilitation results in the DCSM so that a high risk link without rehabilitation cannot be used for using in the logistics network and cannot be restored. What is meant by the restoration in the present study includes road clearing and debris removal for those links that are rehabilitated before disaster or for those which are determined in advance as safe and resistance links against disaster.

Figure 4 shows the relation of rehabilitation and restoration decisions so that a link can be selected for rehabilitation if that link is in a high-risk situation ($FL^0=0$) based on opinion of experts before a disaster. If a high-risk link is not selected for rehabilitation, it will be closed after the first shock (see * in Figure). Also, debris clearance scheduling during the response phase can be done for those links that are selected to be rehabilitated ($RH=1$) with $FL^0=0$ (**) or for those which are not in a high-risk situation (***).

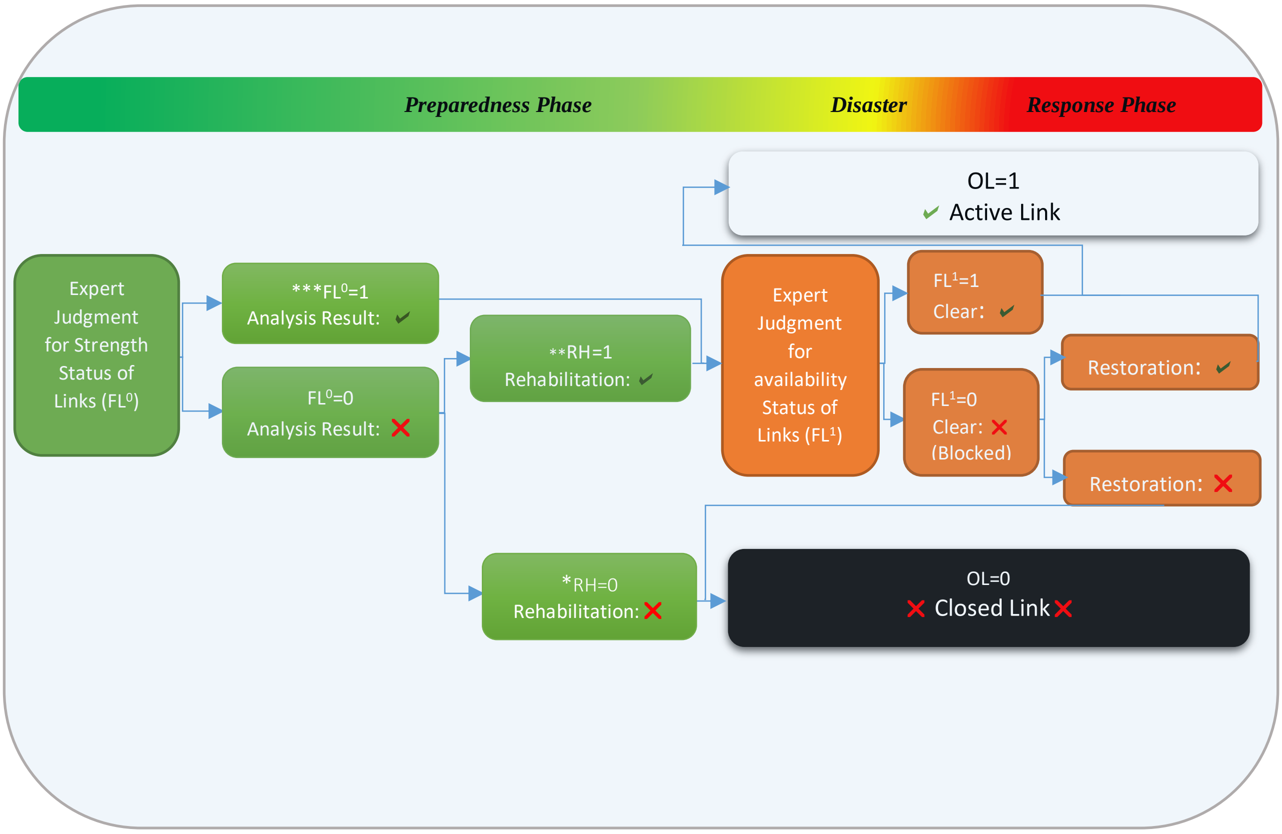

Fig 4. Effects of rehabilitation and restoration on links

3-2-Assumptions

In addition to the aforementioned explanations, the following assumptions have been made:

- The redundant DC can share and consolidate its capacity and mobilizations to only one destination DC (whether existing or newly established DCs).
- The roads and links can be active after disasters if it would be available and safe by (a) own strength or (b) rehabilitation in preparedness phase against main shock.
- In the response phase, if more than one period is required for debris clearance, all clearance periods must be considered successive and continuously.

3-3- Notations and mathematical model

In this section, after introduction of the notations in section 3-3-1, a multi-stage stochastic programming model in a MIP formation is proposed in section 3-3-2. Subsequently, in section 3-3-3, non-anticipatively approach is considered.

3-3-1- Notations

The notations describe the indices, parameters, and decision variables used in the model, as follows:

Nomenclature	
Parameters:	
$P_{\bar{s}}$	Occurrence probability of scenario path $\bar{S}$
$SW_{ckt\bar{s}}$	Shortage weight of commodity *c* at demand point *k* at period *t* on path $\bar{S}$
$PR_{cijt\bar{s}}$	Cost per unit for procurement and transportation of commodity *c* from supplier *i* to *DC j* at time period *t* on path $\bar{S}$
$TR_{cjkrt\bar{s}}$	Shipment cost per unit of commodity *c* from *DC j* to demand node *k* thorough *r*-th route at time period *t* on path $\bar{S}$
$IC_{cjt\bar{s}}$	Storage cost per unit for relief good *c* at *DC j* during time period *t* on path $\bar{S}$
FC_j	Fixed cost of handling and maintenance for active *DC j* in the preparedness phase until estimated time for crisis occurrence
RV_j	Estimated revenue of using the usable spaces of *DC j* for cultural and social purposes in preparedness phase
NC_n	Fixed cost of establishing new eligible *DC n* (excluding fixed cost of handling and maintenance)
CB_e	Income from phasing-out the redundant *DC e* (sale of land and building)
CRL_{ej}	Overhead costs required for consolidating *DC e* to *DC j*
CCP_{cj}	Cost per unit for capacity mobilization of the *DC j* (commodity *c*)
$CPRL_{ce}$	Throughput capacity of the commodity *c* at *DC e* available to be consolidated in the other active *DCs*
$FRH_l^{j,k,r}$	Fixed Rehabilitation cost for *l-th* link of route *r* between *j* and *k* in the preparedness phase
$RT_{l\bar{s}}^{j,k,r}$	The required number of time periods for restoration dedicated to the blocked link *l* on *r-th* route between *j* and *k*
$FOL_l^{j,k,r}$	Fixed cost per period for restoration of *l-th* link of route *r* between *j* and *k* in the response phase Note: $\bar{S}$ is not considered in *FOL*, because the effect of earthquake intensity has been considered in the required periods for restoration in $RT_{l\bar{s}}^{j,k,r}$
$\theta_{lg}^{j,k,r}$	The usage rate of resource *g* for restoration of link *l* of *r-th* route between *j* and *k* at time period *t*
RET_{gt}	Total number of available restoration resource *g* (equipment or teams) can be allocated for re-opening the links during the period *t*
LK_{jkr}	The number of links on *r-th* route between $j,\ k$
FL_{rjkl}^{0}	Binary strength status of the link *l* on *r-th* route between *j* and *k* before rehabilitation decisions predicted by experts based on the worst shocks which may occur
$FL_{jkrl\bar{s}}^{1}$	$FL_{jkrlt\bar{s}}^{1}=1$ if link *l* on *r-th* route between *j* and *k* does not require to be cleared or restored at period *t* on path $\bar{S}$ (based on prediction of experts before disaster occurrence)
$BDG_{\bar{s}}$	The budget can be provided for preparedness and response phase for satisfying the demands on path $\bar{S}$
$\lambda_{t,\bar{s}}^{j,k}$	Maximum acceptable distance between *DC j* and demand node *k* at period *t* on path $\bar{S}$ (response phase)
$Ds^{j,k,r}$	Distance between *DC j* and demand node *k* (*r-th* route)
P_{cit}^{MAX}	Maximum procurement capacity of commodity *c* prepared by supplier *i* at the beginning of period *t*
CP_{cj}^{MAX}	Maximum capacity of *DC j* for commodity *c*
CP_{cj}^{0}	Initial capacity of *DC j* for commodity *c*
II_{cj}^{0}	Current or initial inventory level of commodity *c* at existing *DC j* (it is zero for the new *DCs*)
IRL_{ce}	Throughput relief goods *c* in *DC e* available for consolidation
$D_{ckt\bar{s}}$	Demand of node *k* for relief good *c* in period *t* on path $\bar{S}$ (for *t=0, D* equals 0)
μ_c	Capacity coefficient of commodity *c*
CY_{rjkt}	The available capacity of the *r-th* route between *DC j* and demand node *k* for transportation at time period *t*

Decision Variables (Binary Variables):	
Z_{ej}	Consolidation decision of *DC e* to *DC j* (*DC e* is consolidated in *j* if $e\neq j$ and $Z_{ej}=1$)
Z_{jj}	Decision variable for remaining *DC e* open if $Z_{ee}=1$ or establishment decision of the new *DC n* if $Z_{nn}=1$ ($Z_{jj}=Z_{ee}\cup Z_{nn}$)
$RH_l^{j,k,r}$	Rehabilitation decision for improving the strength of link *l* (*r-th* route of *j* and *k*) before earthquake
$OL_{lt\bar{s}}^{j,k,r}$	The availability status of *l-th* link on *r-th* route between *j* and *k* at time period *t* and on path $\bar{S}$ (*OL=1* if a link is available)
$LS_{lt\bar{s}}^{j,k,r}$	*Is 1* if a blocked link is opened in period *t*
$OR_{t\bar{s}}^{j,k,r}$	Is 1 if route *r* is active in time period *t* and on path $\bar{S}$

Decision Variables (Continuous Variables):	
$X_{cijt\bar{s}}$	Quantity of relief good *c* provided by supplier *i* for *DC j* at time period *t* on path $\bar{s}$
$Y_{cjkrt\bar{s}}$	Quantity of relief good *c* shipped from *DC j* to the demand node *k* through *r*-th route at time period *t* on path $\bar{s}$
$W_{ckt\bar{s}}$	Shortage of *c* at demand point *k* , at period *t* on path $\bar{s}$
$II_{cjt\bar{s}}$	Inventory level of commodity *c* being held at *DC j* at the end of time period *t* on path $\bar{s}$
CP_{cj}	Capacity needed to be internally extended (for commodity *c*) in *DC j* (excluding consolidated and equipped capacity from other *DCs*)

Sets and Indices:	
I	Set of suppliers, indexed by $i = 1,...,\|I\|$
EJ	Set of existing DCs, indexed by $e = 1,...,\|EJ\|$
NJ	Set of new eligible DCs, indexed by $n = \|EJ\| + 1,...,\|EJ\| + \|NJ\|$
J	Set of all DCs, indexed by $j = 1,...,\|J\|$, $J = EJ \bigcup NJ$
K	Set of demand nodes, indexed by $k = 1,...,\|K\|$
R_{jk}	Set of routes between *j* and *k* indexed by, $r_{jk} = 1,...,\|R_{jk}\|$
C	Set of commodities, indexed by $c = 1,...,\|C\|$
$L^{j,k,r}$	Set of links on *r-th* route, between *j* and *k*, indexed by $l = 1,...,\|L^{j,k,r}\|$
G	Set of equipment or team groups for restoration, indexed by $g = 1,...,\|G\|$
S	Set of scenarios (events) at each period, $s = 1,...,\|S\|$
$\bar{S}$	Set of scenario paths (hereafter path) in scenario tree, each path consists of some sequential events in the scenario tree, $\bar{s} = 1,...,\|\bar{S}\|$
T	Set of the time periods, $t = 0,...,\|T\|$ (t=0: pre-disaster or preparedness phase)

3-2-2- Model definition

In the following, the objective function and relevant constraints are given in a multi-stage stochastic mixed-integer programming formulation. The goal of the problem is to minimize the equation (1) as weighted loss function of shortages in the subsequent stages. This function determines the value of shortage penalty of unmet demands throughout the post disaster periods ($t > o$). The objective function value concludes the summation of weighted shortages at the end of each post disaster's period so that the effect of unmet demands, weight of shortage (determined by expert judgments based on period, commodity type and demand node) and occurrence probability of considered path have been taken into account. The calculation of $P_{\bar{s}}$ is based on multiplying the occurrence probabilities of successive events (s) on path $\bar{s}$ up to the last decision stage.

$$Min \sum_{t \in T \setminus \{0\}} \sum_{\bar{s} \in \bar{S}} \sum_{c \in C} \sum_{k \in K} P_{\bar{s}} . W_{ckt\bar{s}} . SW_{ckt\bar{s}} \tag{1}$$

Equation (2) limits the reconfiguration (strategic and operational costs), rehabilitation and restoration costs based on available budget for each path of the scenario tree. The budget constraint (2) for each path of the scenario tree is composed of ten terms on the left-hand side whose their summation must be less than the available budget on the right-hand side for the considered path of scenario tree. Terms (2-1), (2-2) and (2-3) represent the some operational costs of relief goods procurement from the suppliers and transportation to DCs, relief goods supply to demand nodes, and inventory storage at DCs, respectively. Term (2-4) considers the maintenance expense of DCs in the pre-disaster and post-disaster durations and the revenue earned by temporarily using the free spaces and capacities of DCs for pre-disaster cultural and social services. In addition, term (2-5) determines the establishment costs of new DCs and term (2-6) determines the cost savings resulting from the closure of redundant DCs. Also, (2-7) and (2-8) are the relevant terms for capacity extension wherein (2-7) focuses on total consolidation costs of the redundant DCs to other active DCs and (2-8) considers increasing costs of needed extra capacity (mobilization for new consolidation or internal development). The last two terms deal with rehabilitation cost of high-risk links before disaster occurrence (2-9) and link restoration and reopening for the purpose of debris clearance in the post disaster periods (2-10).

$$
\begin{aligned}
&\left[\left[\overbrace{\sum_{c\in C}\sum_{i\in I}\sum_{j\in J}\sum_{t\in T} PR_{cijt\bar{s}}.X_{cijt\bar{s}}}^{(2-1)} + \overbrace{\sum_{c\in C}\sum_{j\in J}\sum_{k\in K}\sum_{r\in R_{jk}}\sum_{t\in T\setminus\{0\}} TR_{cjkrt\bar{s}}.Y_{cjkrt\bar{s}}}^{(2-2)}\right.\right.\\
&+\left.\overbrace{\sum_{c\in C}\sum_{j\in J}\sum_{t\in T} IC_{cjt\bar{s}}.\left(\frac{II_{cj(t-1)\bar{s}}+II_{cjt\bar{s}}}{2}\right)}^{(2-3)}\right]+\left[\overbrace{\sum_{j\in J}(FC_j-RV_j).Z_{jj}}^{(2-4)}\right]+\\
&\left[\overbrace{\sum_{n\in NJ} NC_n.\ Z_{nn}}^{(2-5)}\right]-\left[\overbrace{\sum_{e\in EJ} CB_e.(1-Z_{ee})}^{(2-6)}\right]+\left[\overbrace{\sum_{e\in EJ}\sum_{\substack{j\in J\\(j\neq e)}} CRL_{ej}.\ Z_{ej}}^{(2-7)}\right]+ \qquad (2)\\
&\left.\left[\overbrace{\sum_{c\in C}\sum_{j\in J} CCP_{cj}.\left(CP_{cj}+(\sum_{\substack{e\in EJ\\(e\neq j)}} CPRL_{ce}.Z_{ej})\right)}^{(2-8)}\right]\right]+\overbrace{\sum_{j\in J}\sum_{k\in K}\sum_{r\in R_{jk}}\sum_{l\in L} RH_l^{j,k,r}.FRH_l^{j,k,r}}^{(2-9)}\\
&+\overbrace{\sum_{t\in T\setminus\{0\}}\sum_{k\in K}\sum_{j\in J}\sum_{r\in R_{jk}}\sum_{\{l\in L|FL^1=0\}} LS_{lt\bar{s}}^{j,k,r}.RT_{l\bar{s}}^{j,k,r}.FOL_l^{j,k,r}}^{(2-10)} \le BDG_{\bar{s}}, \forall \bar{s}\in\bar{S}
\end{aligned}
$$

In constraint (3), a link can be selected for rehabilitation if that link is in a high-risk situation ($FL^0=0$). Moreover, according to relation (4), if a high-risk link is not selected for rehabilitation ($FL^0=0$ & $RH=0$), it will be closed after the first shock (for more details see figure 4). Also, debris clearance scheduling during the response phase can be done for those high-risk links that are selected to be rehabilitated ($RH=1$) or for those which are not in a high-risk situation against disaster ($FL^0=1$).

$$RH_l^{j,k,r} \le (1-FL_{jkl}^0)\ ,\forall j\in J,k\in K,r\in R_{jk},l\in L \tag{3}$$

$$OL_{lt\bar{s}}^{j,k,r} \le RH_l^{j,k,r}+FL_{jkl}^0\ ,\forall j\in J,k\in K,r\in R_{jk},l\in L,t\in T\setminus\{0\},\bar{s}\in\bar{S} \tag{4}$$

Equation (5) ensures that route r is assumed to be available during the response phase only if all links on that route are active. In addition, relation (6) determines the periods in which a blocked link is being restored and this relation also limits the available resource group for restoration measures. Also, relation (7) determines the first period in which a blocked link is restored and inequality (8) guarantees that a link is restored at most once. In addition, both (7) and (8) ensure that rehabilitation operations occur in continuous and successive periods.

$$\left(\frac{1}{LK_{jkr}}\right).\sum_{l\in L} OL_{lt\bar{s}}^{j,k,r} \ge OR_{t\bar{s}}^{j,k,r}\ ,\forall j\in J,k\in K,r\in R_{jk},t\in T\setminus\{0\},\bar{s}\in\bar{S} \tag{5}$$

$$\sum_j\sum_k\sum_r\sum_{l|FL^1=0}\sum_{t'=t+1}^{t+RT_{l\bar{s}}^{j,k,r}} LS_{l(t'+1)\bar{s}}^{jkr}.\theta_{lg}^{j,k,r} \le RET_{gt}\ ,\forall g\in G,t\in T\setminus\{0\},\bar{s}\in\bar{S} \tag{6}$$

$$OL_{lt\bar{s}}^{jkr}-OL_{l(t-1)\bar{s}}^{jkr} \le LS_{lt\bar{s}}^{j,k,r}\ ,\forall j\in J,k\in K,r\in R_{jk},\{l\in L|FL^1=0\},t\in T\setminus\{0\},\bar{s}\in\bar{S} \tag{7}$$

$$\sum_{t\in T\setminus\{0\}} LS_{lt\bar{s}}^{j,k,r} \le 1,\forall j\in J,k\in K,r\in R_{jk},\{l\in L|FL^1=0\},\bar{s}\in\bar{S} \tag{8}$$

For those links with $FL^1=0$, equality (9) assigns a zero value to the availability status of links during the post-disaster periods up to the earliest completion period for the restoration operation. Moreover, inequality (10) sets the availability status (value 1) for those links that are evaluated as an unblocked and clear link during the response phase ($FL^1=1$).

$$\sum_{\{t\in T\setminus\{0\}|t\le RT_{l\bar{s}}^{j,k,r}\}} OL_{lt\bar{s}}^{j,k,r}=0\ ,\forall j\in J,k\in K,r\in R_{jk},\{l\in L|FL^1=0\},t\in T\setminus\{0\},\bar{s}\in\bar{S} \tag{9}$$

$$FL_{jkrl\bar{s}}^1 \le OL_{lt\bar{s}}^{jkr}\ ,\forall j\in J,k\in K,r\in R_{jk},l\in L,t\in T\setminus\{0\},\bar{s}\in\bar{S} \tag{10}$$

Equation (11) expresses that the number of periods that a restored link can work after restoration must be less than (or equal to) the deviation between required periods for restoration $\left(RT_{l\bar{s}}^{j,k,r}\right)$ and total periods of post-disaster $\left(|T|-1\right)$. Relation (12) guarantees that a blocked link that is positioned after other blocked link(s) can be available at period t only if all of the predecessor links are restored up to $\left(t - RT_{l\bar{s}}^{j,k,r}\right)$-*th* period. Predecessor links of link l for restoration can be defined based on previous links on a specific route for providing the access to link l or can be prioritized and numbered according to the clearance and restoration importance of links from the standpoint of experts.

$$\sum_{t\in T\setminus\{0\}} OL_{lt\bar{s}}^{jkr} \le \left(|T|-1\right) - RT_{l\bar{s}}^{j,k,r} \;,\forall j \in J, k \in K, r \in R, \left\{l \in L \middle| FL^1 = 0\right\}, s \in \bar{s} \tag{11}$$

$$\sum_{\left\{t'\in T\setminus\{0\} \middle| t' \le t - RT_{l\bar{s}}^{j,k,r}\right\}} OL_{l't'\bar{s}}^{jkr} \ge OL_{lt\bar{s}}^{jkr} \;,\forall j \in J, k \in K, r \in R, \left\{l, l'(l' < l) \in L \middle| FL^1 = 0,\right\}, s \in \bar{s}, t \in T \setminus \{0\} \tag{12}$$

Equation (13) limits the capacity of each active route for dispatching the relief goods. This constraint considers capacity limitation form *DCs* to demand nodes. Also, relation (14) guarantees that maximum distance between j and k must be less than $\lambda_{t,\bar{s}}^{j,k}$ so that λ can be set based on the intensity of scenario paths and time period duration.

$$\sum_{c\in C} \mu_c . Y_{cjkrt\bar{s}} \le OR_{t\,\bar{s}}^{j,k,r} . CY_{rjkt} \;,\forall j \in J, k \in K, r \in R_{jk}, t \in T \setminus \{0\}, \bar{s} \in \bar{S} \tag{13}$$

$$Ds^{j,k,r} . OR_{t\,\bar{s}}^{j,k,r} \le \lambda_{t,\bar{s}}^{j,k} \quad , \;\forall j \in J, k \in K, r \in R_{jk}, t \in T \setminus \{0\}, \bar{s} \in \bar{S} \tag{14}$$

Inequality (15) determines the maximum capacity of supply relief provided by each supplier in both pre- and post- disaster horizons (pre-disaster $t=0$ and post-disaster $t>0$). Equation (16) expresses that initial, consolidated and internal development of capacity for each *DC* cannot exceed the maximum capacity of each *DC*.

$$\sum_{j\in J} X_{cijt\bar{s}} \le P_{cit}^{MAX} \quad ,\forall c \in C, i \in I, t \in T, \bar{s} \in \bar{S} \tag{15}$$

$$\left(CP_{cj} + \left(\sum_{\substack{e\in EJ\\(e\ne j)}} CPRL_{ce} . Z_{ej}\right)\right) \le \left(CP_{cj}^{MAX} - CP_{cj}^{0}\right) . Z_{jj} \;,\forall c \in C, j \in J \tag{16}$$

Equalities (17) and (18) set the inventory level of pre-disaster and post-disaster horizons of *DCs*, respectively (inventory equilibrium). The pre-disaster storage level is determined in equality (17) for each *DC* based on its own initial storage, consolidated relief goods provided by redundant DCs and ordered goods as precautionary reserve before disaster occurrence. In addition, relation (18) determines the inventory level of each post-disaster period so that the inventory (on-hand quantity) and dispatched relief goods of each period must be equal in quantity to what was ordered at that period plus inventory that remained from the previous period.

$$II_{cjt\bar{s}} = II_{cj}^{0} + \sum_{\substack{e\in Ej\\(e\ne j)}} IRL_{ce} . Z_{ej} + \sum_{i\in I} X_{cijt\bar{s}} \,, t = 0, \forall c \in C, j \in J, \bar{s} \in \bar{S} \tag{17}$$

$$\sum_{r\in R_{jk}} \sum_{k\in K} Y_{cjkrt\bar{s}} + II_{cjt\bar{s}} = II_{cj(t-1)\bar{s}} + X_{cijt\bar{s}} \,, \forall c \in C, j \in J, t \in T \setminus \{0\}, \bar{s} \in \bar{S} \tag{18}$$

After capacity limitation (16) and inventory determination (17) and (18), inequalities (19) and (20) represent the capacity of *DCs* to maintain storages and receive pre-disaster (19) and post-disaster (20) orders, respectively.

$$II_{cjt\bar{s}} \le \left(CP_{cj} + \left(\sum_{\substack{e\in EJ\\(e\ne j)}} CPRL_{ce} . Z_{ej}\right)\right) + CP_{cj}^{0} . Z_{jj} \,, t = 0, \forall c \in C, j \in J, \bar{s} \in \bar{S} \tag{19}$$

$$II_{cj(t-1)\bar{s}} + \sum_{i\in I} X_{cijt\bar{s}} \le \left(CP_{cj} + \left(\sum_{\substack{e\in EJ \\ (e\neq j)}} CPRL_{ce}.Z_{ej} \right) \right) + CP^{0}_{cj}.Z_{jj} \quad ,\forall c\in C, j\in J, t\in T\setminus\{0\}, \bar{s}\in\bar{S} \tag{20}$$

Constraint (21) indicates the required demands that should be met at each period of considered path in the scenario tree. This would therefore lead to shortage recognition which has been mentioned in the objective function (1).

$$\sum_{j\in J}\sum_{r\in R_{jk}} Y_{cjkrt\bar{s}} + W_{ckt\bar{s}} \ge D_{ckt\bar{s}}, \forall t\in T\setminus\{0\}, c\in C, k\in K, \bar{s}\in\bar{S} \tag{21}$$

Constraint (22) ensures that an existing *DC* cannot be consolidated into another existing one, unless destination *DC* remains active. In order for the reduction of constraints, the cardinality $|EJ|$ results from the summation of the constraints $z_{ej} \le z_{jj}$ over set *EJ* with an equal right-hand side (RHS). Similarly, constraint (23) assures the above-mentioned condition for the newly established *DCs*.

$$\sum_{e\in EJ} Z_{ej} \le |EJ| Z_{jj}, \forall j\in EJ \tag{22}$$

$$\sum_{e\in EJ} Z_{ej} \le |EJ| Z_{jj}, \forall j\in NJ \tag{23}$$

Also, inequality (24) ensures that redundant *DCs* can be merged with only one destination *DC*. Equality (25) limits the value of dispatched relief goods to zero in the pre-disaster horizon (*t=0*). As mentioned in (26), non-anticipativity constraints will be discussed in the next section.

Constraints (27) and (28) require operational and strategic decision variables to be positive and binary, respectively.

$$\sum_{j\in J(j\neq e)} Z_{ej} \le 1, \forall e\in EJ \tag{24}$$

$$Y_{cjkrt\bar{s}=0}, t=0, \forall c\in C, j\in J, k\in K, r\in R, \bar{s}\in\bar{S} \tag{25}$$

{Non-Anticipativity Constraints}: Section 3-3-3 (26)

$$X_{cijt\bar{s}}, Y_{cjkrt\bar{s}}, II_{cjt\bar{s}}, CP_{cj} \ge 0 \tag{27}$$

$$Z_{ej}(e\neq j), Z_{jj} : (Z_{ee}, Z_{nn}) = \{0,1\}, OL^{j,k,r}_{lt'\bar{s}} \in \{0,1\}, OR^{j,k,r}_{t\bar{s}} \in \{0,1\} \tag{28}$$

3-3-3- Non-anticipativity

In this section split-variable formulation for non-anticipativity is proposed. The non-anticipativity constraints appear where we have a decision node in the scenario tree which is in the rout of some future leaves. The necessity for these constraints is vital when we wish to fix the value of a decision variable at the present node while it is related to the future stochastic events (the main shock and aftershocks levels and relief demands) that are not distinguishable at the present stage of decision making. So the determined values for the current node associated with decision variables at now, must be the same for all leaves initiated with the present node (c.f., Ahmed et al., 2003). In the presented model, some decision variables such as *X*, *Y*, *II*, *OL* must be decided stage by stage so that these fixed values are the same for all subsequent nodes and scenarios that may occur.

Figure 5 illustrates the structure of the scenario tree, decision nodes as routs and paths as their leaves as well as related notations. In this regard, we denote the set of paths which are not distinguishable from path $\bar{s}$ up to *t* by $\{\bar{s}\}_t$. For example, according to figure 5, if we consider the minus symbol (t^-) for those variables that must be made at the start of each period and a positive symbol (t^+) for variables made at the end of each period, according to Arc_1, $\{5\}_{1+} = \{5\}_{2-} = \{5,\ldots,8\}$.

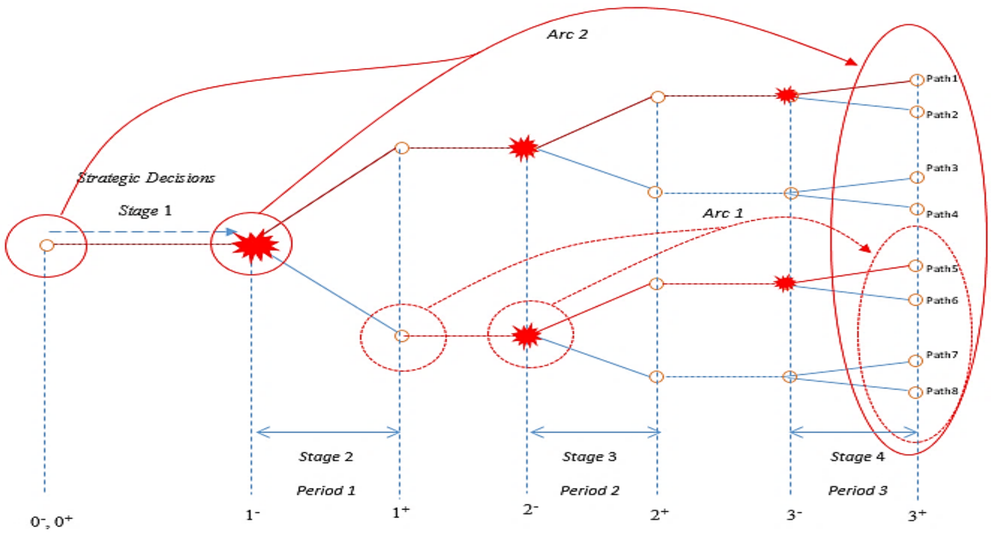

Fig 5. A scenario tree structure for four decision stages (pre-disaster (1), post-disaster (2,3,4))

This notation means at the start of second period or at the end of first period, paths 5, …, 8 are not distinguishable and these paths must be classified in a similar category. The decision variables must be written according to mentioned non-anticipativity approach. Therefore, non-anticipativity equations are given as follows:

$$X_{cijt\bar{s}} = X_{cijt\bar{s}'}\ ,\ \forall \bar{s},\bar{s}' \in \{\bar{s}\}_{t-}\ (t \in T, \bar{s}, \bar{s}' \in \bar{S}) \tag{26-1}$$

$$Y_{cjkt\bar{s}} = Y_{cjkt\bar{s}'}\ ,\ \forall \bar{s},\bar{s}' \in \{\bar{s}\}_{t+}\ (t \in T, \bar{s}, \bar{s}' \in \bar{S}) \tag{26-2}$$

$$II_{cjt\bar{s}} = II_{cjt\bar{s}'},\ \ \forall \bar{s},\bar{s}' \in \{\bar{s}\}_{t+}\ (t \in T, \bar{s}, \bar{s}' \in \bar{S}) \tag{26-3}$$

$$OL^{jkr}_{lt\bar{s}} = OL^{jkr}_{lt\bar{s}'}\ ,\ \forall \bar{s},\bar{s}' \in \{\bar{s}\}_{t+}\ (t \in T, \bar{s}, \bar{s}' \in \bar{S}) \tag{26-4}$$

Equation (26-1) considers non-anticipativity for supplying from suppliers to *DCs* according to split-variable formulation. For those variables such as *Y* (26-2), *II* (26-3) and *OL* (26-4) which are made at the end of each period after scenario realization, the non-anticipativity are considered based on the revealed scenarios ($t+$).

4- Case study

Iran is one of the most seismically active countries in the world, being crossed by several major faults. In what follows, a problem relying on the real data is introduced for one of the Tehran districts as highlighted in Figure 6. Based on census results issued by Statistical Center of Iran (Years 2012 and 2017), more than 276,000 people reside in this district. The selection of this district was made primarily for its real data availability and its close proximity to fault lines. In this regard, Zolfaghari and Peyghaleh (2010) have estimated that up to 3,854 damaged buildings and more than 60,000 fatalities could occur during an earthquake in District #13 based on the generated scenarios in their study. The scenario tree has been generated in this paper considers decision stages including preparedness and three stages in the response phase. To generate the scenario tree, some modifications have been conducted for transforming the scenarios in Zolfaghari and Peyghaleh (2010) including magnitude of earthquake and number of damaged building into estimation of requested demands and link status. Moreover, using GIS data that has been suggested by Al Theeb and Murray (2016) as one of the realistic techniques in disaster cases, has been used in the present paper for calculating some parameters such as real distances, transportation cost, reference points for location of facilities (*Appendix A: sections1-5)*. The considered case study includes three suppliers located out of the seismic zone (eastern and northern zones) that provide the relief goods for *DCs* and demand points, without considerable trouble for navigating through seismic zones and roads. Moreover, thirteen *DCs* (nine existing and four candidate *DCs*) have been identified and positioned on the GIS maps. Existing *DCs* have been positioned based on real location of the current disaster management support bases, health centers and local disaster management centers in this district. Also, 82 demand points have been recognized so it is expected that people would seek refuge there temporarily (i.e. schools, parks and etc. in the first 72 h).

4-1- Current network vs. reconfiguration

In this section, implementation results of the proposed reconfiguration model named P_1 on the real case study are discussed and evaluated in comparison with the performance of existing network (*P2*) in the event of a disaster. The main purpose is to ascertain that to what extent the solution quality has been improved by implementing the P_1 solutions. The criteria for evaluating improvement are the objective function and demand satisfaction level. In this regard, available budgets have been fixed as a basic parameter for both P_1 and P_2 in the above-mentioned case study. In other words, all situations for P_1 and P_2 are the same except impossibility of conducting reconfiguration policies in P_2 regarding phasing out, new establishment and consolidation of DCs. However, other components of the proposed model including rehabilitation, debris clearance and problem-solving approach are the same for both problems. The models have been solved by GAMS software and the CPLEX solver (CPU: Core i5, 2.4 GHz, with 8 GB of RAM). After solving P_1, as illustrated in figure 6, the redesigned network is structured by maintaining 7 of 9 existing DCs (*DCs* 3, 4, 5, 6, 7, 8& 9) as well as establishing 3 of 4 eligible ones (*DCs* 10, 12& 13). Also, the first existing DC should be consolidated with a new DC numbered 13 and the second existing DC should be consolidated with a newly established DC numbered 10. Although DC #1 has been positioned in the center of some shelters or camps that may be utilized during a disaster, many of its link connections would be shut down based on FL^0 =0 (derived from the opinion of experts) and $RH=0$. So, this facility would not be selected as an active *DC*. In P_2, there are nine DCs without any options for consolidation, new establishment or phase-outs. Figure 7 and table 2 clarify the comparison between a reconfigured network (P_1) and an existing one (P_2) in terms of objective function and the demand satisfaction percentage. The considered budget for both cases is 9.0E+10 Tomans (Iranian Currency). Moreover, the scenarios, demands and any other input for both cases are considered the same so that the results would be pure and comparable. As illustrated in figure 7, the breakdown of the various costs mentioned in the budget constraint (equation 2) under the current configuration and the new network reconfiguration (proposed model) are displayed for comparison with the specific budget (9.00E+10). The cost of newly established DCs increased slightly, mainly due to selection of new DCs with less maintenance cost and more suitable performance for satisfying the requested demands. This increase not only is offset by a decrease in the cost of procurement, transportation and storage during the pre- and post-disaster as well as consolidation savings, but it also improves the unmet demand percentage from 17.5% to 2.2% according to table 2.

As can be seen in table 2, all the P_1 results are better than those of P_2 causing the objective function of P_1 (93,963) to be significantly less than that of P_2 (1,345,663). Moreover, shortages and uncovered demand nodes occurring based on continuing the existing network in a disaster (P_2) are significantly higher than reconfiguration results with the same budget. In this regard the allocation of demand nodes to DCs illustrated in *Appendix A (A-6* and *A-7* for P_1 and P_2) demonstrates the superiority of applying the proposed model in P_1.

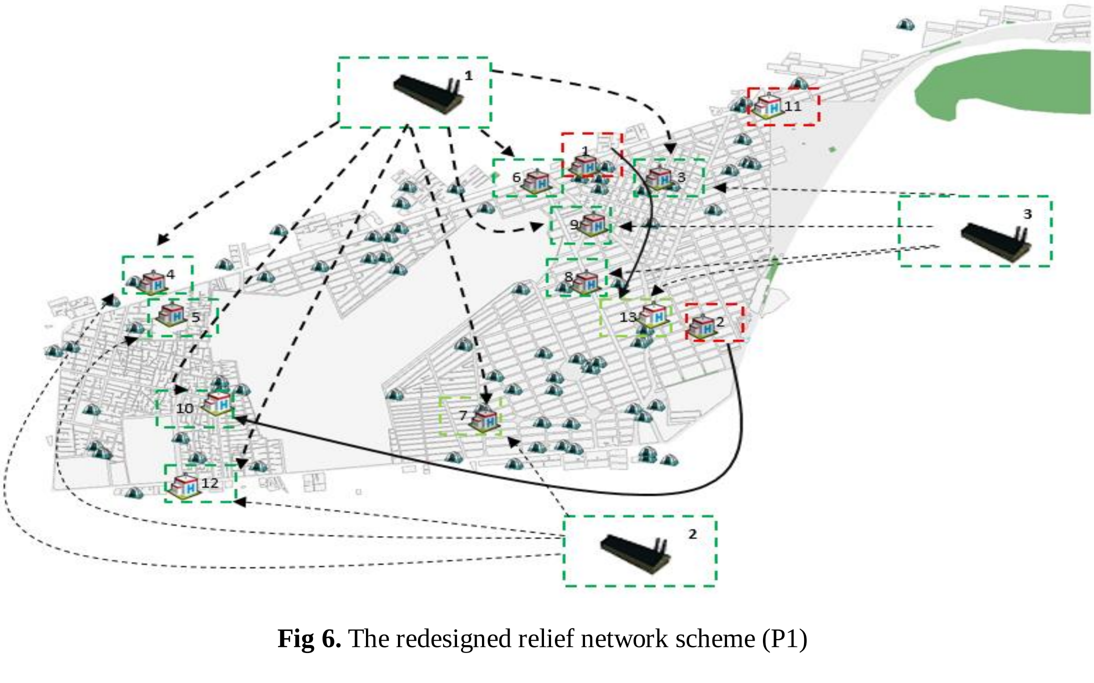

Fig 6. The redesigned relief network scheme (P1)

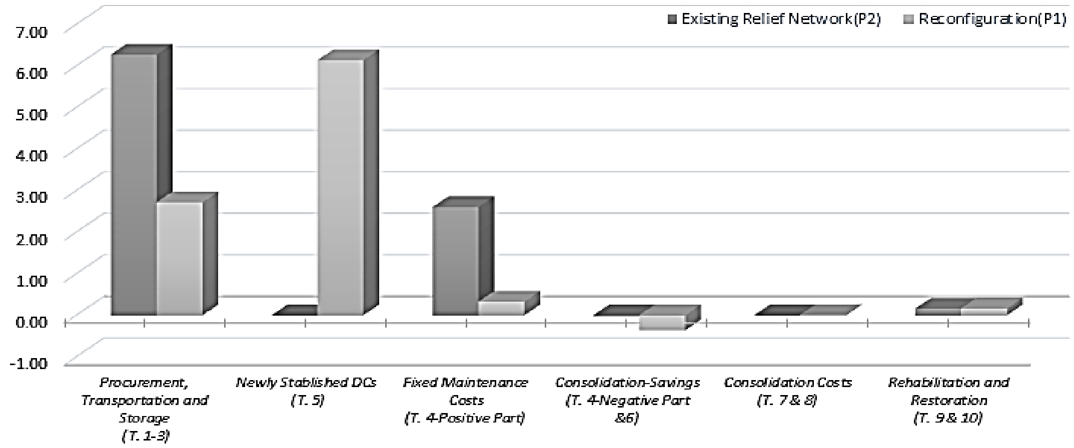

Fig 7. Cost of each budget term in equation 2 for P_1 and P_2 (E+10)

Table 2. Redesigned network (*P1*) vs. existing network (*P2*)

Criteria	Reconfiguration (*P1*)	Existing Network(*P2*)
Objective Function ▼	93,963	1,345,663
Demand Satisfaction (%) ▲	97.8 %	82.5 %
Absolute Gap ▼	0	0
Computational Time (s) ▼	122	58

4-2- Performance of multi-stage stochastic programming

In this section, the stochastic solving approach is evaluated. Let Obj_{EV} be the optimal value of the objective function in the average scenario deterministic model, *EV*. *EV* is defined where the expected value of each parameter on the scenario tree for each time period is fixed, as follows:

$$Obj_{EV} = Min \sum_{t \in T} \bar{a}_t x_t + \bar{b}_t y_t \qquad \text{(EV Model)}$$

$$\bar{A}'_{t-1}.x_{t-1} + \bar{A}_t \,.x_t + \bar{B}'_{t-1}.y_{t-1} + \bar{B}_t \,.y_t = \bar{d}_t, \ \forall t \in T$$

$$x_t \in X, y_t \in Y, \forall t \in T$$

To determine the value of stochastic solution, let us define EEV_t as the expected result in t of using the expected value solution for t = 2, . . . , T. EEV_t is the optimal value of the multi-stage stochastic programming equations (1) – (25), where the decision variables until stage $t-1$ are fixed as the optimal values of the average scenario model (EV Model) as follows:

$$EEV_t = \begin{cases} eq.(1)-(25) \\ s.t. \\ x_1^{\omega} = \bar{x}_1 \quad \forall \omega \in \Omega \\ \ldots \\ x_{t-1}^{\omega} = \bar{x}_{t-1} \quad \forall \omega \in \Omega \end{cases} \qquad \text{(EEV Model)}$$

Escudero and Merino (2007) have mentioned a *VSS* relation for a *MSSP*, even for those problems that have no feasible solution as in the case of substitution of the *EV* solution in the *EEV* model, so that for any multi-stage stochastic programming and minimization objective function we have the criterion shown below for performance evaluation of stochastic solution resulting from *MSSP*:

$$VSS_t = EEV_t - MSSP \qquad \text{(VSS-Performance)}$$

The positive values for *VSS* in Table 3 demonstrate the appropriate quality of solutions obtained by *MSSP*. For *T=0*, *EEV* will be equal to objective function of *MSSP* (Escudero and Merino, 2007).

Table 3. Value of stochastic solution at each decision stage (for budget of 9.0E+10)

Decision Stage	VSS
Stage1:T=0	0
Stage 2: T=1	*2048402*
Stage 3: T=2	*2191790*
Stage 4: T=3	*2367133*

5- Conclusion and future research

In this study a novel mathematical model for reconfiguration of relief networks, considering the preparedness and response phases was investigated. This model provides an analytical framework for comprising the performance of existing relief logistics network and the redesigned network obtained by the proposed model so that the disaster managers can get managerial insights for improving the level of preparedness and response phases. The contributions of the present paper can be briefly expressed as: proposing a novel mathematical model for redesigning the relief network; integrating road rehabilitation in the preparedness phase and DCSM in the response phase as well as proving the efficiency of proposed model and its stochastic solving approach (MSSP) in a real case study. The results demonstrate that the proposed model proved superior with less unmet demand (2.2%) in respect to continuing existing relief network and facilities (17.3%). Moreover, consideration of rehabilitation and restoration had a serious effect on demand satisfaction. Moreover, the solution quality was not only superior to the solution of the *EV* model, but also it displayed positive *VSS* throughout the decision-making stages which shows the positive value of applying *MSSP*. Future research studies are proposed in table 4.

Table 4. Future research road map

	Suggestions	**Noteworthy reference(s)**
1	Consideration of other strategic decisions such as investment in the rehabilitation in structure of multi-stage stochastic programming	*Nickel et al. (2012)*
2	Considering the perishable releif goods for the future mathematical models	*Rezaei-Malek et al. (2016b)*
3	Adding the cuts to accelerate the solving approach for all districts of Tehran using 22 candidate locations in study of Bozorgi-Amiri and Asvadi (2015)	*Melo et al. (2006)* *Bozorgi-Amiri & Asvadi (2015)*
4	Applying sampling-based Progressive Hedging Algorithms (PHA)	*Aydin Nezir (2012)*

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Appendix A

A-1- Some relevant Data for studied case- Supplementary GIS Data (For those who are familiar with Arc Map GIS)
https://www.dropbox.com/s/3ff8tjv633l1wyl/All%20GIS%20layers%20of%20Region13.rar?dl=0
Note: $TR_{cjkrt\bar{s}}$ is calculated based on a function of distances between nodes. For $c=1,\ r=1,\ \bar{s}=1,\ t=1$,
$TR_{cjkrt\bar{s}} = \alpha \times Ds^{j,k,r}, \alpha = 0.01$. Also $PR_{cijt\bar{s}}$ is obtained according to $\alpha \times Distance(i,j) + relief\ good\ Price$.

A-2, A-3, A-4, A-5, A-6 and A-7
https://www.dropbox.com/s/u1hgsqnl0wojed2/A-2%2C%20A-3%2C%20A-4%2C%20A-5%2C%20A-6%20and%20A-7.pdf?dl=0

A-2- Some reconfiguration Costs (main costs)

A-3- Scenario definition and demand estimation

A-4- Weight determination of commodities at each period based on expert opinions

A-5- A sample structure for determination of FL0 for occurrence of path 1 of scenario tree based on expert judgments.

A-6- Allocation of demand nodes to DCs in the redesigned network: P1 (for scenario paths 1,2,3 and 4 at period 1).

A-7- Allocation of demand nodes to DCs in the existing network: P2 (for scenario paths 1,2,3 and 4 at period 1).