A Three-level Sustainable and Resilient Supply Chain Network Design under Disruption

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***Abstract* —Today supply chain management is emerging in a new dimension by having the sustainability as its primary focus, but in reality, however, facilities and the links connecting them, disrupt from time to time due to poor weather, natural or man-made disasters, or a combination of any other factors. Due to these unexpected disruptions, supply chain system drop its sustainability while coping with them. Now, the new challenges for the supply chain managers are to design an efficient and effective supply chain network that will be resilient enough to bounce back from any disruption and also should have sufficient vigilance to offer same sustainability under disruption state. Out of three pillars of sustainability namely ecological, social and economic sustainability, this paper is focusing more on the ecological sustainability because environmental focus in supply chain system is more important and also link with other pillars as the products need to be produced, packed and transported in an ethical way which should not harm social balance and environment. Owing to importance of the issue, this paper attempts to introduce network optimization model for sustainable and resilient supply chain network. The proposed goal programming (GP) model optimizes the total cost while considering the resilience and sustainability of the supply chain network.**

***Keywords*:** resilient supply chain; sustainable supply chain; disruptions

I. Introduction and Literature Review

The basic aim of traditional supply chain management was to make qualitative products or services with minimum costs. The organizations previously just focus on the activities or processes that are within their four walls, but much less attention was towards the management of the entire chain of activities or processes that are involved from purchasing of raw material to the distribution of finished goods to the end customers. This concept of supply chain is considered as a traditional concept whereas the modern concept is much more complex than this traditional one. Today supply chain management is emerging in a new dimension by having the sustainability as its primary focus, but in reality, however, facilities and the links connecting them, disrupt from time to time due to poor weather, natural or man-made disasters, or a combination of any other factors. At the same time, corporations are accepting broader responsibility for the social and environmental impacts of their supply chains and due to unexpected disruptions, supply chain system drop its sustainability while coping with them. Therefore supply chain managers are now trying to develop the trade-off between supply chain disruptions and sustainable system. In order to manage these modern supply chain networks more effectively and efficiently there is a need to make more resilient and sustainable supply chain networks. Resilience is a new approach to the design of supply chains and business processes. It is derived from the study of resilience in biological systems, which have a variety of mechanisms for sensing and responding to disturbances or threats. Whereas sustainability was only considered previously as a means to manage the logistics of supply chain, but the modern supply chain networks considers sustainability as its primary focus [1]. The current supply chains already realize the importance of making more sustainable networks and try to concentrate more on environmental and social facts in order to make more transparent supply chain networks.

Research and practical application of sustainable supply chain management (SSCM) have been growing steadily in recent times [2]. Elkington [3] described three pillars of sustainability, namely economy, ecology, and society. This paper is focusing more on the ecological sustainability because environmental focus in supply chain system is more important and also link with other pillars as the products need to be produced, packed and transported in an ethical way which should not harm social balance and environment. Many authors considered sustainable procurement [e.g, 4, 5-9] and sustainable transportation [e.g., 10, 11, 12] in supply chain context. However, the focus of ecological sustainability has now moved from local optimization to entire supply chain [13]. There are very few articles which considered sustainability factor to entire supply chain [e.g., 2, 14, 15, 16] which means that all activities from procurement of raw material to distribution of finished goods should consider sustainable factors.

In the socio-economic literature, there are many evidences which shows the connections and relationship between the resilience and sustainability, like; Derissen, et al. [17] discuss about the relationship between sustainability and resilience in ecological-economic systems. They consider sustainability as a normative concept whereas resilience as a descriptive concept, with the help of simple dynamic model they try to explain the relationship between sustainability and resilience. Rose [18] in his paper discuss about the role of sustainability and resilience in the face of natural disasters and also discuss the relationship between them. The author also describe the different types of resilience and concluded that the sustainability helps a lot for improvements after the severe nature disasters but it cannot be possible without having adaptive and inherent resilience associated with disaster recovery. Turner [19] considers that the resilience and vulnerability are two parallel and coalescing approaches which belongs to the sustainability science and the author also explain the similarities and differences among the two concerned areas in respect to sustainability science practices. Lebel, et al. [20] illustrated that resilience is one of the critical factors for sustainability

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and in order to pursuit an efficient and effective sustainable development there is a need to strengthen the ability of societies to manage resilience. Perrings [21] explains how the relationship between the sustainability and resilience effects the economics of development and also claims that, "A development strategy is not sustainable if it is not resilient". Cutter [22] illustrated a framework in his paper in which he consider resilience as a bridge between disaster risk management and sustainable communities. According to him it is very important to consider resilience as a major element that helps in achieving the sustainable development and further stated that considering resilience is necessary for both the sustainable development and disaster risk management.

In accordance with importance of above literature, this paper give considerations to both the resilience and sustainability in the context of supply chain management. According to Rose [18] the extreme disruptions could badly effect the environment, which disrupts the major activities of supply chains. The major barrier in developing the sustainable supply chain network is uncertainty associated with supply chain activities. Therefore, sustainable supply chain should be resilient and flexible enough to cope with uncertain disruptions [23]. This requires to build sustainable supply chains which simultaneously resilient, agile, and lean to cope with uncertain disruption such as natural or man-made disasters [24]. Disruption of supply chain network lead to supply uncertainty and is important to sustainable supply chain performance, because firms try to find alternate solution to cope with disrupted supply and might lose sustainability. There is enormous literature exist on supply chain resilience [e.g., 25, 26-30], which shows the importance of this research in supply chain area, however, to the best of authors knowledge, no single study is available in literature which jointly discussed resilience and sustainability issue in supply chain context. In order to design sustainable supply chain network which simultaneously resilient enough to cope with uncertain events, we used resilience metric known as Expected Disruption Cost (EDC) which is based on expected losses incurred due to network failures. According to Shukla, et al. [31] "The EDC is defined in terms of loss of opportunity cost incurred due to not meeting demand on time after a disruption has occurred". This paper proposed the weighted goal programming (WGP) model aiming to balance the level of ecological sustainability and disruption costs as a resilience metric. The model and methodology is discussed in next section.

II. MATHEMATICAL MODEL

In this section, the mathematical model for resilient and sustainable supply chain network will be discussed in detail. We have used weighted goal programming (WGP) approach to construct the model, because WGP is generally used to deal with multi-objective optimization problem. This paper deal with different conflicting objectives, and WGP is the suitable approach for obtaining compromise solution [32]. This paper considered supply chain consisting a set of manufacturing zones (*J*), where product is manufactured and distributed to various warehouse zones (*K*), from which product is dispatched to customer zones (*I*). This study considered three different type of trucks (*T*) which is used to deliver products between each supply chain node. The proposed model trade-off the total cost associated with supply chain network, disruption cost due to vulnerability of manufacturing and/or warehouse zones, and total carbon emission due to transportation and manufacturing. Parameters and variables used in the model are as follows:

A. Sets

$i-$ set of customer zones $\quad i \quad \{i \mid 1,2,...,I\}$

$j-$ set of manufacturing zones $\quad j \quad \{j \mid 1,2,...,J\}$

$k-$ set of warehouse zones $\quad k \quad \{k \mid 1,2,...,K\}$

$t-$ set of different type of trucks $\quad t \quad \{t \mid 1,2,...,T\}$

$s-$ set of scenarios $\quad s \quad \{s \mid 1,2,...,S\}$

B. Parameters

d_{is} Annual demand at customer zone *i* in scenario *s*

M_j Cost of installing a manufacturing unit in zone *j*

W_k Cost of installing a warehouse in zone *k*

$TCMW_{jkts}$ Transportation cost from manufacturing zone *j* to warehouse zone *k* using truck *t ($/unit)* in scenario *s*

$TCWC_{kits}$ Transportation cost from warehouse zone *k* to customer zone *i* using truck *t ($/unit)* in scenario *s*

$HCMW_{jks}$ Handling cost from manufacturing zone *j* to warehouse in zone *k ($/unit)* in scenario *s*

$HCWC_{kis}$ Handling cost from warehouse in zone *k* to customer zone *i ($/unit)* in scenario *s*

$CEMW_{jkts}$ Carbon emission by truck *t* from manufacturing zone *j* to warehouse zone *k (kg/unit)* in scenario *s*

$CEWC_{kits}$ Carbon emission by truck *t* from warehouse zone *k* to customer zone *i (kg/unit)* in scenario *s*

MC_{js} Manufacturing cost at zone *j ($/unit)* in scenario *s*

CE_j Carbon emission by manufacturing unit in zone *j (kg/unit)*

CM_{js} Capacity of manufacturing unit in zone *j* in scenario *s*

CT_{ts} Capacity of truck *t* in scenario *s*

CW_{ks} Capacity of inventory in warehouse *k* in scenario *s*

p_s Profit margin on each unit in scenario *s*

md_{js} Manufacturing zone's disruption probability in scenario *s*

wd_{ks} Warehouse zone's disruption probability in scenario *s*

C. Decision Variable

$x_k = \begin{cases} 1 \\ 0 \end{cases}$ If a warehouse in zone *k* is open 1, otherwise 0

$y_j = \begin{cases} 1 \\ 0 \end{cases}$ If a manufacturing unit in zone *j* is open 1, otherwise 0

$TQMW_{jkts}$ Transportation quantity from manufacturing zone j to warehouse zone k using truck t in scenario s

$TQWC_{kits}$ Transportation quantity from warehouse zone k to customer zone i using truck t in scenario s

D. Deviational Variable

d_a^-, d_a^+ Under and over achievement from total supply chain cost goal.

d_b^-, d_b^+ Under and over achievement from carbon emission goal

d_c^-, d_c^+ Under and over achievement from disruption cost goal as a measure of resilience.

E. Model

The objective of the proposed GP model is to minimize the deviations from the goals. Objective function in equation (1) minimizes the weighted deviation around the goals.

$$\text{Minimize } \beta_1 d_a^+ + \beta_2 d_b^+ + \beta_3 d_c^+ \quad (1)$$

Where $d_a^+, d_b^+, and\ d_c^+$ represent the deviational variables of cost, carbon emission, and resilient supply chain goals respectively, and β_1, β_2, and β_3 are the corresponding weights of above objective deviations. Various costs associated with supply chain are calculated in equation (2) –(5), production cost in different manufacturing zones are calculated in equation (2). Equation (3) computes the transportation cost of supply chain network. Handling cost is shown in equation (4). Installation cost of manufacturing units and warehouses is computed in equation (5). Finally, total supply chain cost goal (A) can be computed as in equation (6).

$$\text{Production cost} = \sum_j \sum_s MC_{js} \sum_k \sum_t TQMW_{jkts} \quad (2)$$

Transportation cost =

$$\sum_j \sum_k \sum_t \sum_s TQMW_{jkts} TCMW_{jkts} + \sum_k \sum_i \sum_t \sum_s TQWC_{kits} TCWC_{kits} \quad (3)$$

$$\text{Handling cost} = \sum_j \sum_k \sum_s HCMW_{jks} \sum_t TQMW_{jkts} + \sum_k \sum_i \sum_s HCWC_{kis} \sum_t TQWC_{kits} \quad (4)$$

$$\text{Installation cost} = \sum_j M_j y_j + \sum_k W_k x_k \quad (5)$$

Total supply chain cost goal (A) =

$$\text{Production cost} + \text{Transportation cost} + \text{Handling cost} + \text{Installation cost} + d_a^- - d_a^+ \quad (6)$$

Various carbon emissions in the supply chain are computed in equation (7) – (9). Equation (7) computes the total carbon emission during transport of finished products form manufacturing zones to warehouse zones. Total carbon emission for transporting the products from warehouses to customer zones is computed in equation (8). Equation (9) computes the carbon emission during manufacturing. Finally, Total carbon emission goal (B) can be shown by equation (10).

Carbon emission during transport of products from manufacturing zones to warehouse zones =

$$\sum_j \sum_k \sum_t \sum_s TQMW_{jkts} CEMW_{jkts} \quad (7)$$

Carbon emission during transport of products from warehouse zones to customer zones=

$$\sum_k \sum_i \sum_t \sum_s TQWC_{kits} CEWC_{kits} \quad (8)$$

Carbon emission in manufacturing =

$$\sum_j CE_j \sum_k \sum_t \sum_s TQMW_{jkts} \quad (9)$$

Total carbon emission goal (B) =
Carbon emission during transport of products from manufacturing zones to warehouse zones +
Carbon emission during transport of products from warehouse zones to customer zones +
Carbon emission in manufacturing + $d_b^- - d_b^+$ (10)

One of the main objective of this research is to consider the supply chain resilience. There may be many metrics for supply chain resilience, however, expected disruption cost (EDC) is a major metric. We use EDC as a metric for designing resilient supply chain network, for example sustainability and resiliency will be affected if manufacturing unit and/or warehouse are located in zones which are vulnerable due to any reason such as earthquake, tsunami, or man-made disaster. The goal (C) tries to minimize the expected disruption cost which means increasing the supply chain resilience. Equation (11) estimates the expected disruption cost, which is due to vulnerability of manufacturing zones, and warehouse zones.

Disruption cost goal (C) =

$$\left(\sum_j \sum_s TQMW_{jkts} md_{js} y_j + \sum_k \sum_s TQWC_{kits} wd_{ks} x_k \right) p_s + d_d^- - d_d^+ \quad (11)$$

The model constraints are described in equation (12) – (24) Constraint (12) insures that products can only be shipped from manufacturing unit in zone j if it exist in that zone. Similarly constraint (13) insures that products can only be shipped from warehouse in zone k if it is open in that zone. Where m is very large number.

$$TQMW_{jkts} \le m \times y_j \quad (12)$$

$$TQWC_{kits} \le m \times x_k \quad (13)$$

Constraint (14) - (15) guarantee that transportation quantities form manufacturing zones and warehouse zones should not be more than their respective capacities.

$$\sum_{k}\sum_{t} TQMW_{jkts} \le CM_{js} \quad (14)$$

$$\sum_{i}\sum_{t} TQWC_{kits} \le CW_{ks} \quad (15)$$

Constraints (16) – (17) insure that transportation quantities form manufacturing zones and warehouse zones should not exceed the total capacity of truck.

$$\sum_{j}\sum_{k} TQMW_{jkts} \le CT_{ts} \quad (16)$$

$$\sum_{k}\sum_{i} TQWC_{kits} \le CT_{ts} \quad (17)$$

Constraint (18) balances the input and output of finished products in warehouse units. The incoming products from manufacturing units are equal to outgoing units to various customer zones.

$$\sum_{j}\sum_{t} TQMW_{jkts} - \sum_{k}\sum_{t} TQWC_{kits} = 0 \quad (18)$$

Constraint (19) confirms that the amount of products coming from manufacturing units to warehouse in zone k must be less than its inventory capacity.

$$\sum_{j}\sum_{t} TQMW_{jkts} \le CW_{ks} \quad (19)$$

Constraint (20) certifies that the amount of products manufactured in zone j unit must be less than its capacity.

$$TQMW_{jkts} \le CM_{js} \quad (20)$$

Constraint (21) promises that the amount of products transported from warehouses to customer zone i should satisfy its demand.

$$\sum_{k}\sum_{t} TQWC_{kits} - d_{is} = 0 \quad (21)$$

Constraints (22) - (24) imposes positive and binary restrictions to all the corresponding decision variables, respectively.

$$TQMW_{jkts}, TQWC_{kits} \ge 0 \text{ and integer } \ \forall\, i, j, k, t, s \quad (22)$$

$$d_a^+, d_b^+, d_c^+, d_a^-, d_b^-, d_c^- \ge 0 \quad (23)$$

$$x_k, y_j \in \{0,1\} \quad \forall k, j \quad (24)$$

III. NUMERICAL EXAMPLE

For experiment purpose we take single product and $i = 3$, $j = 3$, $k = 3$, $t = 3$, $s = 3$. Various goals are set as cost goal (A) = $ 772,688.50.00, carbon emission goal (B) = 29,249.00 kg, and disruption cost goal (D) = $ 77925.00. These goals value are found by separately minimizing the each goal using linear programming. The probability of disruption is hard to quantify [31], Klibi, et al. [33] showed the use of international disaster database to quantify the probability. To calculate the probability of disruption, the historic data for man-made disasters and natural disasters can be collected from various sources. The disruption probability of manufacturing zones and warehouse zones depend on the region in which they are located as shown in Table 1. In order to analyze the relationship between objectives, we take three different cases: Case I: the weight of goals A, B, and C are set $\beta_1 = 0.6$, $\beta_2 = 0.2$, and $\beta_3 = 0.2$ respectively, Case II: the weight of goals A, B, and C are set $\beta_1 = 0.2$, $\beta_2 = 0.6$, and $\beta_3 = 0.2$ respectively, and Case III: the weight of goals A, B, and C are set $\beta_1 = 0.2$, $\beta_2 = 0.2$, and $\beta_3 = 0.6$ respectively. Table II -

TABLE *XI* show the required parameters used for solving the proposed model.

Table I. DISRUPTION PROBABILITY OF ZONES

Zone		**Probability**		
		Scenario 1	Scenario 2	Scenario 3
Manufacturing	1	0.05	0.03	0.03
	2	0.02	0.03	0.02
	3	0.01	0.02	0.02
Warehouse	1	0.05	0.03	0.02
	2	0.02	0.03	0.01
	3	0.01	0.01	0.02

Table II. FINISHED PRODUCT HANDLING COSTS FROM MANUFACTURING ZONES TO WAREHOUSE ZONES ($/UNIT) AT DIFFERENT SCENARIOS.

Scenario		Manufacturing zone 1			Manufacturing zone 2			Manufacturing zone 3		
		1	2	3	1	2	3	1	2	3
Warehouse Zones	1	0.010	0.020	0.009	0.015	0.019	0.020	0.011	0.014	0.013
	2	0.015	0.011	0.014	0.013	0.014	0.016	0.012	0.019	0.013
	3	0.020	0.015	0.020	0.008	0.012	0.020	0.013	0.020	0.015

Table III. FINISHED PRODUCT HANDLING COSTS FROM WAREHOUSE ZONES TO CUSTOMER ZONES ($/UNIT) AT DIFFERENT SCENARIOS.

Scenario		Warehouse Zone 1			Warehouse Zone 2			Warehouse Zone 3		
		1	2	3	1	2	3	1	2	3
Customer Zones	1	0.010	0.015	0.020	0.020	0.016	0.020	0.014	0.012	0.011
	2	0.020	0.011	0.015	0.015	0.012	0.013	0.012	0.019	0.015
	3	0.008	0.009	0.011	0.011	0.015	0.020	0.015	0.016	0.013

Table IV. Finished product transportation costs ($/unit) from manufacturing zones to warehouse zone by different trucks at different scenarios.

Scenario				Truck type 1			Truck type 2			Truck type 3		
				1	2	3	1	2	3	1	2	3
Manufacturing Zone	1	Warehouse Zone	1	0.24	0.24	0.24	0.29	0.28	0.33	0.44	0.48	0.45
			2	0.35	0.35	0.35	0.39	0.40	0.41	0.48	0.46	0.50
			3	0.29	0.30	0.28	0.30	0.35	0.33	0.41	0.45	0.45
	2	Warehouse Zone	1	0.31	0.35	0.34	0.41	0.43	0.42	0.49	0.50	0.49
			2	0.46	0.46	0.46	0.50	0.51	0.53	0.55	0.56	0.56
			3	0.37	0.37	0.37	0.45	0.44	0.46	0.56	0.57	0.57
	3	Warehouse Zone	1	0.53	0.53	0.55	0.58	0.60	0.58	0.61	0.63	0.60
			2	0.44	0.44	0.46	0.54	0.54	0.55	0.64	0.64	0.66
			3	0.36	0.36	0.37	0.46	0.46	0.46	0.49	0.48	0.50

Table V.FINISHED PRODUCT TRANSPORTATION COSTS ($/UNIT) FROM WAREHOUSE ZONES TO CUSTOMER ZONES BY DIFFERENT TRUCKS AT DIFFERENT SCENARIOS.

Scenario				Truck type 1			Truck type 2			Truck type 3		
				1	2	3	1	2	3	1	2	3
Warehouse Zone	1	Customer Zone	1	0.13	0.14	0.14	0.25	0.24	0.24	0.34	0.34	0.35
			2	0.18	0.18	0.19	0.29	0.30	0.28	0.39	0.38	0.39
			3	0.15	0.16	0.16	0.27	0.26	0.26	0.36	0.36	0.37
	2	Customer Zone	1	0.15	0.15	0.14	0.25	0.25	0.24	0.34	0.35	0.34
			2	0.18	0.19	0.19	0.29	0.28	0.26	0.38	0.39	0.38
			3	0.17	0.17	0.17	0.27	0.27	0.27	0.36	0.37	0.37
	3	Customer Zone	1	0.13	0.13	0.15	0.23	0.23	0.24	0.33	0.33	0.35
			2	0.18	0.18	0.16	0.26	0.28	0.28	0.36	0.39	0.39
			3	0.16	0.16	0.17	0.29	0.30	0.29	0.136	0.36	0.37

TABLE VI. CARBON EMISSIONS ($\times\frac{1}{10^3}$ KG) FOR FINISHED PRODUCT TRANSPORTATION FROM MANUFACTURING ZONES TO WAREHOUSE ZONES BY DIFFERENT TRUCKS AT DIFFERENT SCENARIOS.

Scenario				Truck type 1			Truck type 2			Truck type 3		
				1	2	3	1	2	3	1	2	3
Manufacturing Zone	1	Warehouse Zone	1	200	200	200	280	280	280	300	300	300
			2	150	150	150	200	200	200	250	250	250
			3	100	100	100	110	110	110	120	120	120
	2	Warehouse Zone	1	60	60	60	70	70	70	90	90	90
			2	40	40	40	50	50	50	70	70	70
			3	20	20	20	30	30	30	50	50	50
	3	Warehouse Zone	1	110	110	110	140	140	140	150	150	150
			2	90	90	90	110	110	110	120	120	120
			3	60	60	60	80	80	80	90	90	90

TABLE VII. EMISSIONS ($\times\frac{1}{10^3}$ KG) FOR FINISHED PRODUCT TRANSPORTATION FROM WAREHOUSE ZONES TO CUSTOMER ZONES BY DIFFERENT TRUCKS AT DIFFERENT SCENARIOS.

Scenario				Truck type 1			Truck type 2			Truck type 3		
				1	2	3	1	2	3	1	2	3
Warehouse Zone	1	Customer Zone	1	150	150	150	170	170	170	190	190	190
			2	120	120	120	130	130	130	150	150	150
			3	90	90	90	100	100	100	110	110	110
	2	Customer Zone	1	260	260	260	280	280	280	300	300	300
			2	250	250	250	260	260	260	280	280	280
			3	120	120	120	150	150	150	170	170	170
	3	Customer Zone	1	150	150	150	170	170	170	180	180	180
			2	120	120	120	150	150	150	200	200	200
			3	80	80	80	90	90	90	110	110	110

TABLE VIII. PRODUCT MANUFACTURING COSTS ($/UNIT) AT DIFFERENT SCENARIOS.

		Scenario 1	Scenario 2	Scenario 3
Manufacturing zone	1	1.35	1.23	1.51
	2	1.50	1.56	2.01
	3	2.56	2.50	2.65

TABLE IX. CAPACITIES OF THE MANUFACTURING ZONES, AND WAREHOUSE ZONES AT DIFFERENT SCENARIOS.

		Scenario 1	Scenario 2	Scenario 3
Manufacturing zone	1	13200	10500	12000
	2	12500	13500	12500
	3	11500	12000	12500
Warehouse Zone	1	13200	12500	11500
	2	10500	13500	12000
	3	12000	12000	12500

TABLE X. DEMANDS OF THE CUSTOMER ZONES AT DIFFERENT SCENARIOS.

		Customer Zone 1	Customer Zone 2	Customer Zone 3
Scenario	1	8500	8700	8600
	2	9000	8000	8500
	3	7500	8500	9000

TABLE XI. TRUCK'S CAPACITIES AT DIFFERENT SCENARIOS.

		Scenario 1	Scenario 2	Scenario 3
Truck type	1	8800	8800	8800
	2	10000	10000	10000
	3	12000	12000	12000

TABLE XII. CASE EXAMPLE SOLUTIONS AND COMPARISON AMONG THREE CASES

Optimized Goal Values	Cost goal (A) = $ 772,688.50.00, Carbon emission goal (B) = 29,249.00 kg, Disruption cost goal (D) = $ 77925.00	
Case I $\beta_1 = 0.6, \beta_2 = 0.2, \beta_3 = 0.2$	**Case II** $\beta_1 = 0.2, \beta_2 = 0.6, \beta_3 = 0.2$	**Case III** $\beta_1 = 0.2, \beta_2 = 0.2, \beta_3 = 0.6$
d_a^+ = $ 2152.70	d_a^+ = $ 5958.85	d_a^+ = $ 15435.30
d_b^+ = 4748.00 Kg	d_b^+ = 1059.00 Kg	d_b^+ = 4225.00 Kg
d_c^+ = $ 8025.00	d_c^+ = $ 8025.00	d_c^+ = $ 1425.00

The proposed model is solved using LINDO to obtain optimal solution as shown in TABLE XII. Three cases are solved and solution reveals that network design depends on weightage given to each objective. The analysis of result shows that if more importance given to total cost goal than sustainability of supply chain reduces and vulnerability of SC network increases. This shows that sustainability also depends of resilience of network, that is, increase in resilience of SC network also increase its sustainability. This is due to reason that during disruption in networks, the firms try to switch its operation from one zone to another which results in reduction of sustainability due to increase in CO_2 emissions and/or embodied carbon footprints. The presented model considered the resilience factor in supply chain network design, which helps to maintain the sustainability during disruption risks. The proposed model gives many insights to manage the sustainable supply chain network under disruption risks, the model provides compromise solution to meet different goals.

IV. CONCLUSION

This paper highlights the importance of supply chain resilience in design of sustainable supply chain network. The paper proposed optimization model for designing sustainable and resilience supply chain network considering disruption risks. Multi-objective goal programming based approach is proposed to handle conflicting goals such as cost, carbon emission, and disruption cost. The significant contribution of this paper is the inclusion of resilience factor in the design of sustainable supply chain network, because it was observed in practice that maintaining sustainability in supply chain network is difficult during disruption risks such as natural or man-made disaster. The proposed model can be extended by incorporating more realistic complexities such as stochastic demand, multiple products, and real-time GIS data to calculate the probability of disruption risks in various regions.

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