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CUSTOMER SATISFACTION AND ENVIRONMENTAL CONCERN BASED MULTIPLE OBJECTIVE OPTIMIZATION MODEL FOR SUSTAINABLE SUPPLY CHAIN IN REAL LIFE: AN INTUITIONISTIC FUZZY T-SET APPROACH

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ABSTRACT

In this paper, one customer satisfaction and environmental concern based multiple objective optimization model is presented to manage supply chain under uncertainty. Although much research work is going on sustainability of supply chain, very few of them are found to be optimization based analytical studies. Whereas extensive literature review suggests that aggregate revenue, customer satisfaction and environmental concern are three major performance indicators for sustainability of supply chains, existing optimization based supply chain models primarily consider at most any two of these three indicators. Present study is unique since these three performance indicators are considered simultaneously in it. Further, proposed model is multiple objective optimization model. Furthermore, it is presented in real life based environment and one new set: intuitionistic fuzzy T-set, which was proposed by the author in 2017, is employed to yield corresponding Pareto optimal solution. Numerical results show that the Pareto optimal solution to this model in real life based intuitionistic fuzzy T-environment is more preferable to decision maker than corresponding solution in classical intuitionistic fuzzy environment. Finally, conclusions are drawn.

Subject Classification Codes: *90B06, 90C08, 03E72, 90C70, 90B50, 90C29.*

Keywords: *Intuitionistic fuzzy decision making, Customer satisfaction, Green supply chain, Multiple objective optimization, Reverse chain, Supply chain network, Sustainability, intuitionistic fuzzy T-set, Pareto optimal solution.*

1. INTRODUCTION

We may term the supply chain as a set of facilities, supplies, customers, products and methods of controlling inventory, purchasing and distribution [51]. Traditionally, the chain links suppliers with customers, beginning with the production and/or acquisition of raw materials by suppliers, and ending with the consumption of finished products by customers. In a supply chain, the flow of goods between suppliers and customers passes through several stages and each stage can consist of many facilities. Although in corporate sectors, traditionally, several planning, manufacturing, distribution, marketing and purchasing organizations operate independently, but their objectives are often conflicting in nature. Subsequently, business communities and scientists felt the need for one mechanism for integrating those diverse functions. They found that supply chain management (SCM) might be the strategy through which this integration can be realized. Collaborative planning, forecasting and replenishment are the most recent prolific management initiatives that can provide supply chain collaboration and visibility. Companies can dramatically improve upon the level of efficiency by forecasting the future demand, synchronized production scheduling, logistic management, new product design etc. [6].

We may observe that one major component in design and analysis of supply chain is the establishment of appropriate performance indicator. A performance indicator or a set of performance indicators can be used to determine efficiency and/or effectiveness of existing system, to compare with alternative system as well as to design new system. A survey by Deloitte (http://www.deloitte.com) of 421 Business Leaders in more than ten countries found that 79% of supply

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chain leaders reported significant revenue growth that was above industry average. Further, they identified the supply chain network design problem to be one of the most comprehensive strategic decision making problems. Furthermore, they observed that the supply chain network required to be optimized for long term efficient operations as well as for determining the number, location, capacity and type of suppliers, plants, distribution centres etc., and thereby for overall sustainability of whole supply chain. Since supply chains usually involve several components, and livelihood of hundreds of thousands of stakeholders hinges on the performance, we may find the sustainability to be the single major indicating factor scientifically, economically, politically, socially as well as environmentally. Also, we may note that sustainability allows organizations to accomplish goal of long term multiple dimensional viability.

Sustainable supply chain management (SSCM) has emerged as one growing topic with increased interest among scientists and corporate. Here we may observe that the SSCM field is dominated by either case or survey based research; and very few attempts have been made to optimize different parameters of sustainability by taking one much general and broader look at the overarching core topics of SSCM in literature. Although researchers have identified quite a few other key factors like corporate social responsibility, adoption of emerging technologies, innovation, collaboration, leadership etc., in this paper we may consider revenue, customer satisfaction index and environmental concern as three primary performance indicators. First, the concentration may lie on revenue. Be it a single business or cluster of businesses, generating revenue continues to be the prime concern since time immemorial. There are innumerable studies to determine the mean of maximizing aggregate revenue (or analogously net profit) for businesses. So we may skip this parameter revenue and consider other aspects of sustainability of SCM viz. customer satisfaction and environmental concern, one by one.

We may observe that customer satisfaction with a company's product or service is often perceived as the key point to the company's long term success and competitiveness [33]. It is an established truth that in the context of relationship marketing, customer satisfaction is a central determinant of customer retention and ensuing addition of new customers. Scientists have observed that customer satisfaction with products can be influenced by the effort that is expended to acquire the product along with the expectation concerning the product. Specifically, studies have yielded that satisfaction with the product might be higher, when customers expended considerable effort to get the product than when they exercised only modest effort. Further, researchers have noted that expectation do not directly affect satisfaction as often suggested in the satisfaction literature, but quality, which fell short of expectation, can have a greater impact on satisfaction and repurchase intention than quality exceeding expectation [5]. Several research articles also suggest that timely delivery of manufactured items or finished goods can increase the confidence level of customers and subsequently can increase customer satisfaction level significantly.

On the other hand, as environmental concern remains at the forefront of the debate of global and local social interests, green supply chain management (GSCM) turn out to be very essential. There is a growing need for integrating environmentally sound choices into SCM research and practice. The motivation for the introduction of GSCM may be ethical (e.g., reflecting the value of manager) and/or commercial (e.g., gaining competitive advantage by signaling environmental concern) [65]. We may observe that the number of organizations, contemplating the integration of environmental practices into their strategic plans and daily operations is continuously increasing. Further, numerous initiatives have granted attractive incentives to organizations for becoming more environmentally benign [6]. Organizations view many of these environmental programs including technological and organizational development projects, as possible alternatives for gaining or maintaining the competitive advantage. In a nutshell, formulation of a comprehensive framework in form of one multiple objective optimization model for systematic management of logistics flows among chain members by considering three major performance indicators in a sustainable supply chain is urgently needed.

We may organize the rest of this article as follows. In Section 2, we provide specifications of proposed SSCM model. In Section 3, we formulate the SSCM model by assembling all the objective functions and constraints. In Section 4, we discuss multiple objective optimization method under real life environment in short. In this paper, we may employ intuitionistic fuzzy T-set to represent real life environment and thereby solve proposed SSCM model. Next in Section 5, we consider numerical application of proposed model under intuitionistic fuzzy T-environment. Next we compare between the Pareto optimal solution obtained in intuitionistic fuzzy T-environment and classical intuitionistic fuzzy environment. We draw the conclusions in Section 6.

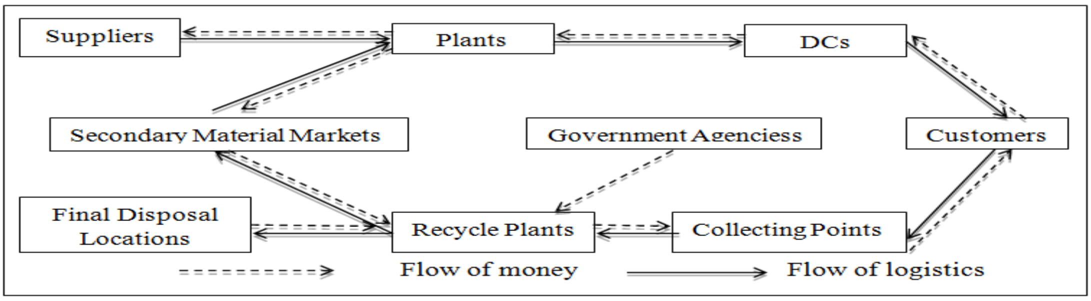

Figure-1: Flow chart of logistics flows and induced monetary flows of SSCM model

2. SPECIFICATIONS OF PROPOSED SSCM MODEL

Based on those discussions, we plan to develop one comprehensive conceptual framework for formulating one integrated logistics operational SSCM model by involving eight potential chain members. Further we may classify these chain members into two layers:
i. Manufacturing Chain (MC) and
ii. Reverse Chain (RC).

In MC layer, we may propose potential chain members as a. suppliers of raw materials, b. plants, c. distribution centers (DCs), d. customers. In RC layer, we may propose potential chain members as a. collecting points, b. recycle plants, c. secondary material markets, d. final disposal (waste) locations. Furthermore, we may suggest another important anchor of proposed SSCM to be Governments/independent environmental protection authorities, not only for forming regulations (to be followed by SSCM members) but also for providing monetary supports. We may note that these authorities may infuse tax payers' hard earned money in form of subsidies to recycle plants in particular and SSCM in general, for recycling untreated items. Here we may link members of proposed SSCM with solid and dashed lines to illustrate corresponding directional relationships in terms of logistics flow and induced monetary flow respectively, as given in Fig. 1.

Hypothesis*:*
To specify scopes of study and to further simplify the proposed SSCM model, we may hypothesize following assumptions

i. In proposed SSCM model, we investigate single product scenario, i.e. there is exactly one manufactured product in entire time interval.
ii. The time varying capacity of inventory associated with each chain member in both MC layer and RC layer in any given time interval is known.
iii. The time varying maximum quantity of products manufactured at plants as well as time varying maximum quantity of items, treated at recycle plants are known in any given time interval. Here those maximum limits are same for each time interval.
iv. The time varying numbers of available suppliers, customers, collecting points, recycles plants, secondary material markets, final disposal locations are known in each time interval.
v. The maximum allowable numbers of total plants and/or DCs are known in each time interval.
vi. Further social stability is vital for sustainability (e.g., supply chain members should stay away from adverse situations that can arise from labour unrest, political interferences, degradation of brand values etc.). Consequently, when new plant(s) and/or DC(s) become operational, we cannot shut those within given total time period.
vii. In each time interval, a customer is served by one and only one DC.
viii. The time varying quantity of demand of customers is known in any given time interval.
ix. The time varying value of used product return ratio, referring to proportion of quantity of used products returned by customers and passing to RC layer is known in any given time interval. Here these values are same in any given time interval.

3. DEVELOPMENT OF SSCM MODEL

With all those aforementioned assumptions, we may construct one composite multiple objective optimization model to yield optimal values of aggregate revenue and customer satisfaction index. We may consider following identifications of proposed SSCM model.

Integer Variables: Following binary integer variables are used in proposed SSCM

$$\forall j \in J, z_j = \begin{cases} 1, & \text{if DC 'j' is open} \\ 0, & \text{otherwise} \end{cases}; \qquad \forall k \in K, p_k = \begin{cases} 1, & \text{if plant 'k' is open} \\ 0, & \text{otherwise} \end{cases}$$

$$\forall i \in I, j \in J, y_{ji} = \begin{cases} 1, & \text{if customer 'i' is served by DC 'j'} \\ 0, & \text{otherwise} \end{cases}$$

Mathematical Model:

The mathematical model of the proposed supply chain is as follows

- ***A. Objective Functions:***

We may construct two objective functions of proposed SSCM model as follows

- Maximizing aggregate revenue of proposed sustainable supply chain network, including manufacturing chain based total revenue, reverse chain based total revenue and revenue in terms of subsidies associated with given reverse chain from Government agencies and/or environment protection authorities;
- Maximizing customer satisfaction by considering percentage of customer demand that is deliverable within stipulated access time.

Aggregate revenue of proposed SSCM $\left(AR_{SSCM}\right)$ is composed of three major items. We may find the aggregate revenue by adding combined revenue associated with given manufacturing chain $\left(TR_{mc}\right)$ and combined revenue associated with given reverse chain $\left(TD_{rc}\right)$ and total government subsidies associated with given reverse chain $\left(TS_{mc}\right)$ within given total time period as follows

$$AR_{SSCM} = TR_{mc} + TD_{rc} + TS_{rc} \tag{1A}$$

The combined time varying amount of revenue associated with given manufacturing chain within given total time period T (TR_{mc}) may be termed as follows

$$TR_{mc} = \sum_{\mu=1}^{T}\left(\sum_{s}\sum_{k}\left(R_{sk}(\mu)\times b_{sk}(\mu)\right) + \sum_{k}\sum_{j}\left(R_{kj}(\mu)\times \mathrm{f}_{kj}(\mu)\right) + \sum_{j}\sum_{i}\left(R_{ji}(\mu)\times \mathrm{q}_{ji}(\mu)\right)\right) \tag{2}$$

The combined time varying amount of revenue associated with given reverse chain within given total time period T (TD_{rc}) may be termed as follows

$$TD_{rc} = \sum_{\mu=1}^{T}\left(\begin{array}{l} \sum_{i}\sum_{x}\left(R_{ix}(\mu)\times (\mathrm{qr})_{ix}(\mu)\right) + \\ \sum_{x}\sum_{t}\left(R_{xt}(\mu)\times \mathrm{r}_{xt}(\mu)\right) + \\ \sum_{t}\sum_{m}\left(R_{tm}(\mu)\times \mathrm{r}_{tm}(\mu)\right) + \\ \sum_{m}\sum_{k}\left(R_{mk}(\mu)\times (\mathrm{rq})_{mk}(\mu)\right) \end{array}\right) \tag{3}$$

The combined time varying amount of government subsidies associated with given reverse chain within given total time period T (TS_{mc}) may be termed as follows

$$TS_{rc} = \sum_{\mu=1}^{T}\left(\sum_{t}\sum_{m}\left(S_{tm}(\mu)\times \mathrm{r}_{tm}(\mu)\right)\right) \tag{4}$$

Next customer satisfaction increases as the total customer demand (in %) that can be met within given total time period T can be maximized. Hence the combined time varying amount of customer satisfaction $\left(CS_{SSCM}\right)$ within given total time period T may be termed as follows

$$CS_{SSCM} = \sum_{\mu=1}^{T}\left(\sum_{j}\sum_{i}\left(z_j \cdot q_{ji}(\mu)\right) / \sum_{i} d_i(\mu)\right) \tag{1B}$$

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- ***B. Constraints:***

In addition, we may consider corresponding logistics conditions either restricted by operational requirements or compelled by regulations and consequently augment five groups of constraints in proposed SSCM model as A. Inventory constraints, B. Return resource constraints, C. Operational constraints, D. Capacity constraints and E. Production constraints.

A. Inventory Constraints:

- Manufacturing Chain Layer (MC-layer)

a. Suppliers of Raw Materials

$$\forall s,\mu : \inf_s(\mu) \le (qi)_S(\mu) = (qi)_S(\mu-1) + q_S(\mu) - \sum_k b_{sk}(\mu) \le \sup_s(\mu) \quad (5)$$

b. Plants $\forall k \in o_p, \forall \mu: \inf_k(\mu) \le (qi)_k(\mu) =$

$$(qi)_k(\mu-1) + \left(\sum_s b_{sk}(\mu) + \sum_m (rq)_{mk}(\mu)\right) + q_k(\mu) - \tau^{r/m} \cdot \left(q_k(\mu)\right) - \sum_j f_{kj}(\mu) \le \sup_k(\mu) \quad (6)$$

We may note that this relation can hold only for those plants that remain open in given time interval μ. Further we have considered variations of flows from raw materials to manufactured products; and involved corresponding coefficient $\tau^{r/m}$.

c. Distribution Centers (DCs)

$$\forall open \text{ DC}, \forall \mu : \inf_j(\mu) \le (qi)_j(\mu) = (qi)_j(\mu-1) + \sum_k f_{kj}(\mu) - \sum_i q_{ji}(\mu) \le \sup_j(\mu) \quad (7)$$

We may note that this relation holds only for those DCs, which remain open in given time interval μ .

- Reverse Chain Layer (RC-layer)

a. Collecting Points

$$\forall x,\mu : \inf_x(\mu) \le (ri)_x(\mu) = (ri)_x(\mu-1) + \sum_i (qr)_{ix}(\mu) - \sum_t r_{xt}(\mu) \le \sup_x(\mu) \quad (8)$$

b. Recycle Plants

We may note that recycle plants usually have three types of inventories: Type I for untreated items that are received from collecting points, Type II for treated items that are transported to secondary material markets and Type III for waste items that are transported to final disposal locations. $\forall t, \mu:$

$$\forall x,\mu : \inf_x(\mu) \le (ri)_x(\mu) = (ri)_x(\mu-1) + \sum_i (qr)_{ix}(\mu) - \sum_t r_{xt}(\mu) \le \sup_x(\mu) \quad (9)$$

$$\inf_t^m(\mu) \le (ritm)_t(\mu) = (ritm)_t(\mu-1) + \tau^{u/m} \cdot (rt)_t(\mu) - \sum_m r_{tm}(\mu) \le \sup_t^m(\mu) \quad (10)$$

$$\inf_t^w(\mu) \le (ritw)_t(\mu) = (ritw)_t(\mu-1) + \tau^{u/w} \cdot (rt)_t(\mu) - \sum_w r_{tw}(\mu) \le \sup_t^w(\mu) \quad (11)$$

Here the corresponding physical transformation rate must satisfy the condition that $\tau^{u/m} + \tau^{u/w} = 1$.

c. Secondary Material Markets

$$\forall m,\mu : \inf_m(\mu) \le (ri)_m(\mu) = (ri)_m(\mu-1) + \sum_t r_{tm}(\mu) - \sum_k (rq)_{mk}(\mu) \le \sup_m(\mu) \quad (12)$$

d. Final Disposal Locations (rc-layer 'w')

$$\forall w,\mu : \inf_w(\mu) \le (ri)_w(\mu) = (ri)_w(\mu-1) + \sum_t r_{tw}(\mu) - (rf)_w(\mu) \le \sup_w(\mu) \quad (13)$$

B. Return Resource Constraints $\forall \mu : R_{rc}(\mu) = \left(\sum_i \sum_x (qr)_{ix}(\mu)\right) = \gamma \cdot \sum_i d_i(\mu) \ge 0$ (14)

C. Operational Constraints

On Number of Operational Plants $\forall \mu : \sum_{k \in O_p} p_k(\mu) \le P$ (15)

$$\forall k, \mu_i (\text{time interval}), \mu_j (\text{time interval}), \; p_k(\mu_i) = p_k(\mu_j) \quad (16)$$

On Number of Operational DCs $\forall \mu : \sum_{j \in O_D} z_j(\mu) \le W$ (17)

$\forall j, \mu_i$(time interval), μ_j(time interval): $z_j(\mu_i) = z_j(\mu_j)$ (18)

On Relations between DCs and Customers $\forall i, \mu : \sum_j q_{ji}(\mu) \le d_i(\mu) \cdot y_{ji}(\mu)$ (19)

$$\sum_j y_{ji}(\mu) = 1 \quad (20)$$

D. Capacity Constraints

Suppliers $\forall \overline{T} \le T, s : \left(\sum_{\mu=\mu_1}^{\overline{T}} q_s(\mu) \right) \ge \left(\sum_{\mu=\mu_1}^{\overline{T}} \sum_k b_{sk} \right)$ (21)

Plants $\forall \overline{T} \le T, k :$

Associated with raw materials: $\sum_{\mu=\mu_1}^{\overline{T}} \tau^{r/m} \cdot q_k(\mu) \le \sum_{\mu=\mu_1}^{\overline{T}} \left(\sum_s b_{sk}(\mu) + \sum_m (rq)_{mk}(\mu) \right)$ (22)

Associated with manufactured products: $\sum_{\mu=\mu_1}^{\overline{T}} q_k(\mu) \ge \sum_{\mu=\mu_1}^{\overline{T}} \sum_j f_{kj}(\mu)$ (23)

DCs $\forall \overline{T} \le T, j : \sum_{\mu=\mu_1}^{\overline{T}} \sum_k f_{kj}(\mu) \ge \sum_{\mu=\mu_1}^{\overline{T}} \sum_i q_{ji}(\mu)$ (24)

Collecting Points $\forall \overline{T} \le T, x : \sum_{\mu=\mu_1}^{\overline{T}} \sum_i (qr)_{ix}(\mu) \ge \sum_{\mu=\mu_1}^{\overline{T}} \sum_t r_{xt}(\mu)$ (25)

Recycle Plants

Untreated Items $\forall \overline{T} \le T, t : \sum_{\mu=\mu_1}^{\overline{T}} \sum_x r_{xt}(\mu) \ge \sum_{\mu=\mu_1}^{\overline{T}} (rt)_t(\mu)$ (26)

Treated Items (to be transported to secondary material markets)

$$\forall \overline{T} \le T, t : \sum_{\mu=\mu_1}^{\overline{T}} \sum_m r_{tm}(\mu) \le \sum_{\mu=\mu_1}^{\overline{T}} \tau^{u/m} \cdot (rt)_t(\mu) \quad (27)$$

Treated Items (to be transported to final disposal locations)

$$\forall \overline{T} \le T, t : \sum_{\mu=\mu_1}^{\overline{T}} \sum_w r_{tw}(\mu) \le \sum_{\mu=\mu_1}^{\overline{T}} \tau^{u/w} \cdot (rt)_t(\mu) \quad (28)$$

Secondary Material Markets $\forall \overline{T} \le T, m : \sum_{\mu=\mu_1}^{\overline{T}} \sum_k (rq)_{mk}(\mu) \le \sum_{\mu=\mu_1}^{\overline{T}} \sum_t r_{tm}(\mu)$ (29)

E. Production Constraints

Plants $\forall k, \mu : \mathrm{q}_k(\mu) \le \mathrm{Cap}_k(\mu)$ (30)

Recycle Plants $\forall t, \mu : \mathrm{r}_t(\mu) \le \mathrm{Cap}_t(\mu)$ (31)

4. MULTIPLE OBJECTIVE OPTIMIZATION TECHNIQUE IN IMPRECISE ENVIRONMENT

We may note that multiple objective optimization is the process of optimizing systematically and simultaneously a collection of objective functions [71]. By assuming that the decision maker (DM) has imprecise aspiration level for each objective function, mathematicians have proposed several methods in literature for characterizing Pareto optimal solutions to multiple objective optimization problems (MOOP) [78]. In one of these approaches, scientists have used fuzzy set theory [7, 31, 73]. As pointed out by Zimmermann in 1976 and later in 1978, various kinds of uncertainties can be categorized as fuzziness [76-77]. Zimmermann and successive researchers converted MOOP into single objective optimization problems to yield Pareto optimal solutions by applying fuzziness of the DM's aspiration with

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respect to goals of uncertain objective functions (and constraints, till they are symmetric) [25-27]. Advantages of employing fuzzy sets to represent uncertainty in optimization models are manifold and well known [27, 71, 78]. In subsequent years, researchers have worked on this technique to solve MOOP under uncertain and real life based environments.

On the other hand, fuzzy set theory has been widely developed and several modifications and generalizations have appeared. One of them is the concept of intuitionistic fuzzy (IF) sets that was introduced by K. T. Atanassov in 1986. IF sets consider not only membership values but also non-membership values such that sum of these values does not exceed unity for any IF objective function.

Advantages of employing IF sets to represent impreciseness in optimization models are manifold and well known. Plamen P. Angelov (in 1995 and next in 1997) first introduced the solution technique of optimization models under IF environment. In subsequent years, researchers have worked on this technique to solve MOOP under uncertainty. In 2015, the author proposed IFT- sets to supersede IF sets in representing uncertainty [25-26]. Here in this paper, we may solve the proposed SSCM model in IFT-environment.

5. NUMERICAL RESULTS

To illustrate the applicability of proposed method, we may conduct one simplified numerical study. The data used in this study are partly inspired from the article by J.-B. Sheu et al, entitled “An integrated logistics operational model for green-supply chain management”, published in the journal “Transportation Research” in 2005 [59] and partly from the article by Altiparmak et al, entitled “A genetic algorithm approach for multi-objective optimization of supply chain networks”, published in the journal “Computers and Industrial Engineering” in 2006 [2].

Here we take T = 4, i.e. we consider 4 quarters of the year. Further, we assume the number of suppliers, plants, DCs, customers, collecting points, recycle plants, secondary material markets, final disposal locations as unity in each case. The other parameters of proposed SSCM are taken as follows

Parameter settings:
We set the numbers of units of product demand and used-product returns as given in Table 1. Next we set the estimated unit revenues for both MC-layer and RC-layer as given in Table 2. The other parameters of proposed model are given in Table 3.

Analysis of Numerical Results:
We may assume that the objective functions of proposed SSCM model are considered in real life environment. Here we may solve the proposed multiple objectives SSCM model with imprecise objective functions by employing IFT-sets. In order to determine the $T^{+}-$characteristic functions and $T^{-}-$characteristic functions of IFT-objective functions, we may compute individual maximum and minimum values of objective functions subject to given constraints and obtain optimal values of single objective optimization models as given in Table 4.

Table-1: Product Demand and Used-Product Return

Time Interval	Product Demand	Used-Product Return $(\gamma = 0.25)$
1	4290	1072
2	4263	1065
3	4049	1012
4	4115	1028

Table-2: Unit Revenues for MC-layer and RC-layer of SSCM Model

Parameters	Unit Revenues ($)	
	Lower Bound	Upper Bound
MC-layer		
Suppliers of raw materials $R_{sk}(\mu)$	29	55
Plants $R_{kj}(\mu)$	360	610
Distribution Centers $R_{ji}(\mu)$	521	825
Customer $R_{ix}(\mu)$	0	5

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RC-layer		
Collecting points $R_{xt}(\mu)$	4.3	6.8
Recycle plants $R_{tm}(\mu)$	6.1	9.5
Secondary material markets $R_{mk}(\mu)$	15.	30

Table-3: Summary of Other Parameters

Parameters	Values	Parameters	Values
Government subsidy $S_{tm}(\mu)$	8.7	Physical transformation rate of finished products, manufactured from raw materials $\tau^{r/m}$	1
Physical transformation rate of treated items from untreated items $\tau^{u/m}$	0.8	Physical transformation rate of waste items from untreated items $\tau^{u/w}$	0.2
Used-product return flow ratio γ	0.25	Weights associated with MC- chain and RC-chain	1, 1
Maximum allowable number of open plants P	1	Maximum allowable number of open DCs W	1
Minimum Inventory Capacities		*Maximum Inventory Capacities*	
Suppliers $\inf_s(\mu)$	0	Suppliers $\sup_s(\mu)$	5000
Plants $\inf_k(\mu)$	0	Plants $\sup_k(\mu)$	5000
DCs $\inf_j(\mu)$		DCs $\sup_j(\mu)$	5000
Collecting points $\inf_x(\mu)$	0	Collecting points $\sup_x(\mu)$	3000
Untreated items at recycle plants $\inf_t^u(\mu)$	0	Untreated items at recycle plants $\sup_t^u(\mu)$	1000
Treated items at recycle plants $\inf_t^m(\mu)$	0	Treated items at recycle plants $\sup_t^m(\mu)$	1000
Waste items at recycle plants $\inf_t^w(\mu)$	0	Waste items at recycle plants $\sup_t^w(\mu)$	1000
Secondary material markets $\inf_m(\mu)$	0	Secondary material markets $\sup_m(\mu)$	2000
Disposal Locations $\inf_w(\mu)$	0	Disposal Locations $\sup_w(\mu)$	1000

Table-4: Individual Maximum and Minimum Values of Objective Functions

Objective Functions	Maximum Values	Minimum Values
Aggregate revenue AR_{SSCM}	2,80,33,520	10,442
Customer satisfaction index CS_{SSCM}	4	0

Table-5: Comparison of Results of Proposed SSCM Model

Optimal Values	IFT-Environment	IF Environment	Remarks
AR_{SSCM}	$\$2,00,79,224$	$1,75,06,749	The optimal values of both the objective functions of proposed SSCM model are more preferable than the values obtained under classical IF environment.
CS_{SSCM}	4	3.5	

Next we may suppose that the DM desires the maximum value of aggregate revenue AR_{SSCM} as $ 11,390,000 with acceptable tolerance level at $ 1,13,900; but its value must not be less than $ 1,00,000. Further suppose that DM desires the maximum value of customer satisfaction index CS_{SSCM} as 3.5 with acceptable tolerance level at 2.5; but its value must not be less than 2.

Based on the pre-determined goals and tolerances, we may construct $T^{+}-$ characteristic functions and $T^{-}-$ characteristic functions of IFT-objective functions AR_{SSCM} and CS_{SSCM} as follows [25-26]

$$T^{+}(AR_{SSCM})=\frac{AR_{SSCM}-1,13,900}{11276100},\forall AR_{SSCM}\ ;\ T^{-}(AR_{SSCM})=\frac{1,13,90,000-AR_{SSCM}}{11290000},\forall AR_{SSCM}$$

$$T^{+}(CS_{SSCM})=\frac{CS_{SSCM}-2.5}{1},\forall CS_{SSCM}\ ;T^{-}(CS_{SSCM})=\frac{3.5-CS_{SSCM}}{1.5},\forall CS_{SSCM}$$

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We use LINGO 17 to solve the optimization model having around 131 constraints and 87 variables including 3 binary integer variables. Here we apply the optimization method under IFT-environment and obtain the Pareto optimal solution as follows

$$AR_{SSCM}* = \$2,00,79,224,\ CS_{SSCM}* = 4\ .$$

Here we may observe that the optimal values of both the objective functions are superior to the respective goals. Next we may compare the relative performance of proposed method by comparing the results with those obtained by employing existing classical intuitionistic fuzzy technique, as presented in Table 5.

6. CONCLUSIONS

In this paper, we present one customer satisfaction and environmental concern based multiple objective optimization model for sustainable management of supply chain in real life environment. We have extensively reviewed the literature and can find lesser number of optimization based supply chain management studies. And even in most of these studies, scientists have either considered only one objective function, or applied utilization functions, weights etc. to convert multiple objective SSCM models into single objective optimization models. But we know it well that using multiple objective SSCM model and thereby yielding Pareto optimal solution has several advantages over finding optimal solution to single objective optimization model, especially in real life cases. And present study is unique, since the proposed SSCM model considers aggregate revenue and customer satisfaction index, two major performance indicators for sustainable management of supply chain, as objective functions simultaneously, along with the impact of SCM activities on the environment and develops into one multiple objective optimization model.

On the other hand in idealistic perspective, we may find in real life based optimization models that the most important purpose to maximize the up-gradation of most misfortunate is better served when some constraints present in existing, well established techniques, are removed [27]. In existing optimization methods under IF environment, membership and non membership functions of IF objective function are found not to be utilized in the way that it is defined [25-26]. In this paper, we solve the proposed SSCM model in real life based environment by making use of one new set, namely IFT-set. We may note that IFT-set, which was suggested by the author [25], can be employed to supersede classical IF set in representing uncertainty or real life environment more precisely. In this paper, the numerical results demonstrate that the Pareto optimal solution to proposed SSCM model in IFT-environment is more preferable to decision maker than corresponding Pareto optimal solution in classical IF environment. In this way, we seem to further ascertain that IFT-set can be more appropriate tool in representing real life cases.

Additionally, present study is unique even if the proposed SSCM model is considered in crisp environment or classical IF environment.

We can find lot of scopes for further improvement of proposed SSCM model. The numerical study presented in this paper is much simplified. We may consider more general data sets, e.g. much large number of plants, DCs, recycle plants, collecting points etc. in future studies on sustainable SSCM model. Further, we may take up extensive empirical and analytical surveys and develop this model further. Also, we may upgrade the customer satisfaction index by considering its other aspects. Furthermore we may take up net profit instead of aggregate revenue as objective function. Also, we may take up other performance indicators like corporate social responsibility, agility, security, sharing of customer-data among businesses, adoption of futuristic technologies as objective functions in future studies. We may consider longer or shorter time frame as per requirement of industries. And last but not the least, we may solve proposed SSCM model in other environments e.g., fuzzy environment, neutrosophic environment, soft environment, rough environment etc.

REFERENCES

1. Agnihotri, Raj, Rebecca Dingus, Michael Y. Hu, and Michael T. Krush. "Social Media: Influencing Customer Satisfaction in B2B Sales." *Industrial Marketing Management* 53 (2016), 172-180.
2. Altiparmak, Fulya, Mitsuo Gen, Lin Lin, and Turan Paksoy. "A Genetic Algorithm Approach for Multi-objective Optimization of Supply Chain Networks." *Computers & Industrial Engineering* 51.1 (2006), 196-215.
3. Anderson, Eugene W., and Mary W. Sullivan. "The Antecedents and Consequences of Customer Satisfaction for Firms." *Marketing Science* 12.2 (1993), 125-143.
4. Anderson, Eugene W., Claes Fornell, and Donald R. Lehmann. "Customer Satisfaction, Market Share, and Profitability: Findings from Sweden." *Journal of Marketing* 58.3 (1994), 53-66.

5. Angelova, Biljana, and Jusuf Zekiri. "Measuring Customer Satisfaction with Service Quality Using American Customer Satisfaction Model (ACSI Model)." *International Journal of Academic Research in Business and Social Sciences* 1.3 (2011), 232-258.
6. Attaran, Mohsen, and Sharmin Attaran. "Collaborative Supply Chain Management." *Business Process Management Journal* 13.3 (2007), 390-404.
7. Bellman, R. E., and L. A. Zadeh. "Decision-Making in a Fuzzy Environment." *Management Science* 17.4 (1970), B-141-B-164.
8. Bhattacharya, Arijit, Priyabrata Mohapatra, Vikas Kumar, Prasanta Kumar Dey, Malcolm Brady, Manoj Kumar Tiwari, and Sai S. Nudurupati. "Green Supply Chain Performance Measurement Using Fuzzy ANP-based Balanced Scorecard: A Collaborative Decision-making Approach." *Production Planning & Control* 25.8 (2013), 698-714.
9. Bowen, Frances E., Paul D. Cousins, Richard C. Lamming, and Adam C. Farukt. "The Role Of Supply Management Capabilities In Green Supply." *Production and Operations Management* 10.2 (2009), 174-189.
10. Brandenburg, Marcus, Gerd J. Hahn, and Tobias Rebs. *Social and Environmental Dimensions of Organizations and Supply Chains: Tradeoffs and Synergies*. Springer, 2018.
11. Cardozo, Richard N. "An Experimental Study of Customer Effort, Expectation, and Satisfaction." *Journal of Marketing Research* 2.3 (1965), 244-249.
12. Carter, Craig R., and Dale S. Rogers. "A Framework of Sustainable Supply Chain Management: Moving toward New Theory." *International Journal of Physical Distribution & Logistics Management* 38.5 (2008), 360-387.
13. Carter, Craig R., and P. Liane Easton. "Sustainable Supply Chain Management: Evolution and Future Directions." *International Journal of Physical Distribution & Logistics Management* 41.1 (2011), 46-62.
14. Churchill, Gilbert A., and Carol Surprenant. "An Investigation into the Determinants of Customer Satisfaction." *Journal of Marketing Research* 19.4 (1982), 491-504.
15. Cronin, J.joseph, Michael K. Brady, and G.tomas M. Hult. "Assessing the Effects of Quality, Value, and Customer Satisfaction on Consumer Behavioral Intentions in Service Environments." *Journal of Retailing* 76.2 (2000), 193-218.
16. Deng, Zhaohua, Yaobin Lu, Kwok Kee Wei, and Jinlong Zhang. "Understanding Customer Satisfaction and Loyalty: An Empirical Study of Mobile Instant Messages in China." *International Journal of Information Management* 30.4 (2010), 289-300.
17. Diabat, Ali, and Kannan Govindan. "An Analysis of the Drivers Affecting the Implementation of Green Supply Chain Management." *Resources, Conservation and Recycling* 55.6 (2011), 659-667.
18. Elhedhli, Samir, and Ryan Merrick. "Green Supply Chain Network Design to Reduce Carbon Emissions." *Transportation Research Part D: Transport and Environment* 17.5 (2012), 370-379. .
19. Eltayeb, Tarig K., Suhaiza Zailani, and T. Ramayah. "Green Supply Chain Initiatives among Certified Companies in Malaysia and Environmental Sustainability: Investigating the Outcomes." *Resources, Conservation and Recycling* 55.5 (2011), 495-506. .
20. Fahimnia, Behnam, Joseph Sarkis, and Hoda Davarzani. "Green Supply Chain Management: A Review and Bibliometric Analysis." *International Journal of Production Economics* 162 (2015), 101-114.
21. Flint, Daniel J., Christopher P. Blocker, and Philip J. Boutin. "Customer Value Anticipation, Customer Satisfaction and Loyalty: An Empirical Examination." *Industrial Marketing Management* 40.2 (2011): 219-230.
22. Fornell, Claes. "A National Customer Satisfaction Barometer: The Swedish Experience." *Journal of Marketing* 56.1 (1992), 6-21.
23. Fornell, Claes, Michael D. Johnson, Eugene W. Anderson, Jaesung Cha, and Barbara Everitt Bryant. "The American Customer Satisfaction Index: Nature, Purpose, and Findings." *Journal of Marketing* 60.4 (1996), 7-18.
24. Fornell, Claes, Sunil Mithas, Forrest V. Morgeson, and M.s. Krishnan. "Customer Satisfaction and Stock Prices: High Returns, Low Risk." Journal of Marketing 70.1 (2006), 3-14.
25. Garai, Arindam, Palash Mandal, and Tapan Kumar Roy. “Intuitionistic fuzzy T-sets based solution technique for multiple objective linear programming problems under imprecise environment.“ Notes on Intuitionistic Fuzzy Sets 21.4, (2015), 104–123.
26. Garai, Arindam, Palash Mandal, and Tapan Kumar Roy. "Intuitionistic Fuzzy T-sets Based Optimization Technique for Production-distribution Planning in Supply Chain Management." *OPSEARCH* 53.4 (2016), 950-975.
27. Garai, Arindam, Palash Mandal, and Tapan Kumar Roy. "Multipollutant Air Quality Management Strategies: T-SetsÂ Based Optimization Technique Under Imprecise Environment." *International Journal of Fuzzy Systems* 19.6 (2017), 1927-1939.

28. Gold, Stefan, Stefan Seuring, and Philip Beske. "Sustainable Supply Chain Management and Inter-organizational Resources: A Literature Review." *Corporate Social Responsibility and Environmental Management* (2009).
29. Govindan, Kannan, Mathiyazhagan Kaliyan, Devika Kannan, and A.n. Haq. "Barriers Analysis for Green Supply Chain Management Implementation in Indian Industries Using Analytic Hierarchy Process." *International Journal of Production Economics* 147 (2014), 555-568.
30. Green, Kenneth W., Pamela J. Zelbst, Jeramy Meacham, and Vikram S. Bhadauria. "Green Supply Chain Management Practices: Impact on Performance." *Supply Chain Management: An International Journal* 17.3 (2012), 290-305.
31. Guu, Sy-Ming, and Yan-Kuen Wu. "Weighted Coefficients in Two-phase Approach for Solving the Multiple Objective Programming Problems." *Fuzzy Sets and Systems* 85.1 (1997), 45-48.
32. Handfield, Robert B., and Ernest L. Nichols. Introduction to Supply Chain Management. Prentice Hall, 1999. ISBN: 978-0136216162.
33. Hennigâ□□Thurau, Thorsten, and Alexander Klee. "The Impact of Customer Satisfaction and Relationship Quality on Customer Retention: A Critical Reassessment and Model Development." *Psychology and Marketing* 14.8 (1997), 737-764. .
34. Hervani, Aref A., Marilyn M. Helms, and Joseph Sarkis. "Performance Measurement for Green Supply Chain Management." *Benchmarking: An International Journal* 12.4 (2005), 330-353.
35. Hsu, Chia-Wei, Tsai-Chi Kuo, Sheng-Hung Chen, and Allen H. Hu. "Using DEMATEL to Develop a Carbon Management Model of Supplier Selection in Green Supply Chain Management." *Journal of Cleaner Production* 56 (2013), 164-172.
36. Hussain, Rahim, Amjad Al Nasser, and Yomna K. Hussain. "Service Quality and Customer Satisfaction of a UAE-based Airline: An Empirical Investigation." *Journal of Air Transport Management* 42 (2015), 167-175.
37. Jabbour, Charbel JosÃ© Chiappetta, and Ana Beatriz Lopes De Sousa Jabbour. "Green Human Resource Management and Green Supply Chain Management: Linking Two Emerging Agendas." *Journal of Cleaner Production* 112 (2016), 1824-1833.
38. Kannan, Devika, Roohollah Khodaverdi, Laya Olfat, Ahmad Jafarian, and Ali Diabat. "Integrated Fuzzy Multi Criteria Decision Making Method and Multi-objective Programming Approach for Supplier Selection and Order Allocation in a Green Supply Chain." *Journal of Cleaner Production* 47 (2013), 355-367.
39. Kim, Miran, Christine A. Vogt, and Bonnie J. Knutson. "Relationships Among Customer Satisfaction, Delight, and Loyalty in the Hospitality Industry." *Journal of Hospitality & Tourism Research* 39.2 (2013), 170-197.
40. Kuo, Ying-Feng, Chi-Ming Wu, and Wei-Jaw Deng. "The Relationships among Service Quality, Perceived Value, Customer Satisfaction, and Post-purchase Intention in Mobile Value-added Services." *Computers in Human Behavior* 25.4 (2009), 887-896.
41. Lun, Y.h. Venus, Kuo-Chung Shang, Kee-Hung Lai, and T.c.e. Cheng. "Examining the Influence of Organizational Capability in Innovative Business Operations and the Mediation of Profitability on Customer Satisfaction: An Application in Intermodal Transport Operators in Taiwan." *International Journal of Production Economics* 171 (2016), 179-188.
42. Luthra, Sunil, Dixit Garg, and Abid Haleem. "An Analysis of Interactions among Critical Success Factors to Implement Green Supply Chain Management towards Sustainability: An Indian Perspective." *Resources Policy* 46 (2015), 37-50.
43. Luthra, Sunil, Vinod Kumar, Sanjay Kumar, and Abid Haleem. "Barriers to Implement Green Supply Chain Management in Automobile Industry Using Interpretive Structural Modeling Technique: An Indian Perspective." *Journal of Industrial Engineering and Management* 4.2 (2011).
44. Markova, Sonja; Petkovska-Mirčevska, Tatjana: "Social Media and Supply Chain", Amfiteatru Economic Journal, 15 (33), (2013), 89-102.
45. Mirhedayatian, Seyed Mostafa, Majid Azadi, and Reza Farzipoor Saen. "A Novel Network Data Envelopment Analysis Model for Evaluating Green Supply Chain Management." *International Journal of Production Economics* 147 (2014), 544-554.
46. Orel, Fatma Demirci, and Ali Kara. "Supermarket Self-checkout Service Quality, Customer Satisfaction, and Loyalty: Empirical Evidence from an Emerging Market." Journal of Retailing and Consumer Services 21.2 (2014), 118-129.
47. Pagell, Mark, and Zhaohui Wu. "Building A More Complete Theory Of Sustainable Supply Chain Management Using Case Studies Of 10 Exemplars." Journal Of Supply Chain Management. Blackwell Publishing Inc, 45.2 (2009), 37-56.
48. Ren, Lianping, Hanqin Qiu, Peilai Wang, and Pearl M.c. Lin. "Exploring Customer Experience with Budget Hotels: Dimensionality and Satisfaction." *International Journal of Hospitality Management* 52 (2016), 13-23.

49. Rust, Roland T., and Anthony J. Zahorik. "Customer Satisfaction, Customer Retention, and Market Share." *Journal of Retailing* 69.2 (1993), 193-215.
50. Ryu, Kisang, Hyeâ□Rin Lee, and Woo Gon Kim. "The Influence of the Quality of the Physical Environment, Food, and Service on Restaurant Image, Customer Perceived Value, Customer Satisfaction, and Behavioral Intentions." *International Journal of Contemporary Hospitality Management* 24.2 (2012): 200-223.
51. Sabri, Ehap H., and Benita M. Beamon. "A Multi-objective Approach to Simultaneous Strategic and Operational Planning in Supply Chain Design." *Omega* 28.5 (2000), 581-598.
52. Saeidi, Sayedeh Parastoo, Saudah Sofian, Parvaneh Saeidi, Sayyedeh Parisa Saeidi, and Seyyed Alireza Saaeidi. "How Does Corporate Social Responsibility Contribute to Firm Financial Performance? The Mediating Role of Competitive Advantage, Reputation, and Customer Satisfaction." *Journal of Business Research* 68.2 (2015), 341-350.
53. Sarkis, Joseph. "A Boundaries and Flows Perspective of Green Supply Chain Management." *Supply Chain Management: An International Journal* 17.2 (2012), 202-216.
54. Sarkis, Joseph, Qinghua Zhu, and Kee-Hung Lai. "An Organizational Theoretic Review of Green Supply Chain Management Literature." *International Journal of Production Economics* 130.1 (2011), 1-15.
55. Sarkis, Joseph. "A Strategic Decision Framework for Green Supply Chain Management." *Journal of Cleaner Production* 11.4 (2003), 397-409. .
56. Seuring, Stefan, and Martin MÃ¼ller. "From a Literature Review to a Conceptual Framework for Sustainable Supply Chain Management." *Journal of Cleaner Production* 16.15 (2008), 1699-1710.
57. Seuring, Stefan, and Stefan Gold. "Sustainability Management beyond Corporate Boundaries: From Stakeholders To Â performance." *Journal of Cleaner Production* 56 (2013), 1-6.
58. Seuring, Stefan. "A Review of Modeling Approaches for Sustainable Supply Chain Management." *Decision Support Systems* 54.4 (2013), 1513-1520.
59. Sheu, Jiuh-Biing, Yi-Hwa Chou, and Chun-Chia Hu. "An Integrated Logistics Operational Model for Green-supply Chain Management." *Transportation Research Part E: Logistics and Transportation Review* 41.4 (2005), 287-313.
60. Siddiqi, Kazi Omar. "Interrelations between Service Quality Attributes, Customer Satisfaction and Customer Loyalty in the Retail Banking Sector in Bangladesh." *International Journal of Business and Management* 6.3 (2011), 12-36.
61. Smith, Amy K., Ruth N. Bolton, and Janet Wagner. "A Model of Customer Satisfaction with Service Encounters Involving Failure and Recovery." *Journal of Marketing Research* 36.3 (1999), 356-372.
62. Srivastava, Samir K. "Green Supply-chain Management: A State-of-the-art Literature Review." *International Journal of Management Reviews* 9.1 (2007), 53-80.
63. Svensson, GÃ¶ran. "Aspects of Sustainable Supply Chain Management (SSCM): Conceptual Framework and Empirical Example." *Supply Chain Management: An International Journal* 12.4 (2007), 262-266.
64. Szymanski, D. M., and D. H. Henard. "Customer Satisfaction: A Meta-Analysis of the Empirical Evidence." *Journal of the Academy of Marketing Science* 29.1 (2001), 16-35.
65. Testa, Francesco, and Fabio Iraldo. "Shadows and Lights of GSCM (Green Supply Chain Management): Determinants and Effects of These Practices Based on a Multi-national Study." *Journal of Cleaner Production* 18.10-11 (2010), 953-962.
66. Tseng, Ming-Lang, and Anthony S.f. Chiu. "Evaluating Firm's Green Supply Chain Management in Linguistic Preferences." *Journal of Cleaner Production* 40 (2013), 22-31.
67. Walker, Helen, and Neil Jones. "Sustainable Supply Chain Management across the UK Private Sector." *Supply Chain Management: An International Journal* 17.1 (2012), 15-28.
68. Walker, Helen, Stefan Seuring, Joseph Sarkis, Robert Klassen. "Sustainable Operations Management: Recent Trends and Future Directions." *International Journal of Operations & Production Management* 34.5 (2014). DOI: 10.1108/IJOPM-12-2013-0557.
69. Wang, Fan, Xiaofan Lai, and Ning Shi. "A Multi-objective Optimization for Green Supply Chain Network Design." *Decision Support Systems* 51.2 (2011), 262-269.
70. Wu, Ing-Long. "The Antecedents of Customer Satisfaction and Its Link to Complaint Intentions in Online Shopping: An Integration of Justice, Technology, and Trust." *International Journal of Information Management* 33.1 (2013), 166-176.
71. Wu, Yan-Kuen, Chia-Cheng Liu, and Yung-Yih Lur. "Pareto-optimal Solution for Multiple Objective Linear Programming Problems with Fuzzy Goals." *Fuzzy Optimization and Decision Making* 14.1 (2014), 43-55.
72. Yeh, Wei-Chang, and Mei-Chi Chuang. "Using Multi-objective Genetic Algorithm for Partner Selection in Green Supply Chain Problems." *Expert Systems with Applications* 38.4 (2011), 4244-4253.
73. Zadeh, L.a. "Fuzzy Sets." *Information and Control* 8.3 (1965), 338-353.

74. Zhu, Qinghua, Joseph Sarkis, and Kee-Hung Lai. "Confirmation of a Measurement Model for Green Supply Chain Management Practices Implementation." *International Journal of Production Economics* 111.2 (2008), 261-273.
75. Zhu, Qinghua, Joseph Sarkis, and Kee-Hung Lai. "Institutional-based Antecedents and Performance Outcomes of Internal and External Green Supply Chain Management Practices." *Journal of Purchasing and Supply Management* 19.2 (2013), 106-117.
76. Zimmermann, Hans-J. "Description And Optimization Of Fuzzy Systems." *International Journal of General Systems* 2.4 (1976), 209-215.
77. Zimmermann, H.-J. "Fuzzy Programming and Linear Programming with Several Objective Functions." *Fuzzy Sets and Systems* 1.1 (1978), 45-55.
78. Zimmermann, H.-J. "Applications of Fuzzy Set Theory to Mathematical Programming." *Information Sciences* 36.1-2 (1985), 29-58.

- **List of symbols and their descriptions**

Symbols	***Descriptions***
Indices	
$s \in S$	Supplier *'s'* among total *'S'* suppliers (of raw materials)
$k \in K$	Plant *'k'* among total *'K'* plants
$j \in J$	DC *'j'* among total *'J'* DC
$i \in I$	Customer *'i'* among total *'I'* customers
$x \in X$	Collecting point *'x'* among total *'X'* collecting points
$t \in P_R$	Recycle plant *'t'* among total 'P_R' recycle plants
$m \in M$	Secondary material market *'m'* among total *'M'* secondary material markets
$w \in W$	Final disposal location *'w'* among total *'W'* final disposal locations

Variables and Parameters

$q_s(\mu)$	Time varying amount of raw material acquired by any given supplier *'s'* in given time interval μ
$q_k(\mu)$	Time varying amount of products manufactured at any given plant *'k'* from raw materials therein in given time interval μ
$(qi)_s(\mu)$	Time varying amount of raw materials in inventory associated with any given supplier *'s'* in any given time interval μ
$(qi)_k(\mu)$	Time varying amount of both raw materials and manufactured products in inventory associated with any given plant *'k'* in any given time interval μ
$(qi)_j(\mu)$	Time varying amount of manufactured products in inventory associated with any given DC *'j'* in any given time interval μ
$(ri)_x(\mu)$	Time varying amount of used items in inventory associated with any given collecting point *'x'* in any given time interval μ
$(ri)_t(\mu)$	Time varying amount of untreated items in inventory associated with any given recycle plant *'t'* in any given time interval μ
$(rt)_t(\mu)$	Time varying amount of untreated items in inventory put to use for recycling associated with any given recycle plant *'t'* in given time interval μ
$(ritm)_t(\mu)$	Time varying amount of treated items in inventory associated with any given recycle plant *'t'* in any given time interval μ
$(ritw)_t(\mu)$	Time varying amount of waste items in inventory associated with any given recycle plant *'t'* in any given time interval μ
$\left((ri)_m(\mu)\right)$	Time varying amount of treated items in inventory associated with any given secondary material market *'m'* in any given time interval μ
$\left((ri)_w(\mu)\right)$	Time varying amount of waste items in inventory associated with any given final disposal location *'w'* in any given time interval μ
$\left((rf)_w(\mu)\right)$	Time varying amount of wastages, disposed off at any given final disposal location *'w'* in given time interval μ

$b_{sk}(\mu)$	Number of raw materials transported from supplier '*s*' to plant '*k*' in given time interval μ
$f_{kj}(\mu)$	Number of manufactured products transported from plant '*k*' to DC '*j*' in given time interval μ
$q_{ji}(\mu)$	Number of manufactured products transported from DC '*j*' to customer '*i*' in given time interval μ
$(qr)_{ix}(\mu)$	Number of used products returned from customer '*i*' to collecting point '*x*' in given time interval μ
$r_{xt}(\mu)$	Number of used products transported from collecting point '*x*' to recycle plant '*t*' in given time interval μ
$r_{tw}(\mu)$	Number of untreated items transported from recycle plant '*t*' to final disposal location '*w*' in given time interval μ
$r_{tm}(\mu)$	Number of treated items transported from recycle plant '*t*' to secondary material market '*m*' in given time interval μ
$(rq)_{mk}(\mu)$	Number of treated items transported from secondary material market '*m*' to plant '*k*' in given time interval μ
$d_i(\mu)$	Time varying demand of manufactured products of customer '*i*' in given time interval μ
T	Total time period
μ	Given time interval
O_p	Number of open plant
O_D	Number of open distribution center
$\tau^{r/m}$	Physical transformation rate of manufactured products from raw materials
$\tau^{u/m}$	Physical transformation rate of treated items from untreated items
$\tau^{u/w}$	Physical transformation rate of waste items from untreated items

Coefficients of objective functions

$R_{sk}(\mu)$	Revenue of supplier '*s*' associated with one unit of raw material transported to plant '*k*'
$R_{kj}(\mu)$	Revenue of plant '*k*' associated with one unit of finished product transported to DC '*j*'
$R_{ji}(\mu)$	Revenue of DC '*j*' associated with one unit of finished product transported to customer '*i*'
$R_{ix}(\mu)$	Compensation received by customer '*i*' associated with one unit of used product returned to collecting point '*x*'
$R_{xt}(\mu)$	Revenue of collecting point '*x*' associated with one unit of used product transported to recycle plant '*t*'
$R_{tm}(\mu)$	Revenue of recycle plant '*t*' associated with one unit of treated item transported to secondary material market '*m*'
$R_{mk}(\mu)$	Revenue of secondary material market '*m*' associated with one unit of treated item transported to plant '*k*'
$S_{tm}(\mu)$	Subsidy associated with one unit of treated item sent to secondary material market '*m*', received by recycle plant '*t*' as a green reverse chain member from Governments/environmental protection agencies

Objective functions

AR_{SSCM}	Aggregate revenue of proposed SSCM
TR_{mc}	Combined time varying amount of revenue associated with given manufacturing chain within given total time period
TD_{rc}	Combined time varying amount of revenue associated with given reverse chain within given total time period
TS_{mc}	Combined time varying amount of government subsidies associated with given reverse chain within given total time period
CS_{SSCM}	Combined time varying amount of customer satisfaction within given total time period T

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