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INVENTORY RELIEF CHAIN MODEL WITH DETERIORATION AND DISPOSAL OF RELIEF COMMODITY

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Abstract: Our environment can be hit by disasters such as earthquake, flood, tornadoes, hurricanes, etc., and if any happens, organizations (private or government) start to provide facilities for evacuation and supply of relief commodities in the affected regions. This paper formulates an inventory-relief-chain (IRC) model with the relief supply chain for the relief commodity distribution. The results of the model provide the optimal number of intermediate distribution and relief centers. However, in the study, every center is considered to distribute relief commodities. The model is formulated with a core objective to optimize the total cost of the relief operation. An algorithm is proposed to find the optimal solution of the model. Furthermore, a numerical analysis is carried out on a numerical example to validate the efficiency of the algorithm. The sensitivity analysis is done over the optimal solution and the respective parameters of the model, at the same time representing the strength of the model,i.e., the extent these parameters are sensitive to the objective. The model can help relief organizations when managing relief supplies to the disaster areas.

Keywords: Inventory Relief Chain, Deterioration, Disposal, Humanitarian Operation.

MSC: 90B05, 90B06, 90C11.

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1. INTRODUCTION

Nowadays, the researchers and practitioners are taking an interest in the area of disaster relief supply chain because the number of natural calamities has increased rapidly during the last decade. According to a U.N.'s report, more than 600,000 people died and near 4 billion were injured or became homeless between 1995 - 2015. In 2004 and 2011, the Indian Ocean's tsunami and Japan's earthquake and tsunami occurred and caused great losses. In the last two decades, the total number of natural disasters occurance is 7474, which caused financial damage of around 2400 billion USD ($). Figure 1 represents the analysis related to the occurrence of natural disasters and the respective financial damage during the span of the last two decades, showing their increas from year to year.

The supply chain and the relief supply chain both work in a similar manner. The supply chain consists of steps that move and transform raw material into the finished product and make it available to the customers. Its key elements are suppliers, producers, warehouses, distribution centers, distributors, and retailers. In a supply chain, the supply sources are centralized and demand is generated from different source points. In contrast, in the relief supply chain, the demand is generated at the affected areas and the supply comes from different sources. The difference between a supply chain and a relief-chain is represented in Figure 2 and Figure 3, where demand and supply patterns of any product in both the situations are presented.

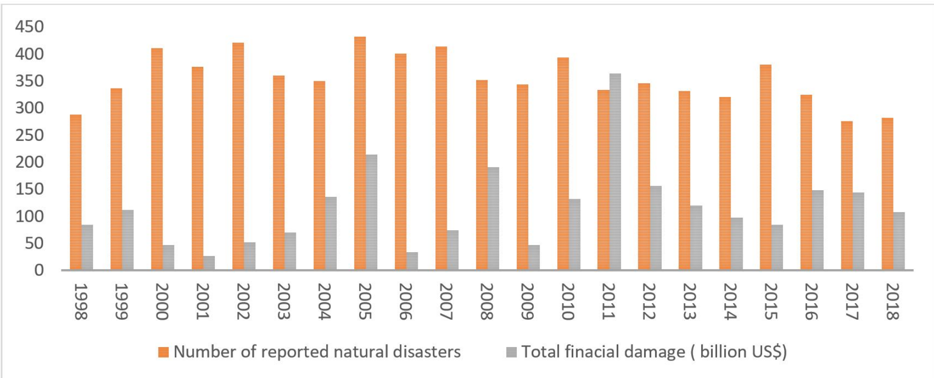

Figure 1: Total reported disasters and financial damage (1988-2018) (Source: EMDAT (2019)

It was found that the role of relief chain during natural disasters have a major concern amongst academicians and researchers from different related areas, such as Social Sciences, Industrial Engineering, Operations research, and many more (Kovàcs and Spens[1]). So, coordination of a relief supply chain (RSC) elements after the impact of a disaster is the most important and challenging effort, allied with the prompt response. Since every natural disaster is highly unpredictable so is the information about the demand for relief commodities. In this situation, the contributions of relief organizations (Government or non-government) are uncertain (Kovàcs and Spens [1]; Murray [2]) and the relief supplies collected and transported to disaster-affected locations for distribution (Hu et al. [3]) are mostly based on decisions of procurement aftermath a calamity if there is a shortage of relief supplies.

It is well known that disasters are extremely unpredictable, so the demand for relief commodities during a disaster is always uncertain because it is not possible to know in advance its location, occurrence time, impact, and strength. There is a need for maintaining an adequate inventory at highly predicted locations, and prompt reactions of facility provider to overcome the demand uncertainty. In such uncertain situations, the inventory holding cost is much higher than the usual (Balcik and Beamon [4]). If the relief commodities are unavailable in an adequate quantity at predicted locations, dependency only on post-disaster relief supplies cannot fulfill the requirement, leading to shortages of relief commodities. On the other hand, pre-disaster inventory planning provides a safety time for the supplier to produce relief commodities.Integrating inventory policies for pre-disaster and procurement policies for post-disaster are helpful in reducing the overstock of relief commodities. Therefore, the integrated decision on deciding about the inventory for pre-disaster and production for post-disaster is advantageous in fast-tracking responses of relief operations and will lead to inventory cost savings (Hu et al. [3]).

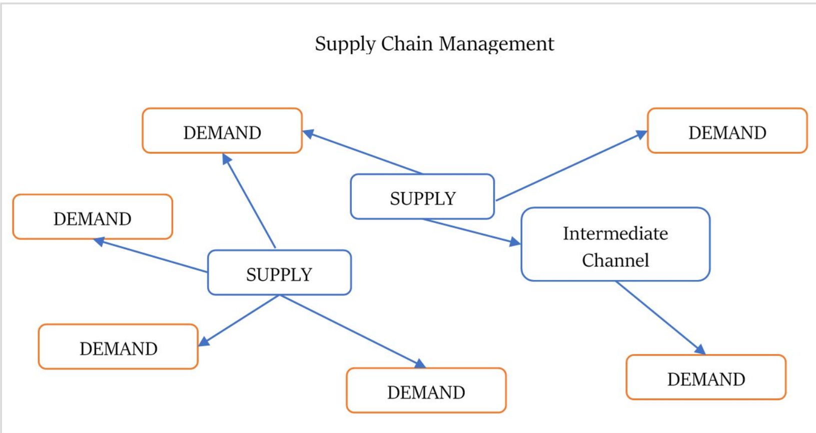

Figure 2: Supply chain management - Flow of goods and position of supply and demand points

1.1. ***Contribution of the study***

Briefly, the key contributions of our study dedicated to RSC are: Firstly, it proposes a new integrated inventory-relief-chain model for relief center (RC) assignment, inventory policy, and the dispersal of relief commodities from the central distribution center (CDC) to the RCs through the intermediate regional distribution centers (RDCs). Secondly, it considers two different real-life scenarios for

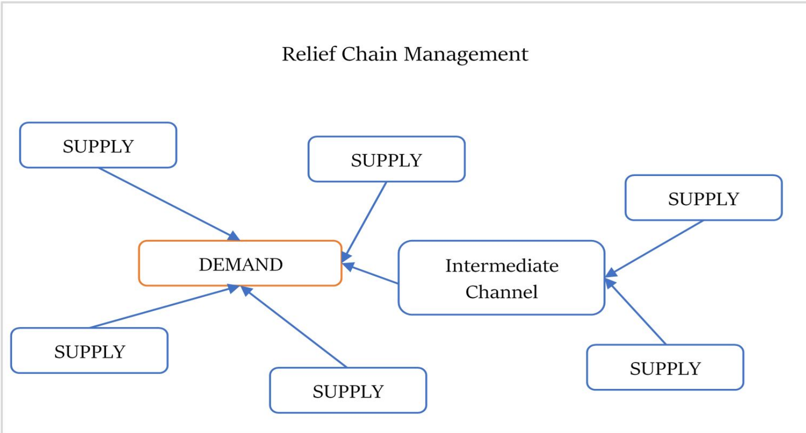

Figure 3: Relief chain management - Flow of goods and position of supply and demand points

RC assignment to distribute relief commodity. The third is in considering the fixed deterioration of relief commodities and their disposal with a finite disposal charge. This research article and its proposed methodology can assist policy-makers of inventory-relief-chain by providing suitable outcomes concerning the strategic problems in the preparation of a disaster.

1.2. ***Organization of the paper***

The remaining part of the paper is given in the upcoming sections and sub-sections. The most relevant literature with different related perspectives is inspected in second 2. The inventory-relief-chain problem is described along with the assumptions and notations in Section 3. In Section 4, the experimental design is presented. The numerical computation, interpretation of results and the related sensitivity analyses are presented in section 5. Finally, the conclusion and future research directions are suggested in section 6.

2. LITERATURE REVIEW

Humanitarian relief chain management can be described as if consisted of four different phases: the first is mitigation phase, which refers to reducing the severity and seriousness of a desaster event; the second is preparedness phase, refering to preparation for the disaster; the third is the response, immediate actions are taken aftermath disaster; and the last is recovery phase, the time nedeed for recovering to original natural conditions (Altay and Green [5]). The count of RSC research outputs have increased significantly since past ten years in the light of the growing occurrence of natural disasters across the world. Altay and Green [5] reviewed a number of manuscripts in which most of the relief chain studies are related to logistics area. Authors pointed out that only 12% of the research articles discussed about natural disasters. Baskaya et al. [6] proposed an integrated model for transportation decisions with facility location including lateral transshipments. An inventory control of perishable goods for longer duration relief operations is discussed by Ferreira et al. [7]. They used a Markov-Decision-Process (MDP) to optimize the inventory problem.

Moreover, Balcik and Kundakcioglu [8] presented a literature survey and the analysis on inventory planning in RSC, focusing on papers that discussed pre-disaster and post-disaster inventory control. Tavana, et al. [9] examined a location-inventory-routing disaster relief chain problem with pre- and post-relief operation and proposed a mixed integer model. Habib, Lee and Memon [10] surveyed the research that studied optimization models for relief distribution, evacuation, facility location, and related problems. Döyen, et al. [11] presented a two-stage stochastic mathematical modeling with an objective to determine pre-disaster relief centers, and post-disaster relief locations. Zanganeh et al. [12] discussed a humanitarian logistics network design by proposing a bi-objective mixed integer linear programming with the objective to maximize the lifesaving utility. Chakravarty [13] studied joint optimization of pre-positioning of stock and quick response with spontaneous delivery. They presented rapid response model by incorporating delivery time for demand supply and logistics cost. Rezaei-Malek et al. [14] developed an original integrated optimization model to calculate the optimized apportioning of location and strategy for distribution. A brief literature review is provided in Table 1 related to inventory-relief-chain with research articles and their objectives. In the presented literature review table, the work done is grouped according to the key concepts of the inventory relief chain.

Table 1: A systemic tabular literature review related to inventory-relief-chain area.

Research article	**Objective**	**Ordering**		**Holding**	**Shortages**	**Facility**	**Transpo-rtation**	**Disposal**
		fixed	**Variable**					
Beamon and Kotleba [15]	Min.	Y		Y	Y			
Das and Hanaoka [16]	Min.	Y	Y		Y			
Davis et al. [17]	Min.				Y		Y	
Hu et al. [3]	Min.	Y		Y			Y	
Lodree [18]	Min.	Y		Y				
Lodree and Taskin[19]	Min.	Y		Y	Y			
McCoy and Brandeau [20]	Min.			Y			Y	
Natarajan and Swaminathan [21]	Min.	Y		Y				
Ozbay and Ozguven [22]	Min.			Y	Y			
Ozguven and Ozbay [23]	Min.			Y	Y			
Pacheco and Batta [24]	Min.				Y	Y	Y	Y
Rabbani et al. [25]	Min.			Y	Y		Y	Y
Rawls and Turnquist [26]	Min.			Y	Y	Y	Y	
Roni et al. [27]	Min.	Y		Y	Y			
Roni et al. [28]	Min.	Y		Y	Y			
Rottkemper et al. [29]	Min.	Y			Y	Y	Y	
Salas et al. [30]	Min.		Y	Y	Y			Y
Shen et al. [31]	Min.	Y		Y				
Taskin and Lodree [32]	Min.		Y	Y	Y			
Yadavalli et al. [33]	Min.			Y	Y			
Proposed paper	Min.	Y		Y	Y	Y	Y	Y

3. PROBLEM DESCRIPTION, ASSUMPTIONS, AND NOTATIONS

The proposed problem is considered as delivering the relief commodities to ultimate beneficiaries at the disaster location. The model is based on assumptions and notations described in the following sub sections.

3.1. ***Assumptions***

The developed mathematical model for inventory control relief item with RSC is formulated under consideration of the following assumptions:

1. Each distribution center distributes only relief commodity (a single bundled commodity). The relief commodity is the same for all DCs and consumable and perishable (such as food, milk, bread). Hong et al. [34] assume that several emergency products (i.e. blankets, tents, kitchen sets) are bundled into a standard kit.

2. CDC is assumed as an initial distribution center for relief commodity distribution. The commodities shipment is considered from CDC to RDC and then RDC to RC, direct shipment is not possible from origin to RC.
3. The fractional assignment of commodity is not allowed, the demand of every RC must be satisfied from any open DC.
4. Each DC has enough storage capacity to fulfill the demand from the connected facility centers.
5. In the model formulation negligible lead time is considered with instantaneous replenishment.
6. For the distribution process of relief commodities, there is a need to consider the distribution centers and relief centers; and these facility centers have operational cost. Therefore, there is a fixed budget for the operational cost of the facility centers. The maximum numbers of the distribution centers are fixed.
7. $D_{oi} = \begin{cases} 1 & \text{If RDC is in operation} \\ 0 & \text{Otherwise} \end{cases}$ and $R_{oi} = \begin{cases} 1 & \text{if , If RC is in operation} \\ 0 & \text{Otherwise} \end{cases}$
8. $Y_{oi} = \begin{cases} 1 & \text{If RDC } i \text{ is assigned to CDC} \\ 0 & \text{Otherwise} \end{cases}$ and

   $Y_{ij} = \begin{cases} 1 & \text{If RC } i \text{ is assigned to RDC} \\ 0 & \text{Otherwise} \end{cases}$

3.2. ***Notations***

The following indices are utilized to represent the mathematical formulation

Indices	***Definition***
i	index of reginal distribution center, $i = 1, 2, 3, \ldots\ldots m$
j	index of reginal center, $j = 1, 2, 3, \ldots\ldots n$
o	index of only central distribution center

The following parameters are considered to represent the mathematical model

Parameter	***Definition***
c_{oi}	Shipping cost of a commodities from CDC o to DC $i, i = 1, 2, 3, \ldots\ldots m$
c_{ij}	Shipping cost of a commodities from RDC $i, (i = 1, 2, 3, \ldots\ldots m)$ to RC $j, j = 1, 2, 3, \ldots\ldots n$
C	Unit cost of the commodity
h_o	Holding cost for CDC center
h_{di}	Holding cost for Regional distribution center $i, i = 1, 2, 3, \ldots\ldots m$
Q_o	Order size of the relief commodity for CDC
Q_{Di}	Order size of the relief commodity for RDC i
Q_Rj	Order size of the relief commodity RC j
ρ	Deterioration rate of perishable commodities
C_d	Disposal charge for deteriorated commodities
O_{Di}	Operational cost of RDC $i, i = 1, 2, 3, \ldots\ldots m$
O_{Rj}	Operational cost of RC $j, j = 1, 2, 3, \ldots\ldots n$
D_{min}	Minimum number of RDC
D_{max}	Maximum number of RDC
R_{min}	Minimum number of RC
R_{max}	Maximum number of RC
x_{oi}	Quantity of commodity shipped from CDC o to RDC $i, i = 1, 2, 3, \ldots\ldots m$
x_{ij}	Quantity of commodity shipped from RDC i to RC $j; i = 1, 2, 3, \ldots\ldots m, j = 1, 2, 3, \ldots\ldots n$
D_{0i}	A $(0, 1)$ variable that produces to 1 if DRC i is in operation otherwise 0
R_{0j}	A $(0, 1)$ variable that produces to 1 if RC j is in operation otherwise 0
Y_{0i}	A $(0, 1)$ variable that produces to 1 if DRC i is assigned to CDC to supply relief commodities otherwise 0
Y_{ij}	A $(0, 1)$ variable that produces to 1 if RC j is assigned to RDC i to supply relief commodities otherwise 0

3.3. Model formulation

The considered problem is related to inventory-relief-chain for the distribution of relief products. The inventory is held in the central distribution center to distribute among relief centers. The distribution of relief products initiated by a central distribution center to different relief centers through some regional distribution centers is considered.

A mathematical model is considered to optimize the total operational cost of the discussed problem. This model incorporates the inventory system cost with distribution cost for the relief supply chain. In the past, very few authors contributed to inventory and distribution problem in the field of relief operations.

Objective function

$$Min(TC) = \left\{ \sum_{i=1}^{m} c_{oi}x_{oi} + \sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij}x_{ij} \right\} + \left\{ \sum_{i=1}^{m} O_{Di}D_{oi} + \sum_{j=1}^{n} O_{Rj}R_{oj} \right\} + ISC \tag{1}$$

where

$$\begin{aligned} ISC = &\left\{ A_o + \sum_{i=1}^{m} A_i D_{oi} + \sum_{j=1}^{n} R_{oj} nA \right\} + \left\{ h_o Q_o + \sum_{i=1}^{m} h_i Q_{Di} D_{oi} \right\} + cQ_o \\ &+ \left\{ C_d \rho Q_o + \sum_{i=1}^{m} D_{oi} C_d \rho Q_{Di} \right\} \end{aligned} \tag{2}$$

Subject to

$$D_{min} \leq \sum_{i=1}^{m} A_i D_{oi} \leq D_{max} \tag{3}$$

$$R_{min} \leq \sum_{j=1}^{n} D_{oi} \leq R_{max} \tag{4}$$

$$\sum_{i=1}^{m} x_{oi} \leq Q_o(1-\rho) \tag{5}$$

$$\sum_{i=1}^{m} x_{oi} \leq \sum_{i=1}^{m} x_{ij} \leq \sum_{i=1}^{m} Q_{Di}(1-\rho) \quad \forall j \tag{6}$$

$$R_{min} \leq \sum_{j=1}^{n} D_{oi} \geq R_{max} \tag{7}$$

$$x_{oi} \geq Q_{Di} \tag{8}$$

$$\sum_{i=1}^{m} Q_{Di} \geq \sum_{i=1}^{m} Q_{Di}(1-\rho) \geq \sum_{j=1}^{n} Q_{Rj} \tag{9}$$

$$\sum_{i=1}^{m} O_{Di} D_{oi} + \sum_{j=1}^{n} O_{Rj} R_{oj} \leq B \tag{10}$$

$$\sum_{i=1}^{m} D_{oi} Y_{oi} \leq 1 \tag{11}$$

$$\sum_{i=1}^{m} D_{oi} R_{oj} Y_{ij} \leq 1 \quad j = 1, 2, 3, ...n \tag{12}$$

$$\sum_{j=1}^{n} x_{oj} = 0 \tag{13}$$

$$Y_{oi} \leq 1 \quad j = 1, 2, 3, ...n \tag{14}$$

$$x_{oi} \geq 0; \quad x_{ij} \geq 0; \quad m \leq n; \quad O_{Rj} \leq O_{Di} \tag{15}$$

The main objective presented in equation (1) is to minimize the total cost incurred in the relief chain operation. The total cost involves the shipping cost of the commodity from source to destination center, the operational cost of the opened facility centers, and inventory system related costs. The inventory system costs (2) capture the fixed cost of placing orders for different facility centers, purchasing cost of the commodity to maintain the inventory level, inventory holding cost for the central distribution center and the regional distribution center, and disposal cost for the deteriorated inventory. It is notable that the transportation cost is considered as linear in nature, which is a function of distance between two facility centers. Constraints (3) and (4) ensure the maximum and minimum RDCs and RCs to be opened for the distribution process. For the optimization problem, the total number of RDCs is lesser than the number of RCs and in the contrast, the operational cost of RDC is always greater than the RC (15). The constraints (5)

– (7) ensure the demand for destination centers (RDC or RC), which is always equal or less than the supplied quantity. Constraint (8) represents the total order quantity of RCs that cannot exceed the order quantity of RDCs. The operational cost budget const is defined with constraint (9). The constraints (10) and (11) make limitation for RDC, as assigned to CDC or not and a RC is assigned to a RDC or not, respectively. The constraints (12) and (13) ensure that every RC and RDC is assigned to a particular RDC and CDC respectively for fulfilling their demand. The constraint (14) defines the non-negativity constraint and relationship between the number of RDC and RC, so as the operational cost of RDC and RC.

4. EXPERIMENTAL DESIGN

In this section, the features of the problems are described, and the computations are done by LINGO 15.0. The computed results are presented in tables 2 - 11, where experiments are examined for many combinations of the model parameters and their different values associated with distribution and inventory system costs. The reason why these data inputs are selected is to present significant variation between distribution, inventory, and disposal costs.

A simple numerical experiment is taken to give a clear explanation of the mathematical problem. In the experiment, a single ($i = 1$) central distribution is considered where all the supply of relief commodity is collected and further distributed to relief centers through some regonal distribution centers. To make the problem simpler, here three RDCs ($m = 3; j = 1, 2, 3$) and five RCs ($n = 5; k = 1, 2, 3, 4, 5$) are considered. A pictorial distribution plan is represented in Figure 4, which shows the possible transportation channels between the source and the destination.

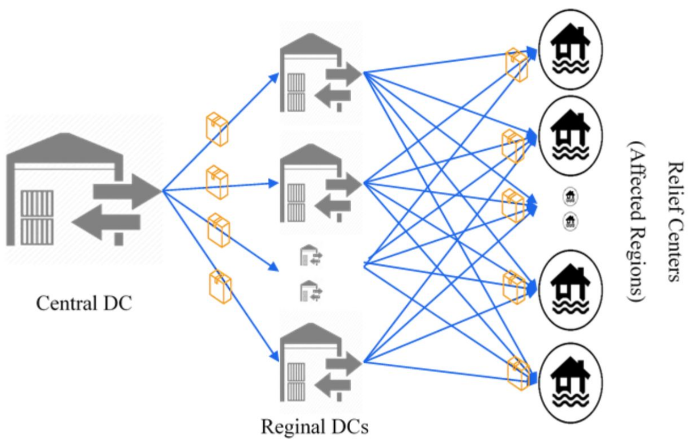

Figure 4: Representation of the distribution of the relief commodity.

5. COMPUTATIONAL RESULT AND ANALYSIS

Tables 2 - 9 summarize the computational results of the experiments where several combinations of the parameters and their different values associated with distribution and inventory system costs were done. We selected these data to present significant variation between distribution, inventory and disposal costs.

*5.1. **Numerical Example***

This sub section presents the solution of our numerical example. The example is solved by LINGO 15.0 using solver type Branch and Bound for class INLP problem. The followings values are taken as the input of their respective parameters. The data values are presented in Tables 2 - 6 and the optimal results are shown in Table 8 and Table 9. The optimal values are computed through by comprehensively taken several trials of data values. These optimal values contribute to minimize total relief operational cost of distributing relief commodities.

Table 2: Different cost associated with shipping, ordering, and holding w. r. t. their center.

Shipping Charges (CDC to RDC)					Ordering Cost					Holding Charges				
c_{oi}	0	1	2	3	c_{ij}	0	1	2	3		0	1	2	3
o	0	50	30	60	A	60	30	40	35	h	10	3	4	5

Table 3: Different operational charges for respective centers.

Operational Charges				Operational Cost					
	1	2	3	0	1	2	3	4	5
OD	500	550	420	OR	450	400	400	400	350

Table 4: Quantity and demand values of different respective distributions and relief centers.

Quantity at centers					Demand at centers					
	0	1	2	3		1	2	3	4	5
Q	4200	1450	1220	1010	D	560	600	900	500	750

Table 5: Shipping charge for shipment of goods between reginal distribution centers to relief centers.

Shipping Charges (RDC to RC)					
C_{ij}	1	2	3	4	5
1	3	4	2	3	2
2	1.5	2	2	5	3
3	3	2	3	3	3.5

Table 6: Shipping charge for shipment of goods between reginal distribution centers to relief centers.

Parameter	C	A	ρ	C_d	D_{min}	D_{max}	R_{min}	R_{max}	m	n
Value	60	20	0.1	10	1	3	1	5	3	5

Table 7: Minimum optimal values of total cost, holding cost, disposal cost, and inventory system cost.

Cost	TC	HC	D_pC	ISC
Value	462605	28140	4200	284495

Table 8: Maximum optimal value of commodity distributed from central to reginal distribution centers.

Shipping Charges (RDC to RC)				
x_{0i}	0	1	2	3
0	0	1450	1220	1010

Table 9: Maximum optimal value of commodity distributed from reginal distribution centers to relief centers.

Shipping Charges (RDC to RC)					
x_{ij}	1	2	3	4	5
1	0	0	900	0	405
2	560	193	0	0	345
3	0	407	0	500	0

Table 7 shows optimal values of the total cost, holding cost, disposal cost, and inventory system cost corresponding to the developed model. Table 8 and

Table 9 show the optimal values of decision variable quantity shipped from one source to another source. In the distribution of relief commodity from RDC to RC some variables have zero value, which means that there is no shipment happened between the sources. In some cases, the requirement is fulfilled with single source but in case of RC $j = 2$ and 5, the relief commodity is received from two reginal distribution centers. i.e., so to optimize the distribution cost and to utilize the requirement and supply.

5.2. ***Sensitivity Analysis***

This sub section presents the sensitivity analysis of the numerical example, used to study the impact of input parameters on the optimal values of the holding cost, disposal cost, inventory system cost, and the complete cost of the inventory relief chain system. The percentage changes are considered as measures of sensitivity over the computational parameters. The sensitivity analysis is exercised by changing the parameters, increasing +10 to +20 and decreasing -10 to -20, respectively. In the computation of sensitivity only one parameter is changed, the rest are untouched. The sensitivity outcomes are presented in Table 10 and Table 11.

Table 10: Sensitivity analysis w. r. t. different holding cost for the numerical example.

Parameter	% change	HC	ISC	TC
$h_0 = 10$	+20	32340	288695	466805
	+10	30240	286595	464705
	-10	26040	282395	460505
	-20	23940	280295	458405
$h_{D1} = 3$	+20	24375	280730	458840
	+10	24157	280512	458622
	-10	23722	280077	458187
	-20	23505	279860	457970
$h_{D2} = 4$	+20	28628	284983	463093
	+10	28384	284739	462849
	-10	27896	284251	462361
	-20	27652	284007	462117
$h_{D3} = 5$	+20	28645	285000	463110
	+10	28392	284747	462857
	-10	27887	284242	462352
	-20	27635	283990	462100

By considering the above results in Table 10, the following observations could be mentioned:

- The table shows that with the increase in the value of the holding cost of central distribution center, the total holding cost, inventory system cost, and the total cost increase. Further, it can also be observed that with the decrease in the charge of the holding of CDC, the total holding cost, inventory system cost, and the total cost decrease.
- Similarly can be concluded that with the increase in the value of holding cost of reginal distribution centers, the total holding cost, inventory system cost, and total cost increase, and if holding cost of RDCs decreases, the total HC, ISC, and TC also decrease.

Table 11: Sensitivity analysis w. r. t. parameters of deterioration rate and disposal cost.

Parameter	% change	D_pC	ISC	TC
$\rho = 0.1$	+20	-	-	-
	+10	-	-	-
	-10	3780	284075	462185
	-20	3360	283655	461765
$c_d = 10$	+20	5040	285335	463445
	+10	4620	284915	463025
	-10	3780	284075	462185
	-20	3360	283655	461765

The following observations can be stated on the basis of results showed in Table 11:

- With the increase in the deterioration rate, the total cost function does not produce any optimal value for the different associated costs, i.e., inventory system cost, disposal cost, and total cost; deterioration rate does not affect HC, that is no sensitivity results are computed.
- It can be concluded that the total disposal cost, inventory system cost, and total cost decrease when the deterioration rate decreases. If the deterioration rate decreases, this means a smaller number of deteriorated or damaged products. Therefore, a smaller number of items is to be disposed, i.e., disposal cost will be less.
- It is visible that with the increment in the value of the disposal cost, the total cost, the inventory system cost, and disposal cost increase. On the other hand, as value of disposal cost decreases, total cost, the inventory system cost, and disposal cost also decrease.

6. APPLICABILITY OF THE MODEL

The proposed optimization model has an implication in the real-life world problem related to humanitarian logistics. This study is useful for a relief supply chain where we need to distribute the relief commodities to ultimate relief centers. In the process, we need to hold the inventory of the commodity. Therefore, the IRC model is formulated in such a way so that it can optimize the distribution cost and inventory holding cost. This model is also useful in general supply chain model that includes same structure of the distribution system. In the numerical example, we have supposed a simple problem with three reginal distribution centers and only five relief centers. These numbers may be higher in the other real-life problems which may result a complex problem but solvable with available tools and heuristic approaches. The model is formulated as a mixed integer programming problem.

7. CONCLUSION

This paper formulates an inventory-relief-chain (IRC) model with relief supply chain for the distribution of the relief commodity. The objective function calculates the values of intermediate DCs and RCs. However, in the study every relief center is considered to distribute the relief commodity because in disaster conditions every relief center is needed. In the presented mathematical model, the main aim is to optimize the total cost of the whole relief operation. The discussed numerical analysis recommend that the presented model can be extensively used to resolve a similar inventory relief chain problem. Furthermore, with the numerical study, a sensitivity analysis is discussed to show the effectiveness of the model with respect to different parameters. The model can help relief organizations in managing relief supplies.

Finally, this study can be further expanded by incorporating assumptions, such as multi-product problem or using deferent demand patterns. Furthermore, inventory routing strategies can also be incorporated in order to study an integrated inventory, location, and routing problems.

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