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Multiple-organizational coordination planning for humanitarian relief operations

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Abstract

In humanitarian relief operations (HRO), due to the excessive number of relief organizations, multiple organizational coordination is a demanding and complicated task. Considering such a problem, this paper proposes a two-phase mechanism to coordinate multiple heterogeneous relief organizations in a decentralized HRO logistics network. To address such a problem, first a bi-level mixed integer linear model under the demand and supply uncertainties is developed, and then a capacity sharing-based-coordination mechanism is proposed. To solve the model for large-scale instances in an acceptable computation time, a fuzzy K^{th}-Best algorithm is developed. Finally, to validate the proposed mathematical model, we compare it to a centralized relief logistics model considering a computational experiment on the earthquake in Tehran, Iran. Results show that the proposed coordinated model reduced the amount of shortage and wastage in Tehran compared to the traditional centralized model employed previously by Tehran Disaster Mitigation and Management Organization.

Keywords: Humanitarian relief logistics, platelets, coordination, capacity sharing; uncertainty, bi-level model.

1-Introduction

What makes the coordination concept more important for platelets logistics is the necessity of on schedule supply since this very crucial and extremely short lifespan relief commodity (typically of 5-7 days) is very valuable for patients with low or poor performance platelets (Ensafian and Yaghoubi, 2017). The coordination of relief organizations in HRO, either homogeneous (e.g., hospital-with-hospital) or heterogeneous (e.g., hospital-with-blood center); however, is complex and challenging due to their different missions, interests, capacity, and expertise (Raju & Becker, 2013).

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For coordination of agencies, certain mechanisms need to be defined. Coordination mechanisms can be defined as “a set of methods used to manage interdependence among the organizations (Xu &Beamon, 2006). To the best of our knowledge and considering the relevant studies in HRO (e.g., Balcik et al., 2010;Caunhye et al., 2011; Belien & Force 2012)and in blood supply chain (e.g., Pierskalla, 2005), (Karaesmen et al., 2011), (Wang & Ma, 2015), (Ensafian & Yaghoubi, 2017) and (Zahiri & Pishvaee, 2017), there is no research on the highly perishable platelets logistics to develop a mathematical model for the coordination mechanisms of heterogeneous relief organizations operating in a decentralized HRO in which the demand and supply uncertainties are considered. Designing a coordination mechanism for coordination of relief agencies providing disaster areas, hospitals, and TMSs with platelets is our main contribution.

The rest of the paper is organized as follows. A review of the most relevant works concerning blood-derived products supply chain as well as the coordination studies in HRO is provided first. In Section3, we present our proposed coordination mechanism and the mathematical models. Solution approach is introduced in Section 4. Section 5 presents a case study, its computational analysis, results, and managerial insights. Finally, we conclude in Section 6providing some relevant observations and noting some opportunities of future research.

2-Literature Review

We first review the relevant literature of blood-derived logistics in both usual daily operations and HRO. Then, we focus on the papers investigating the non-coordinated/coordinated planning of relief agencies providing injured people with the relief commodities.

2-1- Blood supply chain management

The existing body of literature on blood supply chain is quite limited. Moreover, the models for blood-derived products supply chain are few; however, the research trend in this context is promising in recent years (Belien &Force, 2012). Zahiri & Pishvaee (2017) developed a regionalized SCN considering perishability as well as group compatibility of blood-derived components in which donors, temporary shelters, and lab centers were vertically coordinated. Gunpinar & Centeno (2015) presented a model under uncertain demand rates for minimization of total costs as well as shortage and wastage levels of blood products at a hospital. Ensafian et al. (2017) and Ensafian & Yaghoubi (2017) developed an integrated production and distribution network for perishable platelets where demand was age-differentiated according to the type of patient. Dillon et al. (2017) proposed a model to find the optimal periodic review policies for red blood cells inventory management focusing on minimizing operational costs as well as blood shortage and wastage. Jabbarzadeh et al. (2014) proposed a model for designing a blood supply chain network in HRO. They used real data from Tehran and determined the locations for blood collection at the time of earthquake. Salehi et al. (2017) developed a model under uncertainty for designing a three-layer blood supply chain network in a crisis including the donated areas, blood collection centers, and blood transfusion center. Fahimnia et al. (2017) presented a bi-objective supply chain model for efficient blood provision in disasters establishing reasonable trade-offs between supply chain cost and delivery time.

2-2- No coordination/coordination in HRO

For coordination planning in HRO, various mechanisms were developed. Afshar &Haghani (2012) used the clustering approach as a coordination mechanism to group the multiple relief organizations based on the pre-defined missions and geographical locations. Sheu & Pan (2015) presented relief logistics models in a network of multiple homogeneous and heterogeneous organizations. They developed a two-stage coordination mechanism to cluster the organizations based on various characteristics, providing much more organized and faster relief logistics. Edrissi et al. (2013) proposed an integrated responsibility-based coordination mechanism and formulated a relief network of heterogeneous organizations. Camacho Vallejo et al. (2015) presented a decentralized model with integrated and iterative mechanism as for coordinating international agencies with local organizations for the provision of medical items in HRO after a catastrophic disaster. A horizontal inventory sharing coordination mechanism was presented by Toyasaki et al. (2016). They proposed incentives for joining organizations to the relief network. Kamyabniya et al. (2017)proposed a mixed horizontal-vertical coordination mechanism for multiple homogenous relief organizations under uncertainty in a possible earthquake. The studies by Balcik et al. (2010) and Shulz &Blecken (2010) are recommended as they reviewed and analyzed all the coordination mechanisms for relief logistics problems. To the best of our knowledge, the integrated procurement, production and distribution of platelets under uncertainty focusing on the multi-organizational coordination in relief operations has not been addressed in the literature. To bridge the gap, this paper contributes to the literature in the following way:

- Presenting an efficient two-phase coordination mechanism for platelets SCN in a hierarchical decentralized multi-organizational humanitarian relief environment.

3-Problem definition and formulation

In figure1, the bi-level structure without coordination mechanism is depicted. In this phase, the upper level of the hierarchy (RRO) aims at minimizing the overall delivery time of platelets from MDs (located by disaster mitigation and management command center) to TMSs. Since RRO, as the main logistician of medical resources to all demand zones in HRO, has large and fast emergency fleet, minimizing the relief operations time is as its main objective. The lower level (BTO), aiming at minimizing the operational, inventory, and wastage costs, manages the production of platelets in blood regional units (BRU) for supplying the required amount of platelets at each MD. BTO, as the only producer and provider of blood products, takes the amount of inventory and wastage of platelets into account to avoid being penalized. The decision process is further complicated as it is conducted under uncertain environment. In HRO, the existing data on platelets demand and donation at MDs are often vague or inaccurate; therefore, it is often inappropriate to describe the problem parameters as known variables.

3-1- Assumptions and notations

- Naturally, there is a beginning inventory for the blood-derived platelets after the disaster.
- The whole Blood-derived platelets of only O-type as the universal platelet type is considered.
- Due to 48-hour testing process required right after the donation, the practical shelf life of platelets is only 3 days.
- The lead time of supplying whole blood and platelets is zero. In fact, the orders are carried out immediately.

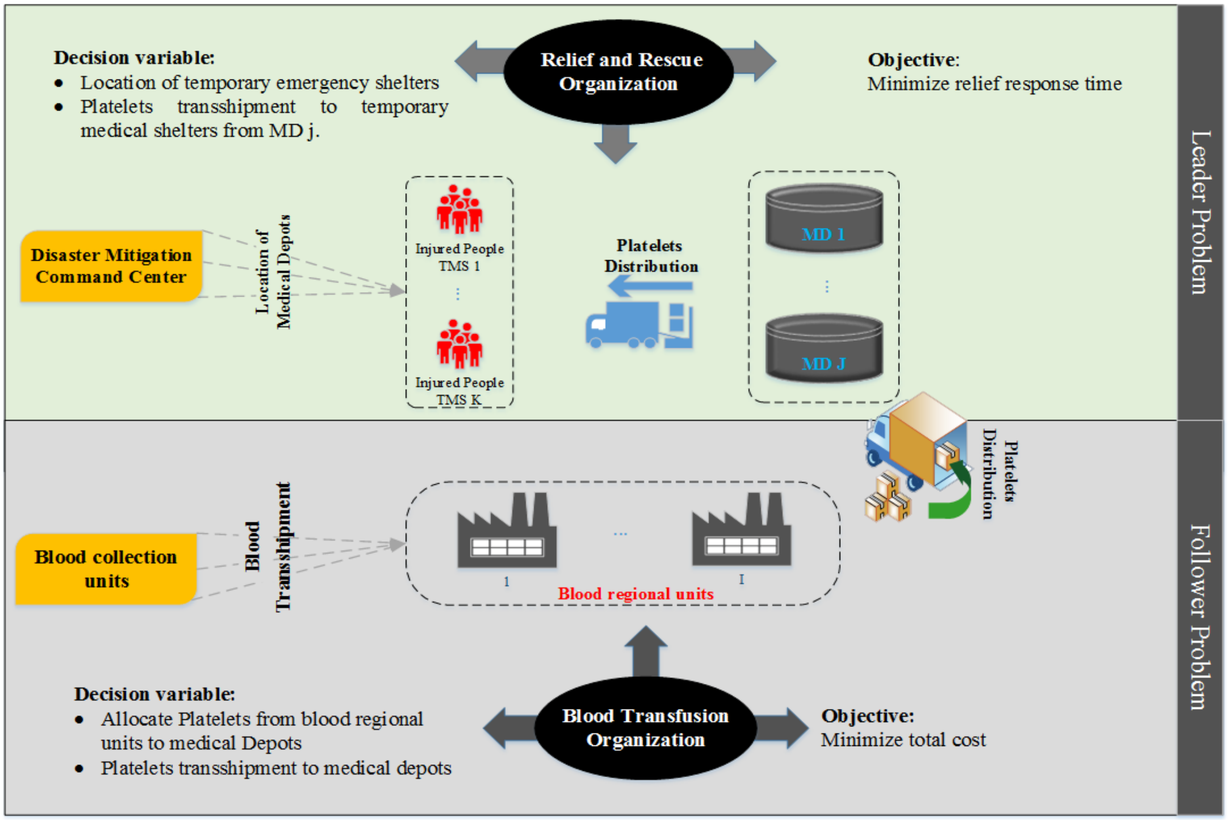

Fig. 1. The structure of proposed decentralized humanitarian relief logistics model

3-2-Model 1: RRO model

The RRO as the upper-level decision maker aims to minimize the delivery time of platelets to TMSs while satisfying any requirement demanded from BTO.

$$\boldsymbol{P}^{\boldsymbol{L}} = min\left(\sum_{v\in V}\sum_{h\in H}\sum_{k\in K}\sum_{j\in J}\sum_{t\in T}(1-RU_k^t)\left((2t_{jk}+\tau_{kh})LT_{jkhv}^t+\sum_{r\in R}\beta_h X_{jkhv}^{rt}\right)\right) \tag{1-R}$$

$$\sum_{v\in V}\sum_{h\in H}\sum_{r\in R}\sum_{j\in J}X_{jkhv}^{rt} \geq \sum_{j\in J}\widetilde{D_{jk}^t}, \quad \forall\, k,t \tag{2-R}$$

$$X_{j,k,v,h}^{r,t} \leq \alpha_t^r.CPM_k \quad \forall j,r,t \tag{3-R}$$

$$\alpha_t^r \geq \alpha_t^{r-1} \quad \forall r \geq 2,t \tag{4-R}$$

$$\frac{\sum_{h\in H}\sum_{v\in V}\sum_{j\in J}X_{jkhv}^{rt}}{\sum_{h\in H}\sum_{v\in V}\sum_{r\in R}\sum_{j\in J}X_{jkhv}^{rt}} \geq \delta_{min}^r, \quad \forall k,r,t \tag{5-R}$$

$$\frac{\sum_{h\in H}\sum_{v\in V}\sum_{r\in R}\sum_{j\in J}X_{jkhv}^{rt}}{\sum_{h\in H}\sum_{v\in V}\sum_{r\in R}\sum_{k\in K}\sum_{j\in J}X_{jkhv}^{rt}} \geq \gamma_{min}^k, \quad \forall k,t \tag{6-R}$$

$$\sum_{v\in V}\sum_{r\in R}\sum_{h\in H}\sum_{j\in J} X_{jkhv}^{rt} - H_k \leq 0, \qquad \forall\, k, t \tag{7-R}$$

$$\sum_{h\in H}\sum_{v\in V}\sum_{r\in R}\sum_{j\in J} X_{jkhv}^{rt} \leq \sum_{v\in V}\sum_{h\in H}\sum_{r\in R}\sum_{j\in J} \underline{Y_{ijvh}^{rt}}, \quad \forall\, i, t \tag{8-R}$$

Indices

i	Set of BRUs (*i*=1,2,…,*I*)
j	Set of MDs (*j*=1,2,…,*J*)
k	Set of TMSs (*k*=1,2,…,*K*)
t	Set of time periods (*t*=1,2,…,*T*)
r	Set of age of platelets (*r*=1,2,…,*R*)

Parameters

Supply and demand

RU_k^t	Relative urgency of O-type platelets
OC_i	Operational capability of BRU *i*
ρ	Quantity of whole blood units
M	Big *M* (a large number)
ε	Percentage of whole blood are unusable
$TAB_{i,t}^r$	Total available platelets before onset of disaster
$UPB_{i,t}$	Number of available platelets donors at BRU *i*
τ	Quantity of extracted platelet by apheresis

Facilities

TMS_{max}^t	Maximum number of candidate TMS locations
H_k	Capacity of TMS *k* for all O-type platelets
CAP_j^t	Storage capacity of platelets at MD *j* in period *t*
CPM_k	Storage capacity of platelets at TMS *k*

Cost items

CP_i	Production costs per O-type platelet at BRU *i*
CI	Inventory costs per O-type platelet
CW	Wastage costs per O-type platelet
CS_h	Supply (transportation) costs by vehicle of type *h*
ψ	Production costs of one unit apheresis platelet at BRU

Inventory and wastage

α_t^r	1 if *r* days O-type platelets are used to satisfy the demands of TMSs
A_t^r	1 if *r* days O-type platelets are used to satisfy the demands of MDs
μ_i^t	Amount of O-type platelets wastage at the end of period *t* in BRU *i*.
Ψ_j^t	Amount of O-type platelets wastage at the end of period *t* in MD *j*.
INB_i^{rt}	Inventory level of *r* days O-type platelets at the end of period *t* in BRU *i*.
INE_j^{rt}	Inventory level of *r* days O-type platelets at the end of period *t* in MD *j*.

Fuzzy parameters

$\widetilde{D_{jk}^t}$	Amount of platelets demanded from MD *j* by TMS *k*
$\widetilde{DB_i^t}$	Amount of platelets donation supplied to BRU *i*

Decision variables

X_{jkhv}^{rt}	Amount of platelets delivered to TMS *k* from MD *j* by vehicle type *h* on its *v*th trip
Y_{ijhv}^{rt}	Amount of *r* days O-type platelets delivered to MD *j* from BRU *i* by vehicle type *h* on its *v*th trip
QP_i^t	Amount of production of O-type platelets at BRU
$APB_{i,t}$	Quantity of platelets apheresis at BRU *i*
$U_{i,t}$	1 if platelet is produced at BRU *i*

$$\sum_{k\in K} F_k^t \leq TES_{max}^t, \qquad \forall t \tag{9-R}$$

$$s_{jk} F_k^t \leq R, \quad \forall j, k, t \tag{10-R}$$

$$\sum_{r\in R} w\, X_{jkhv}^{rt} \leq Q_h LT_{jkhv}^t, \qquad \forall j, k, h, v, t \tag{11-R}$$

$$\sum_{k\in K}\sum_{v\in V}\left(\left(2t_{jk} + \tau_{kh}\right) LT_{jkhv}^t + \sum_{r\in R} \beta_h X_{jkhv}^{rt} \right) \leq U_h F_k^t, \;\; \forall j, h, t \tag{12-R}$$

$$LT_{jkhv}^t, \alpha_t^r, F_k^t \in \{0,1\},\; Binary\ integre\ variables\ \ \forall\, r, j, k, t, h, v \tag{13-R}$$

$$X_{jkhv}^{rt} \in \mathcal{R}^+ \quad Real - valued\ variables\ \ \forall\, r, j, k, t, h, v \tag{14-R}$$

Constraint (1-R) minimizes the sum of all transportation times. Constraint (2-R) enforces that the amount platelets shipment from MDs should satisfy the demand at TMSs. Constraints (3-R) and (4-R) guarantee the FIFO issuing policy, thus reducing the amount of younger platelets to be transshipped through the network before older ones. Constraint (5-R) requires that from all O-type platelets delivered to TMS *k* in period *t*, at least δ_{min}^{r} percent is of *r* days old. Constraint (6-R) ensures that total O-type platelets delivered to TMS *k* in period *t* to be more than a minimum percentage of all O-type platelets delivered among all TMSs. Constraint (7-R) ensures that if a TMS is selected to be set up in potential location *k*, the respected capacity constraint is enforced. Constraint (8-R) requires the amount of O-type platelets delivered to TMS *k* be less than the supplied O-type platelets. Constraint (9-R) obliges the maximum number of opened TMSs to be limited by the maximum allowable numbers. Constraint (10-R) guarantees that potential location for TMS *k* is covered within the distance *R* of MDs to which they are assigned. Constraint (11-R) makes sure that platelets are not sent out from MDs unless a number of vehicles with enough capacity are available at the depot. Constraint (12-R) expresses the maximum daily operations time associated with each vehicle type *h* located at MD*j*.

3-3-Model 2: BTO model

For the lower level problem, the BTO solves the following model in order to react rationally to the decisions made by leader. BTO can produce and supply the amount of platelets independently; i.e., QP_i^t,Y_{ijvh}^{rt}, which can affect the total costs and amount of wastage. Its objective function may not be consistent with that of RRO since BTO seeks to minimize the total operational costs while neglecting the relief response time. The other objectives may also be appropriate for this problem (e.g., minimization of unmet demand, transportation time, number of fatalities, etc.); but, we decided to choose only equation (1-B).

$$\begin{aligned}\boldsymbol{P^F} = min(1-OC_i)\Bigg(\sum_{i\in I}\sum_{t\in T}\psi \times APB_{i,t} \\ + \sum_{t\in T}\sum_{i\in I}\Bigg(QP_i^t \times CP_i + \sum_{r\in R} INB_i^{rt} \times CI + \mu_i^t \times CW \\ + \sum_{v\in V}\sum_{h\in H}\sum_{r\in R}\sum_{j\in J} Y_{ijvh}^{rt} . CS_h\Bigg)\Bigg)\end{aligned} \tag{1-B}$$

$$\sum_{v\in V}\sum_{h\in H}\sum_{r\in R}\left(\sum_{i\in I} Y_{ijvh}^{rt} - \sum_{k\in K}\overline{X_{jkvh}^{rt}}\right) \geq 0, \quad \forall\, j,t \tag{2-B}$$

$$\sum_{v\in V}\sum_{h\in H}\sum_{r\in R}\sum_{j\in J} Y_{ijvh}^{rt} \leq QP_i^t + INB_i^{(r-1)(t-1)}, \quad \forall\, i,t \tag{3-B}$$

$$\sum_{v\in V}\sum_{h\in H}\sum_{r\in R}\sum_{i\in I} Y_{ijvh}^{rt} - CAP_j^t \leq 0, \quad \forall\, j,t \tag{4-B}$$

$$QP_i^t \times \rho \times (1+\varepsilon) - M(1-U_{i,t}) \leq \widetilde{DB_\imath^{t-2}}, \ \ \forall\, i, t = 3, \dots, T \tag{5-B}$$

$$QP_i^t \times \rho \times (1+\varepsilon) + M \times U_{i,t} \geq \widetilde{DB_\imath^{t-2}}, \ \ \forall\, i, t = 3, \dots, T \tag{6-B}$$

$$QP_i^t \leq MCP \times U_{i,t} \quad \forall t = 3, \dots, T \tag{7-B}$$

$$INB_{i,t}^{r} = INB_{i,t-1}^{r-1} - \sum_{h}\sum_{v}\sum_{j} Y_{i,j,v,h}^{r,t} + TAB_{i,t}^{r} \quad \forall i, r = 4, \dots, R; t = 4, \dots, T \tag{8-B}$$

$$INB_{i,t}^{3} = QP_i^t + INB_{i,t-1}^{2} - \sum_{h}\sum_{v}\sum_{j} Y_{i,j,v,h}^{3,t} + TAB_{i,t}^{3} \quad \forall i,t \tag{9-B}$$

$$INB_{i,t}^{2} = INB_{i,t-1}^{1} - \sum_{h}\sum_{v}\sum_{j} Y_{i,j,v,h}^{2,t} + TAB_{i,t}^{2} \quad \forall i,t \tag{10-B}$$

$$INB_{i,t}^{1} = \tau \times APB_{i,t} - \sum_{h}\sum_{v}\sum_{j} Y_{i,j,v,h}^{1,t} + TAB_{i,t}^{1} \quad \forall i,t \tag{11-B}$$

$$\sum_{r} w\, Y_{ijhv}^{rt} \leq Q_h LM_{ijhv}^{t}, \quad \forall i,j,h,v,t \tag{12-B}$$

$$\sum_{j}\sum_{v}\left(\left(2t_{ij} + \tau_{ij}\right) LM_{ijhv}^{t} + \sum_{r} \beta_h Y_{ijhv}^{rt} \right) \leq U_h, \quad \forall i,h,t \tag{13-B}$$

$$Y_{i,j,v,h}^{r,t} \leq A_t^r . CPH_j \quad \forall j,r,t \tag{14-B}$$

$$INB_{t-1}^{r} \leq M \times (1 - A_t^r) \quad \forall r,t \tag{15-B}$$

$$A_t^r \geq A_t^{r-1} \quad \forall r \geq 2, t \tag{16-B}$$

$$APB_{i,t} \leq UPB_{i,t} \qquad \forall i,t \tag{17-B}$$

$$\mu_i^t = INB_i^{Rt}, \quad \forall\, i \in I; \forall t \in T \tag{18-B}$$

$$LM_{ijhv}^{t} \in \{0,1\}, \quad Binary\ integre\ variables\ \ \forall\, i,j,t,h,v \tag{19-B}$$

$$Y_{ijvh}^{rt}, QP_i^t, INB_i^{rt}, \mu_i^t \in \mathcal{R}^{+} Real - valued\ variables\ \ \forall\, i,j,r,t,v,h \tag{20-B}$$

Constraint (1-B) minimizes the total operational costs for all BRUs. Constraint (2-B) dictates that the amount of platelets supply in BRU*i* is not lower than that of platelets shipment at MD*j*. Note that X_{jk}^{rt} is the leader's decision variable which enforces the follower not to supply and produce any amount which is the best for. Constraint (3-B) guarantees that the amount of platelets supply is satisfied by the amount of its production in period *t* and inventory of period *t*-1. Constraint (4-B) ensures that the supply to be less than the capacity of assigned MD. Constraints (5-B) and (6-B)shows the maximum limit on platelets produced at each blood center considering two days for production and testing. Constraint (7-B) enforces an upper bound on the production capacity in BRUs during period *t* if platelets are produced in the corresponding period. Constraints (8-B) - (11-B) are the balance equations for platelets inventories in BRUs at the end of each period for each age group. Constraints (12-B) and (13-B) are defined the same as (11-R) and (12-R). Constraints (14-B) - (16-B) guarantee that the FIFO policy is issued. Constraint (17-B) puts an upper limit on the number of apheresis platelet donors at BRUs. Constraint (18-B) identifies the wastage levels of BRUs at the end of each period.

3-4-Model 3: Fuzzy Mixed-integer bi-level programming (FMIBP)

In order to integrate model (1) with (2), we present a fuzzy mixed-integer bi-level programming in which RRO is considered as the leader and BTO as the follower. This model is denoted as phase 1 in figure2. Depending on the function types as well as variable types, the proposed model can be formulated as different types of bi-level programs.

Without loss of generality, consider the following fuzzy linear bi-level programming problem in a compact form:

$x \in X \subset \mathcal{R}^n$: leader (RRO)'s decision variable, $y \in Y \subset \mathcal{R}^m$: follower (BTO)'s decision variable, $F: X \times Y \subset \mathcal{R}^1$: leader's objective function, $f: X \times Y \subset \mathcal{R}^1$: follower's objective function. It consists of finding a solution to the upper level problem (RRO).

$$\begin{cases} \min\limits_{x \in X} F(x,y) = cx \\ \qquad st. \\ B_1 y - A_1 x = 0 \\ \quad A_1 x \geq \widetilde{b_1} \end{cases} \tag{1-F}$$

Where y, for each value of x, is the solution of lower level problem (BTO):

$$\begin{cases} \min\limits_{y\in Y} f(x,y) = dy \\ \qquad st. \\ B_2y - A_2x \geq 0 \\ \quad B_2y \leq \widetilde{b_2} \end{cases} \tag{2-F}$$

where$\widetilde{b_1}, \widetilde{b_2}$, have the triangle membership functions. $\widetilde{b_1}$and$\widetilde{b_2}$ both denote the uncertainty in demand and supply for amount platelets required for both RRO and BTO models, respectively. Furthermore, parameters A_1 and B_1 belong to RRO model for deterministic and fuzzy constraints. In this regard, A_2 and B_2 belong to BTO model. Parameters c and d denotes the compact form of all response time and costs for the RRO and BTO objective functions, respectively.

According to theorems (3.1) and (3.2) (Zhang and Lu, 2007), the fuzzy bi-level problem is reformulated to the following problem:

$$\begin{cases} \min\limits_{x\in X} F(x,y) = cx \\ \min\limits_{x\in X}(F(x,y))^L = c^Lx \\ \min\limits_{x\in X}(F(x,y))^R = c^Rx \end{cases} \quad \text{St.} \begin{cases} B_1y - A_1x = 0 \\ A_2x \geq b_1, A_2x \geq {b_1}^L, A_2x \geq {b_1}^R \end{cases} \tag{3-F}$$

Where y, for each value of x, is the solution of lower level problem:

$$\min_{y\in Y} f(x,y) = dy \qquad \text{St.} \begin{cases} B_2y - A_2x \geq 0 \\ B_2y \leq b_2, B_2y \leq {b_2}^L, B_2y \leq {b_2}^R \end{cases} \tag{4-F}$$

To solve the reformulated model (3-F)-(4-F), the objective function of leader problem should be rewritten using weighting technique as follows (Zhang et al., 2011):

$$\min_{x\in X} F(x,y) = cx + c^Lx + c^Rx \tag{5-F}$$

Subject to: Equations (3-F)-(4-F).

Therefore, the reformulated model can be solved by the K^{th}-Best algorithm introduced in Section (4).

3-5-Model 4: Coordinated FMIBP (*with capacity sharing-based coordination mechanism)*

To improve the results of first phase; therefore, we introduce a coordination mechanism for HRO with heterogeneous organizations in bellow. The idea is to minimize the shortage and wastage of platelets by optimally allocation of the TMSs' demands to the available capacity of BRUs. The capacity sharing mechanism is designed in two integrated phases: first, a mixed integer programming model (first phase of model 4) is solved for generating the initial relief plan. Then, based upon, the capacity sharing mechanism is triggered to execute, monitor, and modify the initial plan by taking the coordination of BRUs and TMSs into account. To improve the results of model4-first phase (Section 3.4), first constraints (15-R)-(20-R) should be added to model 1 (1-R)-(14-R). Then, the capacity sharing-based coordination mechanism is executed for further improvement in the result of model 4.Fig.3 illustrated the logic of developed coordination mechanism.

$$\sum_{r\in R}\left[INE_j^{(r-1)(t-1)} + \sum_{v}\sum_{h}\left(\sum_{i\in I}\underline{Y_{ijhv}^{rt}} - \left(\sum_{k\in K}X_{jkhv}^{rt}\right)\alpha_t^r\right)\right] - \Psi_j^t = \sum_{r\in R} INE_j^{rt}, \quad \forall j,t \tag{15-R}$$

$$INE_j^{r(t=0)} = 0, \qquad \forall\, j,r \tag{16-R}$$

$$INE_j^{(r=2)t} = 0, \qquad \forall\, j,t \tag{17-R}$$

$$\Psi_j^t = INE_j^{Rt}, \quad \forall\, j, t \tag{18-R}$$

$$\sum_{v}\sum_{h}\sum_{k\in K} X_{jkhv}^{rt} \le INE_j^{(r-1)(t-1)}, \quad \forall j, r, t \tag{19-R}$$

$$\sum_{r\in R} INE_j^{rt} \le CAP_j^t, \quad \forall j, t \tag{20-R}$$

Constraint (15-R) updates the blood inventory level at the end of period for each MD. Constraint (16-R) states that there is no inventory available at the beginning. Constraint (17-R) ensures that two days old platelets are not used to satisfy the demand as MDs only receive the platelets of older than two days from BRUs. The wastage levels of MDs at the end of each period are identified by constraint (18-R). Constraint (19-R) needs to be exchanged with constraint (8-R). The amount of inventory at end of each period is limited by the respective capacity in constraint (20-R).

The proposed capacity sharing mechanism (figure 3-phase 2) is developed for real-time execution of model 3(figure 3-phase 1) in each period. If the relief organizations accept to establish further coordination and negotiation, phase 2 is triggered as a complementary mechanism for improving the performance of FMIBP plan (Model 3), in this case, in terms of the total relief costs and response time. After generating the relief plan obtained from model 3, each BTO with limited capacity submits a proposal with a specified quantity, which determines its priority compared to the other proposals waiting in the queue to be processed by RRO. At Phase 2, Organizations with capacity shortage (demand sharing ones) or those with extra capacity (capacity sharing ones) try to generate coordination proposals and negotiate with their most preferred peers. The procedure of the proposed capacity sharing mechanism (figure3-phase 2) is as bellow.

4-Case study

Iran is as one of the most earthquake-prone countries in the world and has faced many devastating earthquakes during the past few years (Jabbarzadeh et al., 2014). Tehran, the capital city of IRAN, is one of the earthquake-prone largest cities in Western Asia which has not yet experienced any major earthquake. BTO and RRO of Red Crescent Society of IRAN are in charge of blood provision for hospitals and TMSs in response to disasters. Collection of blood as the main duty of BTO is through either temporary mobile blood facilities such as blood donation buses or permanent facilities in different regions. Generally, in practice, TDMMO fully controls the interaction of relief organizations in centralized structure; however, due to the lack of pre-defined coordination mechanisms for decentralized structure in HRO environment, the conflicts between RRO and BTO may increase. Therefore, we compare and analyze the platelets logistics with both centralized and decentralized structures. The initial post-disaster surveys estimate that around 15,000 people for district 6 (called Vali-Asr region, Tehran city) are affected and at least eight points for MDs and nine points for TMSs are needed to serve this population. It should be noted that it is assumed more than one bag of platelets is used for each injured people. The candidate locations for TMSs and MDs are determined based on the distance from disaster zone and are located in the municipal districts as defined by Tehran Municipality.

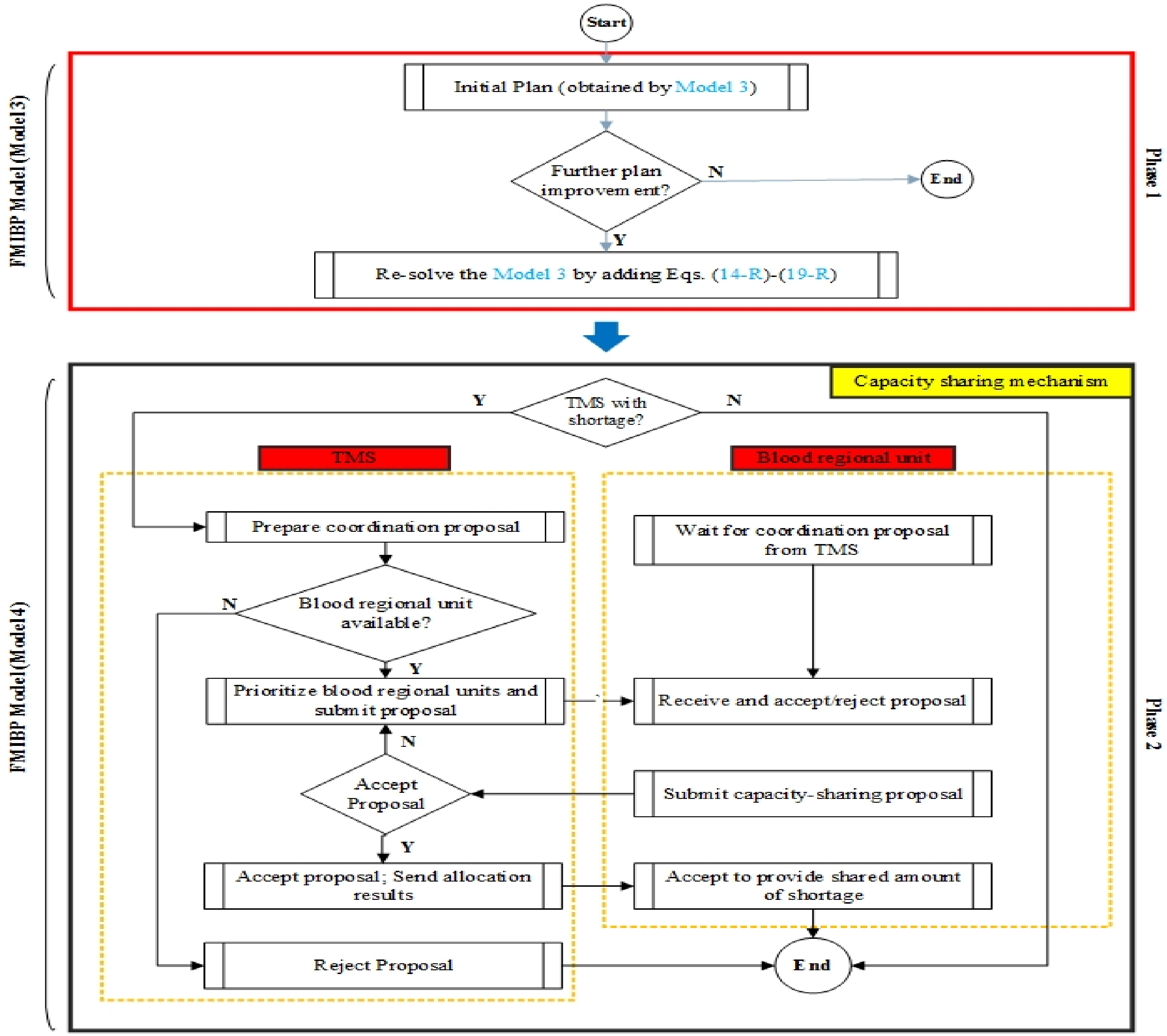

Fig. 2. General flow of capacity sharing-based coordination mechanism

5- Results

We implement the proposed model for case study described in Section (5.1). The model is solved using GAMS 24.1.3 with CPLEX solver running on a laptop with Core i5 2.5 GHZ with 4.0 GB of RAM. To give recommendations about the disastrous situation modeled in this paper, we first compare the decentralized model 3 (FMIBP) with the other two approaches; Centralized-RRO and Centralized-BTO. As seen in table 5, under leader's perspective (RRO), we obtained the fastest distribution plan, but very expensively for BTO ($P^L \leq P^{Bilevel} \leq P^F$). Meanwhile, considering follower's perspective (BTO), the solution gave us the cheapest plan, but the worst in relation to the required time for distribution ($P^F \leq P^{Bilevel} \leq P^L$). On the other hand, model 3 allows us to reach an intermediate point, keeping importance of decisions made by both RRO and BTO. The equilibrium obtained after solving model 3 increases both objectives; this result was expected due to the existing hierarchy among both levels. In Table 5, the gaps of saving in terms of cost and relief time provided by model3 against the leader and follower's perspectives show the advantages of the proposed model 3 and the algorithm efficiency. By selecting the bi-level solution instead of leader and follower's perspective solutions, we reduce the total costs and time by 18% and 40%, respectively. In both cases, the reductions are more significant than the expected increase.

Table 5. Numerical results for the case study under deterministic model 3

Model	P^L	P^F	Solution time	
			Reformulated Solution (seconds)	Direct Solution (seconds)
Leader's perspective	3,600	\$5.88 M[1]	160s	420s
Follower's perspective	10,200	\$4.40M	220s	480s
Model 3 (FMIBP)	6,100	\$4.81M	400s	620s

[1]Milion dollar (US unit)

To better evaluate the characteristics of proposed model, two numerical case studies are generated with variations in the subset of enforced constraints and some parameter values. The considered scenario in this study is obtained from the Tehran Earthquake Damage Estimation System based on Richter scale of floating 7 given in table 6.

Table 6. Computational results of model 4 under two scenarios case study

Case	**Total Demand** $(\boldsymbol{D_1}, \boldsymbol{D_2}, \boldsymbol{D_3}) \times \mathbf{1000}$	**Total supply** $(\boldsymbol{DB_1}, \boldsymbol{DB_2}, \boldsymbol{DB_3}) \times \mathbf{1000}$	**Details**							**Total Value**				**Location of facilities**
			BRB	H	HRd[1] (days)	TMS_{max}	CSh[3]	VC[4] (kg)		RT[7] (hour)	OC[8] (Mil\$)	WL[9]	INVL[10]	TMS (Districts)
								BRB[5]	H[6]					
1	(11,12,13)	(13,14,15)	100	50	6	10	Y	150	550	200	5.8	811	1129	(1,3,4,5,8,15, 18,21,22)
2	(15,16,17)	(18,18,18)	100	50	7	12	Y	150	550	223	6.2	928	1342	(1,3,4,5,8,9,13, 14,15,18,21,22)

[1] Humanitarian relief duration, [2]Total estimated demand and donation do not change in all periods, [3]Capacity sharing[4], Vehicle capacity, [5]Blood rescue bus, [6]Helicopter, [7]Response time, [8]Operational cost, [9]Wastage level, [10]Inventory level

From coordination mechanism point of view, capacity sharing mechanism has shown a satisfactory performance for scenarios (Cases 1 to 4). We assumed that all the generated scenarios have the same value for other parameters except those related to total demand and supply. In figure 3, the variations in level of wastage for Case-1 and Case-2 with or without coordination mechanism are shown over time. As expected, it is increased in two cases; in Case-3 the increase percentage is more observable due to more supply and demand and extra one day relief operation. Moreover, the wastage level over time with capacity sharing mechanism outperforms that with non-capacity sharing one.

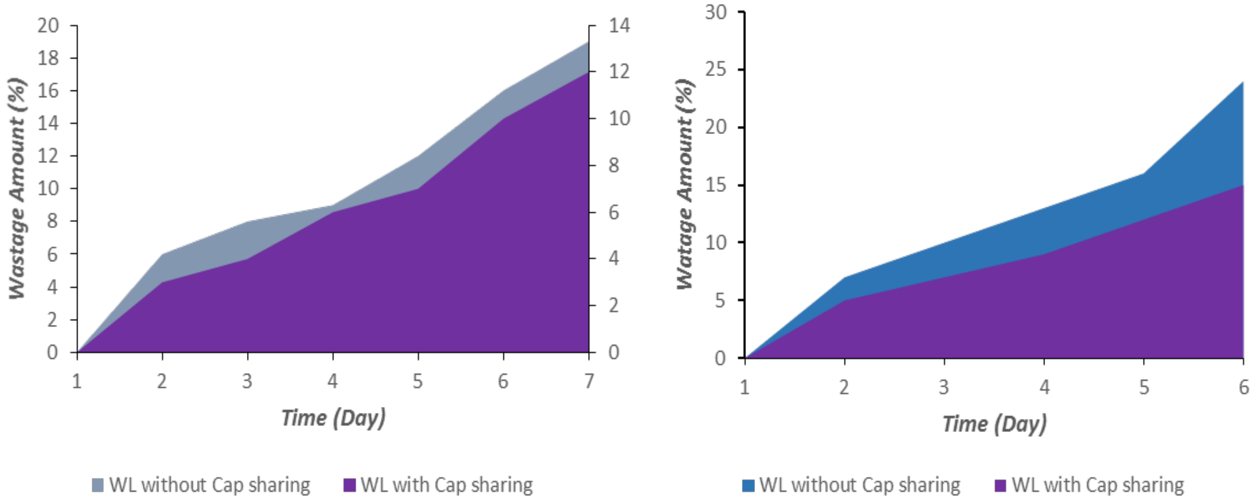

Fig.3. The effect of capacity sharing on level of wastage over time in scenario cases 2 and 3

6-Conclusion and direction for future research

This paper addressed a hierarchical coordinated logistics planning problem in the form of bi-level mathematical programming for blood-derived platelets after a disaster. By formulating a bi-level optimization problem joint with a two-phase coordination mechanism, an integrated and more realistic model of the humanitarian relief operations was provided. To improve the efficiency of decisions made by the responsive organizations, capacity sharing mechanism was introduced to coordinate multiple heterogeneous organizations with different interests and objectives. As a result, we can conclude that the proposed two-phase coordinated model works well for humanitarian relief operations and logistics of blood-derived products, leading us to recommend the necessity of having a coordinated planning in the decentralized structure. For future research opportunities, the problem described here could be modeled as a bi-level problem with multiple non-independent followers under uncertainty. Incorporation of the other coordination mechanisms capable of being used in humanitarian relief operations is also encouraged.

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