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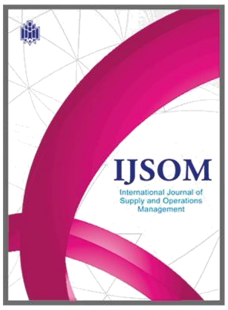

Modeling and Solving a Blood Supply Chain Network: An Approach for Collection of Blood

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Abstract

Management of the blood as a vital and scarce resource is very important. The aim of this research is to present a novel mathematical model for designing a reliable blood supply chain network. This network consists of three main echelons including donors, collection facilities and demand points. At the collection echelon, three types of facilities are considered for receiving the bloods from the donors: main blood centers (MBCs), demountable collection centers (DCCs), and mobile blood facilities (MBFs). DCCs, and MBFs are mobile facilities that don't have a permanent location and always move from a location to another one for collecting the bloods from the donors. The main difference between the MBFs and DCCs is that the DCCs can only visit at most a candidate location in every period, but the MBFs can visit more than one. Also, there are some other differences between their capacities and their costs. Both of DCCs and MBFs dispatch the collected bloods to the MBCs that are permanent facilities and are responsible for receiving the bloods and performing the blood transfusion process and finally sending the bloods to the demand points. Using a numerical example, the applicability of the proposed network is analyzed.

Keywords: Blood supply chain; Perishable product; Mathematical programming; GAMS; Supply chain management.

1. Introduction

The management of the blood and its products is an important issue in the healthcare systems. Collection of blood, processing of it in the labs and finally dispatching the produced blood products to the demand points are the main activities in the blood supply chain networks. The first and final echelons of the blood supply chain network have separated it from the other types of supply chains. From one side, the humans are the only resource for supplying the blood and there is no alternative for it yet. On the other hand, applicants of the blood products are usually patients such that inappropriate response to their demand could result in the death of them. For these reasons, the management of blood supply chain has received considerable attention of many researchers. For example, Cumming et al. (1976) investigated a planning model for assisting regional blood suppliers in diminishing seasonal imbalances between the supply of blood and its demand. In the work of Katsaliaki and Brailsford (2007) discrete-event simulation approach was used to manage the blood inventory system in a typical UK hospital supplied by a regional blood center. Jennings (1968) developed a model of a hospital blood bank whole blood inventory system for providing an accurate representation of actual blood bank operations using computer simulation. Cohen and Pierskalla (1975) applied the techniques of management science and mathematical inventory theory for considering management strategies in the administration of a regional blood bank. Custer et al. (2005) developed a new model to evaluate the safety, sufficiency, and cost of the blood supply. Sapountzis (1984) presented an integer programming model to allocate units of blood from a Regional Blood Transfusion Service to the hospitals of its area, taking into account the characteristics of the hospitals. Cetin and Sarul (2009) proposed a mathematical programming model for location of blood banks among hospitals or clinics. Their model was a hybrid from set covering model of discrete location approaches and center of gravity method of continuous - location models. Zhou et al. (2011) analyzed a periodic review inventory system under two replenishment modes for inventory Management of Platelets in Hospitals. Zahiri and Pishvaee (2016) developed a

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*Corresponding author email address: shr_pasandideh@khu.ac.ir bi-objective mathematical programming model for designing a blood supply chain network considering blood group compatibility. In the work of Gunpinar and Centeno (2016), a vehicle routing problem for a blood center was modeled to propose an approach to identify the number of bloodmobiles to operate and minimize the distance traveled. Jabbarzadeh et al. (2014) proposed a robust network design model for the supply of blood during and after disasters by developing a practical optimization model. They investigated the application of their model in a case problem where real data is utilized to design a network for emergency supply of blood during potential disasters. Similar researches have also done by Chaiwuttisak et al (2016), Fahimnia et al (2015), Zahiri et al (2013), Duan and Liao (2014).

Collection of bloods is an important part of the blood supply chain networks. There are some ways for collecting bloods from the donors that are divided into two main categories including temporary and permanent blood facilities. Permanent blood centers are fixed locations for donation of blood and their location aren't changed. But, temporary or mobile blood facilities don't have a defined location and usually change their locations in every period and go to the locations accessible to the donors. Other differences between these two types of collection facilities are in their capacities and their costs, such that the cost of establishing a permanent blood center is more than a temporary one, but in return its capacity and the quality and quantity of its equipment is better than temporary facilities. In overall each of them has its benefits and its harms and a best mixed of them must be selected in order to facilitate the process of collection of the bloods.

The aim of this research is to present a mathematical programming model in order to design a novel blood supply chain network such that the important problem of collecting blood from the donors is taken into account by considering three ways for collection of blood including mobile collection centers demountable collection centers as temporary facilities and main blood centers as permanent facilities. The echelons of the proposed network consist of donors, mobile collection centers, demountable collection centers, main blood centers and hospitals. The goal is to determine the number and the locations of the mobile collection units and the demountable collection centers, the optimum quantity of bloods collected at mobile collection units, the optimum quantity of bloods collected at demountable collection centers, the optimum quantity of bloods collected at main blood centers, the optimum quantity of blood products to be sent from main blood centers to hospitals, the optimum inventory of bloods at main blood centers and the optimum Shortage quantity of blood at hospitals. The objective function of the model aims to minimize the total costs of the blood supply chain network. In order to evaluate the applicability of the proposed mathematical model, a numerical example is employed. Also, some sensitivity analyses are performed by making changes on the main parameters of the proposed model in order to survey their effect on the value of the objective function.

The remainder of this paper is organized as follows. The problem description and the mathematical model are given in section 2. The performance of the solution methods is evaluated in section 3. Section 4 includes the sensitivity analyses, and finally, conclusions come in Section 5.

2. The problem

The proposed blood supply chain includes donors, mobile collection units, demountable collection centers, main blood centers and hospitals. The process of the chain is starts from donors where they decide to donate their blood. There are three ways for donating the blood including donation at mobile collection units, or demountable collection centers, or even main blood centers. Both of the mobile collection units and the demountable collection centers are temporary facilities that can change their location in every period. But they are different with each other. The mobile collection units are usually buses or coaches that can go to a location accessible to donors and change their location whenever they want and they can even change their location more than one time in a period. In many villages, towns and islands, the amounts of population are too small and constructing a permanent and main blood center is not logical and affordable. However, these areas are suitable locations for collecting blood in every country and cannot be overlooked as a source of blood donations. In these locations, using demountable collection unit can solve the problem so that all the things required for collection of bloods from the donors are transported in a truck to the location. The equipment and furniture are unloaded in an existing building and a temporary facility that is called demountable collection center is created for collection of bloods. Certainly its cost and its capacity is more than mobile collection units. After the collection of bloods by mobile collection units and demountable collection centers, they dispatch the collected bloods to the main blood centers. The main blood centers are responsible for receiving the bloods and preparing and producing the blood products from the received bloods. Finally they dispatch the blood products to the hospitals.

The above-mentioned descriptions are converted into the form of a mathematical programming model while the model has one objective function for minimizing the total costs of the blood supply chain network. The indices, parameters, and decision variables used in the proposed model are as follows:

2.1. Indices

i: index used for a donor group, $i=1,...,I$

y,j: index of candidate locations for mobile collection units, $y=1,...,Y$

c,g: index of candidate locations for demountable collection center, $c=1,...,C$

p: index used for a mobile collection unit, $p=1,…,P$

e: index used for a demountable collection center, $e=1,…,E$

m: index used for a main blood center, $m=1,…,M$

h: index used for a demand point, $h=1,…,H$

t,t' : index used for a period with a fixed length of v , $t=1,…,T$

2.2. Parameters

U_{yjpt} : Cost of moving mobile collection unit p from location j to location y in period t

cw_{cget} : Cost of moving demountable collection center e from location g to location c in period t

$MAXB_{it}$: Maximum blood supply of donor group i

uc_{ypt} : Unit operational cost of mobile collection unit p at location y in period t

udc_{cet} : Unit operational cost of demountable collection center e at location c in period t

umc_{mt} : Unit operational cost at main blood center m in period t

cmm_{ypmt} : Unit transportation cost from mobile collection unit p located at location y to main blood center m in period t

cdm_{cemt} : Unit transportation cost from demountable collection center e located at location c to main blood center m in period t

cmh_{mht} : Unit transportation cost from main blood center m to hospital h in period t

hcm_{mt} : Unit holding cost at main blood center m in period t

sc_{ht} : Unit shortage cost at hospital h in period t

ex_{ht} : Unit expiration cost of blood products at hospital h in period t

cap_p : The capacity of mobile collection unit p

cap_d : The capacity of demountable collection center e

cap_m : Storage capacity available for main blood center m to store blood in a period

dy_{iy} : Distance between donor $i$and location y

dc_{ic} : Distance between donor $i$and location c

cd : Coverage distance of blood facilities

$smh_{m,t}$: Shelf life of blood products that are sent from main blood center m to hospital h in period t

M :A reasonably large number

λ_{mt} : Failure rate of main blood center m to dispatch blood products to demand points in period t

λ_{lt} : Failure rate of local blood center l to dispatch blood products to demand points in period t

D_{ht} : Demand for blood product at hospital h in period t

2.3. Variables

X_{yjpt} : 1, if mobile collection unit p travels from location j to location y in period t, 0 otherwise

Z_{cget} : 1, if demountable collection center e travels from location g to location c in period t, 0 otherwise

O_{iypt} : 1, if mobile collection unit p located at location y is assigned to donor i in period t, 0 otherwise

B_{iect} : 1, if demountable collection center e located at location c is assigned to donor $i$in period t, 0 otherwise

NBM_{iypmt} : Quantity of blood collected at location y from donor i in period t by mobile collection unit p to dispatch to main blood center m

NDM_{icemt} : Quantity of blood collected at location c from donor i in period t by demountable collection center e to dispatch to main blood center m

NMM_{imt} : Quantity of blood collected at main blood center m from donor i in period t

$NMH_{mhtt'}$: Quantity of blood products dispatched by main center m to hospital h in period t to be used in periodt'

IM_{mt} : Inventory level of blood at main blood center m at the end of period t

S_{ht} : Shortage quantity of blood at hospital i at the end of period t

2.4. The mathematical model

$$\begin{aligned}\min F_1 = {} & \sum_{j}\sum_{y}\sum_{p}\sum_{t} U_{yjpt} X_{yjpt} + \sum_{g}\sum_{c}\sum_{e}\sum_{t} cw_{cget} Z_{cget} + \sum_{y}\sum_{p}\sum_{t} uc_{ypt} (\sum_{m} NBM_{iypmt}) \\ & + \sum_{c}\sum_{e}\sum_{t} udc_{cet} (\sum_{m} NDM_{icemt}) + \sum_{m}\sum_{t} umc_{mt} (\sum_{i}\sum_{y}\sum_{p} NBM_{iypmt} + \sum_{i}\sum_{c}\sum_{e} NDM_{icemt} + \sum_{i} NMM_{imt}) \\ & + \sum_{i}\sum_{y}\sum_{p}\sum_{m}\sum_{t} cmm_{ypmt} NBM_{iypmt} + \sum_{l}\sum_{m}\sum_{t} cdm_{cemt} NDM_{icemt} + \sum_{m}\sum_{h}\sum_{t}\sum_{t'} cmh_{mht} NMH_{mhtt'} \\ & + \sum_{m}\sum_{t} hcm_{mt} IM_{mt} + \sum_{h}\sum_{t} sc_{ht} S_{ht} + \sum_{h}\sum_{t} \mathrm{ex}_{ht} (\sum_{m} \sum_{t'>t+smh_{m,t}} NMH_{mhtt'} + \sum_{l}\sum_{t} \sum_{t'>t+slh_{l,t}} NLH_{lhtt'})\end{aligned} \tag{1}$$

Subject to:

$$\sum_{j\in Y}\sum_{p\in P} X_{yjpt} \le 1 \qquad \forall y\in Y,\ \mathrm{t}\in T \tag{2}$$

$$\sum_{j\in Y}\sum_{p\in P} X_{jypt} \le \sum_{j\in Y}\sum_{p\in P} X_{yjpt-1} \qquad \forall y\in Y,\ \mathrm{t}\in T \tag{3}$$

$$\sum_{j\in Y}\sum_{y\in Y} X_{yjpt} \le \delta \qquad \forall p\in P,\ \mathrm{t}\in T \tag{4}$$

$$\sum_{g\in C}\sum_{e\in E} Z_{cget} \le 1 \qquad \forall c\in C,\ \mathrm{t}\in T \tag{5}$$

$$\sum_{g\in C}\sum_{e\in E} Z_{gcet} \le \sum_{g\in C}\sum_{p\in P} Z_{cget-1} \qquad \forall c\in C,\ \mathrm{t}\in T \tag{6}$$

$$\sum_{g\in C}\sum_{c\in C} Z_{cget} \le 1 \qquad \forall e\in E,\ \mathrm{t}\in T \tag{7}$$

$$B_{ict} \le \sum_{g\in C}\sum_{e\in E} Z_{cget} \qquad \forall i\in I, c\in C,\ \mathrm{t}\in T \tag{8}$$

$$O_{iyt} \le \sum_{j\in Y}\sum_{p\in P} X_{yjpt} \qquad \forall i\in I, y\in Y,\ \mathrm{t}\in T \tag{9}$$

$$\sum_{j\in Y}\sum_{p\in P}\sum_{t=a}^{a+n} X_{yjpt} \le 1 \qquad \forall y\in Y,\ a=1,2,\ldots,T-n \tag{10}$$

$$\sum_{j\in Y}\sum_{p\in P}\sum_{t=T-n+a}^{T} X_{yjpt} \le 1 \qquad \forall y\in Y,\ a=1,2,\ldots,n-1 \tag{11}$$

$$\sum_{g\in C}\sum_{e\in E}\sum_{t=a}^{a+r} Z_{cget} \le 1 \qquad \forall c\in C,\ a=1,2,\ldots,T-r \tag{12}$$

$$\sum_{g\in C}\sum_{e\in E}\sum_{t=T-r+a}^{T} Z_{cget} \le 1 \qquad \forall c\in C,\ a=1,2,\ldots,r-1 \tag{13}$$

$$NBM_{iypmt} \le M.O_{iypt} \qquad \forall y\in Y, i\in I, p\in P, m\in M, t\in T \tag{14}$$

$$NDM_{icemt} \le M.B_{icet} \qquad \forall c\in C, i\in I, e\in E, m\in M, t\in T \tag{15}$$

$$dy_{iy}.O_{iypt} \le cd \qquad \forall i\in I, y\in Y,\ \mathrm{p}\in P, \mathrm{t}\in T \tag{16}$$

$$dc_{ic}.\mathrm{B}_{icet} \le cd \qquad \forall i\in I, \mathrm{c}\in C, e\in E, \mathrm{t}\in T \tag{17}$$

$$\sum_{y}\sum_{p}\sum_{m}\sum_{t} NBM_{iypmt} + \sum_{c}\sum_{e}\sum_{m}\sum_{t} NDM_{icemt} + \sum_{m}\sum_{t} NMM_{imt} \le MAXB_{it} \qquad \forall \mathrm{i} \tag{18}$$

$$IM_{mt} = IM_{mt-1} + (\sum_{i}\sum_{y}\sum_{p} NBM_{iypmt} + \sum_{i}\sum_{c}\sum_{e} NDM_{icemt} + \sum_{i} NMM_{imt}) - \sum_{h}\sum_{t'} NMH_{mhtt'} \tag{19}$$

$$S_{\mathrm{h,t}} = S_{\mathrm{h},t-1} + D_{ht} - (\sum_{m} \sum_{t-smh^{k}_{mt'} \le t' \le t} NMH_{mht't}) \quad \forall h\in H,\ \mathrm{t}\in T \tag{20}$$

$$IM_{mt} \leq cap_m \qquad \forall m \in M,\ t \in T \tag{21}$$

$$\sum_i \sum_y \sum_m NBM_{iypmt} \leq cap_p \qquad \forall\ p \in P, t \in T \tag{22}$$

$$\sum_i \sum_c \sum_m NDM_{icemt} \leq cap_d \qquad \forall\ e \in E, t \in T \tag{23}$$

$$NBM_{iypmt}, NDM_{icemt}, NMM_{imt}, S_{ht}, NMH_{mhtt'}, IM_{mt} \geq 0 \tag{24}$$

$$X_{yjpt}, O_{iypt}, Z_{cget}, B_{icet} \in \{0,1\} \tag{25}$$

The objective function of the model shown in Eq. (1) aims to minimize the total cost of the blood supply chain network. The components of the objective function include the cost of moving mobile collection units from a location to another one, the cost of moving demountable collection centers from a location to another one, the operational cost at mobile collection centers, the operational cost at demountable collection centers, the operational cost at main blood centers, the transportation cost of bloods from mobile collection units to main blood centers, the transportation cost of bloods from demountable collection units to main blood centers, the transportation cost of blood products from main blood centers to hospitals, the inventory holding cost of the bloods in main blood centers, the shortage cost of demand points and the cost of expired blood products respectively from left to right. Eq. (2) states that each location doesn't accept more than one mobile collection unit. As mentioned earlier, the mobile collection units travel from a location to another one in every period. But they can't travel from a location where they have not been located there to another. Eq. (3) expresses this subject. Eq. (4) specifies that a mobile collection unit can visit at most δ number of locations in every period. Eq. (5) states that at most one demountable collection center can be located in a location. Eq. (6) enforces that the demountable collection centers can't travel from a location where they have not been located there to another. Eq. (7) expresses that a demountable collection center can visit at most one location in every period. Eqs. (8) and (9) restrict donors to go to the vacant locations. Whenever a donation location is visited by a mobile collection unit or a demountable collection center, it is better that the subsequent visits occur at least n days (for mobile collection units) and r days (for demountable collection centers) after the previous visit constraints in Eqs. (10)- (13) are related to this subject (Eqs. (10) and (11) are for mobile collection units and Eqs. (12) and (13) are for demountable collection centers). Eqs (14) and (15) assure that the bloods can't be transported from the locations that there are no collection facilities in them. The mobile collection units and the demountable collection centers can't serve and collect the bloods of the donors that are so far from them the constraint related to this fact are shown in Eqs. (16) and (17). The capacity of each donor group for donating blood is clarified in Eq. (18). The inventory of the bloods at main blood centers in every period is calculated by Eq. (19). Also Eq. (20) is a balance equation for calculating the shortages of the demands. Eqs. (21), (22) and (23) respectively clarify the capacity of main blood centers, mobile collection units and demountable collection centers. Finally the binary and non-negativity constraints on decision variables are presented in Eqs. (24) and (25).

3. Evaluation of the model

In the following and in order to evaluate the applicability of the proposed blood supply chain network, a numerical example is presented in this section.

3.1. Example

Consider a blood supply chain network with 4 main blood centers. Also, there are 9 mobile collection units and 4 demountable collection centers that the decision makers of the network can select best combination of them in order to optimize the activities of the network for supplying the needs of 20 hospitals. The model is evaluated in 60 time periods (days). Although the mathematical model can be adopted for any types of blood products, because of high perishability of the Platelet, in this example the Platelet is selected for surveying. The shelf life of the Platelet is very low compared to the other blood products like Red Blood Cell or Plasma and its shelf life is up to 5 days. In this example the shelf life of the Platelet is considered as a uniform distribution between 2 and 5 days. Also the values of the other parameters of the mathematical model are randomly generated using uniform distributions presented in Table 1. The example is solved on a laptop with core (TM) i5, 2.40 GHz, RAM 4 Mb using GAMS 24.7.3 software.

The results of implementing the example are shown in Tables 2 that contains the number of mobile collection units and the number of demountable collection centres used in every period, also the total cost of the supply chain network.

Table 1. Parameters values

Parameter	Value	Parameter	Value
U_{yjpt}	(500,900)	ex_{ht}	(6,9)
cw_{cget}	(2500,5200)	hcm_{mt}	(1.5,3)
uc_{ypt}	(3,6)	D_{ht}	(100,700)
udc_{cet}	(3,10)	cap_p	(300,500)
umc_{mt}	(3,14)	cap_e	(1000,2000)
cmm_{ypmt}	(1,3)	cap_m	(4000,6000)
cdm_{cemt}	(1,5)	dy_{iy}	(50,500)
$MAXB_{it}$	(1000,4000)	dc_{ic}	(700,2000)
cmh_{mht}	(2,7)	cdm	(50,300)
sc_{ht}	(6,9)	cdd	(700,1800)

Table2. Results of the numerical example

Period	MBF	DCC	Period	MBF	DCC	Period	MBF	DCC	Period	MBF	DCC
1	5	1	16	4	0	31	3	0	46	3	1
2	3	2	17	3	1	32	2	2	47	2	2
3	6	1	18	4	1	33	4	1	48	5	1
4	2	3	19	5	0	34	2	1	49	4	1
5	4	0	20	1	3	35	5	0	50	3	2
6	0	3	21	5	1	36	1	3	51	4	0
7	4	2	22	2	2	37	4	1	52	1	3
8	2	3	23	3	1	38	6	1	53	3	2
9	1	3	24	4	1	39	0	3	54	4	1
10	4	2	25	6	0	40	3	2	55	2	2
11	3	2	26	3	2	41	2	2	56	5	0
12	2	2	27	4	1	42	4	0	57	0	3
13	5	0	28	1	3	43	1	2	58	3	1
14	3	1	29	3	0	44	3	2	59	5	1
15	2	3	30	3	1	45	2	2	60	1	3
Total Costs of the network: 99457328											

4. Sensitivity analyses

In order to specify the response of the value of the objective function toward making changes in the values of the main parameters of the proposed mathematical model, sensitivity analyses are carried out in this section. For this purpose, main parameters of the model including parameters $MAXB_{it}$, cap_p, cap_d, cap_m, cd, and D_{ht} are selected and the changes are carried out at rates of -50%, -25%, +25%, and +50%. The results of performing these sensitivity analyses are shown in Table3 and Figure1.

The results indicate that there are a reverse relation between the value of the objective function and the parameters $MAXB_{it}$, cap_p, cap_d, cap_m, and cd. Such that, decrement of these parameters leads to an increment in the value of the objective function and a growth in their amount, causes a decrement in the value of the objective function. Also, the results of performing the sensitivity analysis on the parameter D_{ht}, indicate the direct relation of this parameter with the value of the objective function. Such that, decrease of this parameter decreases in the value of the objective function and its increase, increases the value of the objective function. It should be mentioned that, the value of the objective function is more sensitive to the changes in the parameters $MAXB_{it}$ and D_{ht} rather than the other parameters of the model.

Table 3. Results of the sensitivity analyses

Parameter	Change (%)	objective function	Parameter	Change (%)	objective function
$MAXB_{it}$	-50	189,832,157	Cap_m	-50	179,422,834
	-25	139,543,849		-25	133,745,264
	0	99,457,328		0	99,457,328
	25	64,638,369		25	85,352,246
	50	55,249,535		50	77,136,899
cap_p	-50	153,652,843	cd	-50	173,625,378
	-25	110,254,920		-25	125,429,934
	0	99,457,328		0	99,457,328
	25	90,457,392		25	73,267,571
	50	84,862,956		50	73,267,571
cap_d	-50	165,638,266	D_{ht}	-50	68,381,278
	-25	126,835,547		-25	74,472,951
	0	99,457,328		0	99,457,328
	25	93,442,728		25	135,633,672
	50	87,275,146		50	192,841,723

5. Conclusion

This research presented a novel mathematical model for designing a blood supply chain network. This network consisted of three main echelons including donors, collection facilities and demand points. At the collection echelon, three types of facilities were considered for receiving the bloods from the donors: main blood centers, demountable collection centers, and mobile blood facilities. Demountable collection centers, and mobile blood facilities were considered as mobile facilities that don’t have a permanent location and always move from a location to another one for collecting the bloods from the donors. The differences between demountable collection centers and mobile blood facilities were in their capacity and costs and also the number of locations that each of them can visit in every period. The main blood centers were responsible for receiving bloods, producing blood products and finally sending them to the demand points. A numerical example was used in order to evaluate the applicability of the proposed model. The results of the numerical example, demonstrated the optimal number of the demountable collection centers and mobile blood facilities that must be adopted in every period of the planning horizon. Also, the optimal cost of adopting these collection centers in the proposed blood supply chain network was calculated. At the end, some sensitivity analyses were performed by making changes on the main parameters of the proposed model in order to survey their effect on the value of the objective function. The results of these sensitivity analyses indicated a reverse relation between must of the selected parameters of the mathematical model and the value of the objective function.

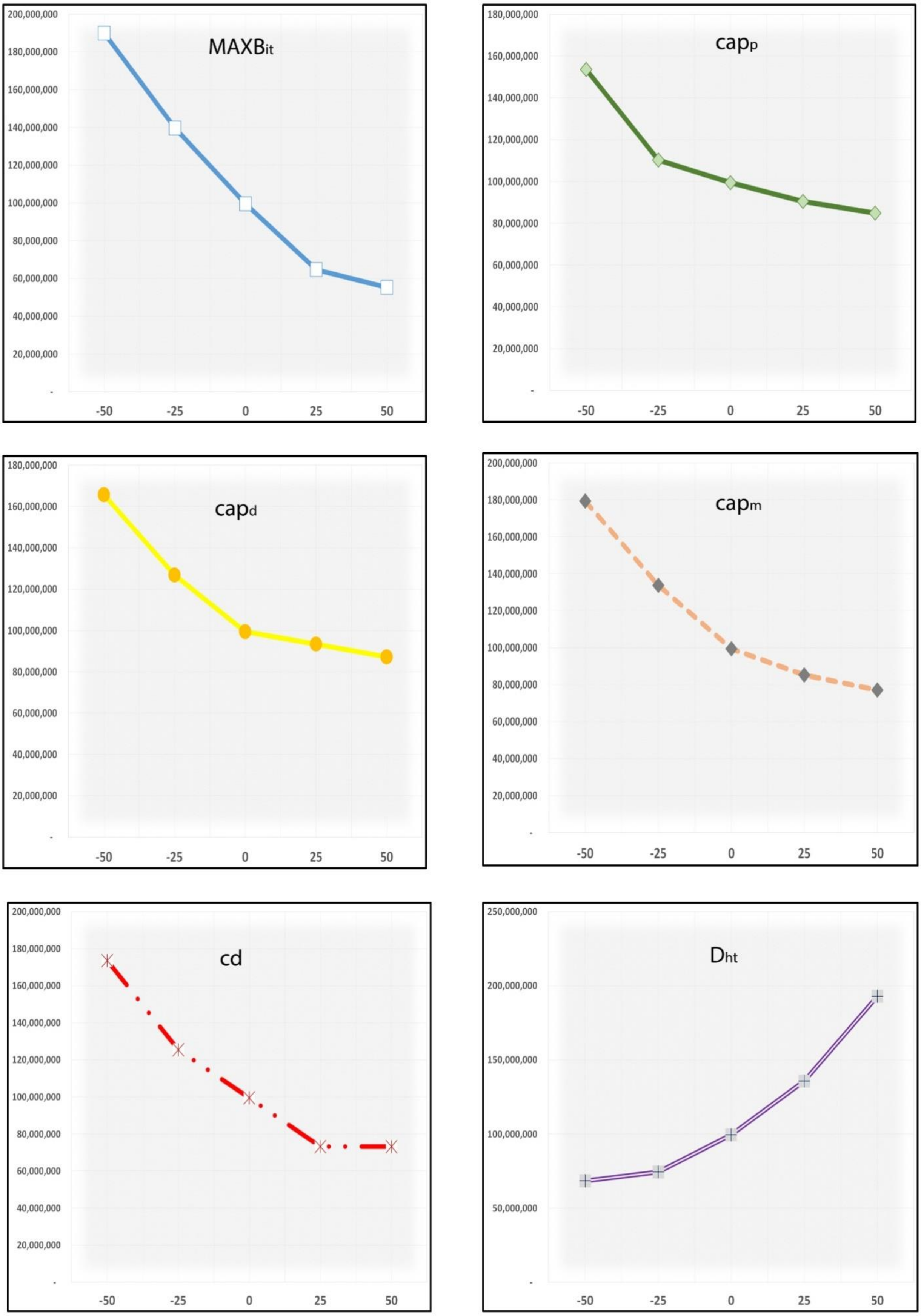

Figure 1. Results of the sensitivity analyses

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