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RESEARCH PAPER

Multi-Objective Fuzzy Programming Model to Design a Sustainable Supply Chain Network Considering Disruption

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ABSTRACT

Sustainable supply chain networks have attracted considerable attention in recent years as a means of dealing with a broad range of environmental and social issues. This paper considered a multi-objective Mixed-Integer Linear Programming (MILP) model and applied it to the design of a sustainable closed-loop supply chain network under uncertain conditions. The proposed model aims to minimize total cost and optimize environmental impacts of establishment of facilities, processing and transportation between each level, and social impacts including customer satisfaction. Due to the variability of the business environment, uncertainty exists in the research problem; hence, this paper applied the chance-constrained fuzzy programming approach to deal with uncertainties associated with the parameters of the proposed model. Then, the proposed multi-objective model solves the single-objective model using LP-metric method.

KEYWORDS: *Supply chain management; Sustainable supply chain; Closed-loop supply chain; Fuzzy optimization; Multi-objective programming.*

1. Introduction

Nowadays, concerns about environmental and social impacts of business activities have changed the operation mode of traditional supply chain networks. Sustainable Supply Chain Networks (SSCNs) have drawn researchers' attention as a means of dealing with a broad range of environmental and social issues. In logistics network design, sustainable development depends on the social dimension in addition to the economic and environmental aspects. Therefore, companies are now seeking a trade-off between sustainability criteria aimed at minimizing total cost and the environmental impact and optimizing social issue. Several factors may be involved n sustainability initiatives such as efficient energy use, job opportunities, renewable resource, work damage, greenhouse gas emissions, recycling, and costumer satisfaction. The relevant initiatives will differ among various researchers and different industries. For designing and operating sustainable bioelectricity supply chain networks, Yue et al. [1] presented a multi-objective optimization model which considered all three dimensions simultaneously: environmental, economic, and social factors. They considered GHG footprint as an environmental metric and the local job opportunities as a social metric. Vafaeenezhad et al. [2] developed a multi-objective linear programming model for a multi-echelon, multi-product, multi-period supply chain planning, which considered all dimensions of sustainable development paradigm simultaneously. They considered three environmental objectives, namely GHG emissions, consumed energy, and generated wastes. Two social objectives are considered as the total travel distance of employees and total number of hires and lay-offs. For the economic objective, we have to integrate three subsets of planning problems.

In recent years, due to harmful effects exerted on the environment and the high volume waste created during the production of the products, the Closed-Loop Supply Chain (CLSC) is of high significance. Stindt et al. [3] pointed out the role of a CLSC when there are both forward and reverse supply chains. Forward logistics includes

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activities that support the conversion of raw materials to finished products consisting of suppliers, manufacturers, distributors, and warehouse. Reverse logistics involves all the matters related to collecting the used products, as well as recycling, remanufacturing, refurbishing, and disposing of them. If both forward and reverse supply chains are considered simultaneously, the resulting network is referred to as a closed-loop supply chain. According to Guide et al. [4], a CLSC aimed to improve the sustainable performance of supply chain that contains forward and reverse logistics activities. Kannan et al. [5] studied integrated forward and reverse logistics to develop a forward logistics closed-loop multi echelon distribution inventory supply chain model. Pishvaee et al. [6] presented a robust optimization model to manage the uncertainty associated with the closed-loop supply chain network design. Anil Jindal et al. [7] developed a network design for closed-loop supply chain and optimized it for multi-period multi-product under uncertainty which was associated with product demand, return volume, and fraction of parts recovered for different product recovery processes.

Apart from environmental considerations, an effective supply chain network design calls for contemplating disruption risks caused by major incidents (e.g., earthquakes, floods, terrorist attacks, hurricanes, etc.) and operational contingencies (e.g., equipment failures, power outages, supplier discontinuities, industrial accidents, etc.) Hasani et al. [8], Baghalian et al. [9], and Fahimnia et al. [10]. Disruption risks can affect transportation costs, order delays, inventory shortages, customer losses, and companies' economic performance [11]. It is assumed that suppliers, production centers, collection centers, and warehouses may be subject to accidental disruption and may not utilize their full capacity. In other words, the capacities of suppliers and different facilities can be partially or completely affected when a disruption occurs. Jabbarzadeh et al. [12] presented a stochastic robust optimization model for designing a closed-loop supply chain network that performs resiliently in the face of disruptions. Yavari et al. [13] presented an integrated two-layer network model for designing a resilient green closed-loop supply chain of perishable products under disruption.

Another main challenge of the supply chain is the existence of various uncertainties related to demand, production, transportation, operation, and prices. Several ways have been suggested to consider uncertainties including applying fuzzy logic. Hatefi and Jolai [14] proposed a robust and reliable model for an integrated forward-reverse logistics network design under demand uncertainty and facility disruption. The proposed model was formulated based on a robust optimization approach to protecting the network against uncertainty.

The remainder of this paper is organized as follows. Section 2 defines the problem and presents a mathematical model. Section 3 gives the experimental results. Finally, Section 4 offers a discussion and some suggestions for future works.

2. Problem Definition

This study presents a multi-period, multi-product, multi-echelon model of closed-loop supply chain network design encompassing suppliers, manufacturers, warehouses, retailers, and collection centers. Raw materials required for production are provided from suppliers for manufacturers. Then, the final products are transferred from manufacturers to retailers via warehouses. Products that do not ensure customer satisfaction are returned to collection centers. At the collection center, the products are separated and usable returned items are sent to manufacturers as semi-prepared products (not raw materials). Products that are manufactured from returned items remain less expensive. The proposed CLSC model is multi-objective and, in addition to the cost minimization, comprises the environmental and social objectives. Furthermore, the demands and transportation costs uncertain parameters. Figure 1 shows the network designed in this study.

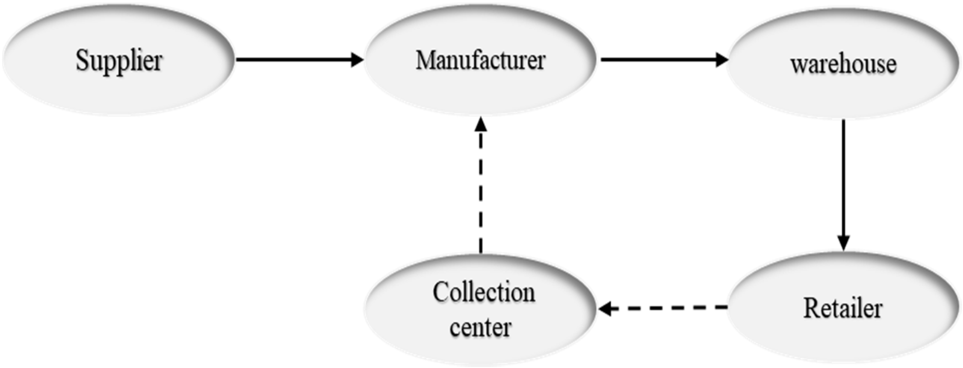

Fig. 1. Proposed supply chain network

2.1. Model assumption

-Model is a multi-product, multi-period, and multi-echelon.

-Demand and transportation costs are under uncertainty.

-Capacities of suppliers, manufacturer, collection centers, and warehouse are vulnerable to random disruptions.

-The flow of products, parts, and materials can occur only in between two consecutive stages; inter-stage flow is not allowed.

2.2. Indices

c:	Index of potential locations of collection centers (*c* =1, 2,...,*C*)
i:	Index of products (*i* =1, 2,..., *I*)
i_b :	Index of single-source products
i_c :	Index of bi-source products
m:	Index of potential locations of manufacturers (*m* =1, 2,...,*M*)
r:	Index of fixed locations of retailers (*r* =1, 2,...,*R*)
s:	Index of fixed locations of suppliers (*s* =1, 2,...,*S*)
t:	Index of time periods (*t* =1, 2,...,*T*)
w:	Index of potential locations of warehouses (*w* =1,2,...,*W*)

2.3. Parameters

$a_{ij} = \begin{cases} 1 \\ 0 \end{cases}$:	if returned product *j* was usable in producing product *I* otherwise;
COM_{imt} :	unit manufacturing cost of product *i* at the manufacturer *m* in time period *t*
DR_{irt} :	demand of retailer *r* for product *i* in time period *t*
EC_c :	environmental impacts of opening collection center *c*
EM_m :	environmental impacts of opening manufacturer *m*
EW_w :	environmental impacts of opening warehouse *w*
EIC_{ic} :	environmental impacts of inventory holding of product *i* at collection center *c*
EIM_{im} :	environmental impacts of inventory holding of product *i* at manufacturer *m*
EIW_{iw} :	environmental impacts of inventory holding of product *i* at warehouse *w*

EIR_{ir} :	environmental impacts of inventory holding of product *i* at retailer *r*
ETC_{icm} :	environmental impacts of shipping product *j* from collection center *c* to manufacturer *m*
ETM_{imw} :	environmental impacts of the shipping of product *i* from manufacturer *m* to warehouse *w*
ETR_{rc} :	environmental impacts related to the trips of pre-allocated trucks from retailer *r* to collection center *c*
ETS_{sm} :	environmental impacts for the shipment from supplier *s* to manufacturer *m*
ETW_{wr} :	environmental impacts related to the trips of pre-allocated trucks from warehouse *w* to retailer *r*
FCC_{c} :	fixed cost for opening the collection center *c*
FCM_{m} :	fixed cost for opening the manufacturer *m*
FCW_{w} :	fixed cost for opening the warehouse *w*
hc_{ic} :	unit inventory holding cost of product *i* at collection center *c* in each time period
hm_{im} :	unit inventory holding cost of product *i* at manufacturer *m* in each time period
hr_{ir}:	unit inventory holding cost of product *i* at retailer *r* in each time period
hw_{iw} :	unit inventory holding cost of product *i* at warehouse *w* in each time period
β_{it}:	total number of returned products *i*
LC_{c} :	capacity of collection center *c*
LM_{m} :	capacity of manufacturer *m*
LS_{s} :	capacity of supplier *s*
LW_{w} :	capacity of warehouse *w*
PCR_{irct} :	unit purchasing cost of product *i* from retailer *r* for collection center *c* in time period *t*
PCS_{smt} :	unit purchasing cost of raw material from supplier *s* for manufacturer *m* in time period *t*
TCC_{icmt} :	unit transportation cost for product *i* shipped from collection center *c* to manufacturer *m* in time period *t*
TCM_{imwt} :	unit transportation cost for product *i* shipped from manufacturer *m* to warehouse *w* in time period *t*
TCR_{rct} :	fixed transportation cost from retailer *r* to collection center *c* in time period *t*
TCS_{smt} :	unit transportation cost for raw material shipped from supplier *s* to manufacturer *m* in time period *t*
TCW_{wrt} :	fixed transportation cost from warehouse *w* to retailer *r* in time period *t*

θ_i : usage factor of milk in the product *i*

σ_i : percentage of the returned products *i* with the quality required for use in producing other products

α_{mt} : Percentage of decrease in capacity of manufacturer *m* in period *t*

μ_{wt} : Percentage of decrease in capacity of warehouse *w* in period *t*

γ_{ct} : Percentage of decrease in capacity of collection center *c* in period *t*

δ_{st} : Percentage of decrease in capacity of supplier *s* in period *t*

2.4. Decision variables

E_{imt} : quantity of product *i* produced by manufacturer *m* in time period *t*

ILC_{ict} : inventory level of product *i* in collection center *c* in period *t*

ILM_{imt} : inventory level of product *i* in manufacturer *m* in period *t*

ILR_{irt} : inventory level of product *i* in retailer *r* in period *t*

ILW_{iwt} : inventory level of product *i* in warehouse in period *t*

Q_{smt} : quantity of raw materials shipped from supplier *s* to manufacturer *m* in time period *t*

$U_{wr} = \begin{cases} 1 & \text{if retailer } r \text{ is allocated to warehouse } w \\ 0 & \text{otherwise;} \end{cases}$

:

$\beta 1_{it}$ Rate/number of returned products which are accepted, have buy-back costs for a firm, and lead to higher customer satisfaction.

$\beta 2_{it}$: Rate/number of returned products which are rejected, do not have buy-back cost for the firm, and lead to decrease in the customer satisfaction.

X_{iwrt} : quantity of products *i* shipped from warehouse *w* to retailer *r* in time period *t*

XCP_{icmt} quantity of products *i* shipped from collection center *c* to manufacturer *m* in time period *t*

:

XM_{imwt} quantity of product *i* shipped from manufacturer *m* to warehouse *w* in time period *t*

:

XC_{irct} : quantity of returned products which are accepted.

XC'_{irct} quantity of returned products which are rejected

:

$YC_c = \begin{cases} 1 & \text{if collection center } c \text{ is opened} \\ 0 & \text{otherwise;} \end{cases}$

:

$YM_m = \begin{cases} 1 & \text{if manufacturer } m \text{ is opened} \\ 0 & \text{otherwise;} \end{cases}$

:

$YW_w = \begin{cases} 1 & \text{if warehouse } w \text{ is opened} \\ 0 & \text{otherwise;} \end{cases}$

:

$$YS_s = \begin{cases} 1 & \text{if supplier s is selected} \\ 0 & \text{otherwise;} \end{cases}$$

:

$$Z_{rc} = \begin{cases} 1 & \text{if warehouse } w \text{ is opened} \\ 0 & \text{otherwise;} \end{cases}$$

:

2.5. Model formulation

$$\begin{aligned}
\text{Iin Z}_1 = & \left(\sum_i \sum_m \sum_t hm_{im}.ILM_{imt} + \sum_i \sum_w \sum_t hw_{iw}.ILW_{iwt} + \sum_i \sum_r \sum_t hr_{ir}.ILR_{irt} + \sum_i \sum_c \sum_t hc_{ic}.ILC_{ict} \right) \\
& \left(\sum_m FCM_m.YM_m + \sum_w FCW_w.YW_w + \sum_c FCC_c.YC_c + \sum_s FOS_s.YS_s \right) \\
& \left(\sum_s \sum_m \sum_t TCS_{smt}.Q_{smt} + \sum_i \sum_m \sum_w \sum_t TCM_{imwt}.XM_{imwt} + \sum_w \sum_r \sum_t TCW_{wrt}.U_{wr} \right. \\
& \left. \sum_r \sum_c \sum_t TCR_{rct}.Z_{rc} + \sum_i \sum_j \sum_c \sum_m \sum_t TCC_{jcmt}.a_{ij}.XCP_{jcmt} \right) \\
& \left(\sum_i \sum_r \sum_c \sum_t PCR_{irct}.XC_{irct} + \sum_s \sum_m \sum_t PCS_{smt}.Q_{smt} \right) \\
& \left(\sum_i \sum_c \sum_m \sum_t 0.2.COM_{imt}.\left(\sum_j a_{ij}.XCP_{jcmt} \right) \right. \\
& \left. \sum_i \sum_{i_c} \sum_m \sum_t COM_{imt}.\left(E_{i_c mt} - \sum_c \sum_j a_{ij}.XCP_{jcmt} \right) + \sum_i \sum_{i_b} \sum_m \sum_t COM_{imt}.E_{i_b mt} \right)
\end{aligned} \tag{1}$$

$$\begin{aligned}
\text{Min } Z_2 = & \left(\sum_i \sum_m \sum_t EIM_{im}.ILM_{imt} + \sum_i \sum_w \sum_t EIW_{iw}.ILW_{iwt} + \sum_i \sum_c \sum_t EIC_{ic}.ILC_{ict} \right. \\
& \left. + \sum_i \sum_r \sum_t EIR_{ir}.ILR_{irt} \right) + \\
& \left(\sum_m EM_m.YM_m + \sum_w EW_w.YW_w + \sum_c EC_c.YC_c \right) \\
& + \left(\sum_s \sum_m \sum_t ETS_{sm}.Q_{smt} + \sum_i \sum_m \sum_w \sum_t ETM_{imw}.XM_{imwt} + \sum_w \sum_r ETW_{wr}.U_{wr} \right. \\
& \left. + \sum_r \sum_c ETR_{rc}.Z_{rc} + \sum_i \sum_j \sum_c \sum_m \sum_t ETC_{jcm}.a_{ij}.XCP_{jcmt} \right)
\end{aligned} \tag{2}$$

$$Max\, Z_3 = \left(\sum_i (\beta 1_{it} - \beta 2_{it}) \right) \tag{3}$$

S.t:

$$\sum_w X_{iwrt} \geq DR_{irt} \qquad \forall i, r, t \tag{4}$$

$$\sum_m XM_{imwt} \geq \sum_r X_{iwrt} \qquad \forall i, \text{w}, \text{t} \tag{5}$$

$$\sum_c XC_{irct} \leq DR_{it} \times \beta 1_{it} \qquad \forall i, r, t \tag{6}$$

$$\sum_{c} XC'_{irct} \le DR_{it} \times \beta 2_{it} \qquad \forall i, r, t \tag{7}$$

$$\sum_{r} \sigma_i \times XC_{irct} \ge \sum_{m} XCP_{icmt} \qquad \forall i, \mathrm{c}, \mathrm{t} \tag{8}$$

$$\sum_{s}\sum_{t} Q_{smt} \ge \sum_{i}\sum_{w}\sum_{t} \theta_i \times XM_{imwt} - \sum_{i}\sum_{j}\sum_{c}\sum_{t} \theta_i \times a_{ij} \times XCP_{jcmt} \qquad \forall m \tag{9}$$

$$E_{imt} \ge \sum_{w} XM_{imwt} \qquad \forall i, \mathrm{m}, \mathrm{t} \tag{10}$$

$$\sum_{i} E_{imt} \le (1-\alpha_{mt}) \times LM_m \times YM_m \qquad \forall m, t \tag{11}$$

$$\sum_{m} Q_{smt} \le (1-\delta_{st}).LS_s \qquad \forall s, t \tag{12}$$

$$\sum_{i} ILW_{iw(t-1)} + \sum_{i}\sum_{m} XM_{imwt} \le (1-\mu_{wt}) \times LW_w \times YW_w \qquad \forall w, t \tag{13}$$

$$\sum_{i} ILC_{ic(t-1)} + \sum_{i}\sum_{r} XC_{irct} \le (1-\gamma_{ct}) \times LC_c \times YC_c \qquad \forall c, t \tag{14}$$

$$ILM_{imt} = E_{imt} + ILM_{im(t-1)} - \sum_{w} XM_{imwt} \qquad \forall i, \mathrm{m}, \mathrm{t} \tag{15}$$

$$ILW_{iwt} = \sum_{m} XM_{imwt} + ILW_{iw(t-1)} - \sum_{r} X_{iwrt} \qquad \forall i, \mathrm{w}, \mathrm{t} \tag{16}$$

$$ILC_{ict} = \sum_{r} XC_{irct} + ILC_{ic(t-1)} - \sum_{m} XCP_{icmt} \qquad \forall i, \mathrm{c}, \mathrm{t} \tag{17}$$

$$ILR_{irt} = ILR_{ir(t-1)} + \sum_{w} X_{iwrt} - DR_{irt} \qquad \forall i, r, t \tag{18}$$

$$YM_m \le \sum_{i}\sum_{t} E_{imt} \le M \times YM_m \qquad \forall m \tag{19}$$

$$YW_w \le \sum_{i}\sum_{m}\sum_{t} XM_{imwt} \le M \times YW_m \qquad \forall w \tag{20}$$

$$YC_c \le \sum_{i}\sum_{r}\sum_{t} XC_{irct} \le M \times YC_c \qquad \forall c \tag{21}$$

$$U_{wr} \le \sum_{i}\sum_{t} X_{iwrt} \le M \times U_{wr} \qquad \forall w, r \tag{22}$$

$$Z_{rc} \le \sum_{i}\sum_{t} XC_{irct} \le M \times Z_{rc} \qquad \forall r, c \tag{23}$$

$$\sum_{w} U_{wr} \le 1 \qquad \forall r \tag{24}$$

$$\sum_{c} Z_{rc} \le 1 \qquad \forall r \tag{25}$$

$$E_{i_c mt} \ge \sum_{c}\sum_{j} a_{ij} \times XCP_{icmt} \qquad \forall i, m, t \tag{26}$$

$$\beta 1_{it} + \beta 2_{it} = \beta_{it} \qquad \forall i, t \tag{27}$$

The first objective function minimizes the total cost of the supply chain network that includes holding cost of inventory, shortage cost, fixed cost of facilities, transportation costs between facilities and purchase costs of the returned products from retailers, and raw material from suppliers.

The second objective function minimizes the environmental pollutants that include environmental impacts associated with keeping inventory, opening the facilities, and transportation. The third objective function also maximizes the level of customer satisfaction by maximizing the acceptance rate of returned products. Constraints (4) and (5) ensure the existence of sufficient input flows in retailers, warehouses, and manufacturer. Constraints (6) and (7) calculate the accepted and unaccepted returned products, respectively. Constraint (8) guarantees that the flows of qualified input should be greater than the flows of output at each collection center. The balance between incoming and outgoing flows for each manufacturer is provided by Constraint (9). Constraint (10) expresses that production amount of each manufacturer should at least be as much as the number of products sent from the manufacturer to warehouses. Constraints (11)-(14) indicate the limited capacity of manufacturers, suppliers, warehouses, and collection centers considering disruption. The inventory level of each product in each period in manufacturers, warehouses, collection centers, and retailers is calculated via Constraints (15)-(18), respectively. Inequalities (19)-(23) illustrate that product flow in a facility is only accepted if the facility is established. Constraint (24) states that each retailer only receives products from only one warehouse. Constraint (25) represents that each retailer sends returned products only to one collection center. Constraint (26) ensures that all of the returned products, being sent by collection centers, must be used to produce new products by the manufacturer in the same period. Constraint (27) guarantees that the summation of accepted and rejected coefficients should be equal to the total returned rate.

2.6. The chance-constrained fuzzy programming model

In this paper, to cope with uncertainties in objective functions and constraints, the chance-constraint fuzzy programming (CCFP) is used. For more introductions, this will first present, for simplicity, the compacted form (without considering the second objective function) of the proposed model as follows:

$$
\begin{aligned}
& Min\, Z = fy + cx \\
& s.t: \\
& Ax \geq d \\
& Bx = 0 \\
& Sx \leq Ny \\
& y \in \{0,1\}\ ,\ x \geq 0
\end{aligned}
\tag{28}
$$

Suppose that f is a crisp parameter and c, d, and N are uncertain parameters. This study has done so and used the trapezoidal fuzzy distribution for modeling because it can be defined by four sensitive points $(i.e.\, \tilde{\theta} = \tilde{\theta}_{(1)}, \tilde{\theta}_{(2)}, \tilde{\theta}_{(3)}, \tilde{\theta}_{(4)})$. Therefore, the *CCFP* basic model can be formulated as follows:

$$
\begin{aligned}
& Min\, E[z] = fy + \left(\frac{c_{(1)} + c_{(2)} + c_{(3)} + c_{(4)}}{4}\right)x \\
& s.t: \\
& Ax \geq (1-\alpha_j)d_3 + \alpha_j d_4 \qquad \forall j \in J \\
& Bx = 0 \\
& Sx \leq [(1-\alpha_j)N_2 + \alpha_j N_3]y \qquad \forall j \in J \\
& y \in \{0,1\}\ ,\ x \geq 0
\end{aligned}
\tag{29}
$$

Therefore, the proposed model of this paper will turn into its equivalent deterministic model as follows:

$$\text{Min } E[Z_1] = \left(\sum_i \sum_m \sum_t hm_{im} \times ILM_{imt} + \sum_i \sum_w \sum_t hw_{iw} \times ILW_{iwt} + \sum_i \sum_r \sum_t hr_{ir} \times ILR_{irt} + \sum_i \sum_c \sum_t hc_{ic} \times ILC_{ict} \right)$$

$$+ \left(\sum_m FCM_m \times YM_m + \sum_w FCW_w \times YW_w + \sum_c FCC_c \times YC_c + \sum_s FOS_s \times YS_s \right)$$

$$\left(\begin{aligned} &+ \sum_s \sum_m \sum_t \frac{(TCS_{smt(1)} + TCS_{smt(2)} + TCS_{smt(3)} + TCS_{smt(4)})}{4} \times Q_{smt} \\ &+ \sum_i \sum_m \sum_w \sum_t \frac{(TCM_{imwt(1)} + TCM_{imwt(2)} + TCM_{imwt(3)} + TCM_{imwt(4)})}{4} \times XM_{imwt} \\ &+ \sum_w \sum_r \sum_t \frac{(TCW_{wrt(1)} + TCW_{wrt(2)} + TCW_{wrt(3)} + TCW_{wrt(4)})}{4} \times U_{wr} \\ &+ \sum_r \sum_c \sum_t \frac{(TCR_{rct(1)} + TCR_{rct(2)} + TCR_{rct(3)} + TCR_{rct(4)})}{4} \times Z_{rc} \\ &+ \sum_i \sum_j \sum_c \sum_m \sum_t \frac{(TCC_{jcmt(1)} + TCC_{jcmt(2)} + TCC_{jcmt(3)} + TCC_{jcmt(4)})}{4} \times a_{ij} \times XCP_{jcmt} \end{aligned} \right)$$

$$+ \left(\sum_i \sum_r \sum_c \sum_t PCR_{irct} \times XC_{irct} + \sum_s \sum_m \sum_t PCS_{smt} \times Q_{smt} \right)$$

$$+ \left(\sum_i \sum_c \sum_m \sum_t 0.2 \times COM_{imt} \times \left(\sum_j a_{ij} \times XCP_{jcmt} \right) \right.$$

$$\left. + \sum_i \sum_{i_c} \sum_m \sum_t COM_{imt} \times \left(E_{i_c mt} - \sum_c \sum_j a_{ij} \times XCP_{jcmt} \right) + \sum_i \sum_{i_b} \sum_m \sum_t COM_{imt} \times E_{i_b mt} \right)$$

S.t:

$$\sum_w X_{iwrt} \geq (1 - \tau_1).DR_{irt(3)} + \tau_1.DR_{irt(4)}$$

$$\sum_c X_{irct} \geq (1 - \frac{\tau_2}{2})(\frac{\mathrm{DR}_{irt(1)} + \mathrm{DR}_{irt(2)}}{2}) + (\frac{\tau_2}{2})(\frac{\mathrm{DR}_{irt(3)} + \mathrm{DR}_{irt(4)}}{2}).\beta 1_{it}$$

$$\sum_c X_{irct} \leq (1 - \frac{\tau_2}{2})(\frac{\mathrm{DR}_{irt(3)} + \mathrm{DR}_{irt(4)}}{2}) + (\frac{\tau_2}{2})(\frac{\mathrm{DR}_{irt(1)} + \mathrm{DR}_{irt(2)}}{2}).\beta 1_{it}$$

$$\sum_c X'_{irct} \geq (1 - \frac{\tau_3}{2})(\frac{\mathrm{DR}_{irt(1)} + \mathrm{DR}_{irt(2)}}{2}) + (\frac{\tau_3}{2})(\frac{\mathrm{DR}_{irt(3)} + \mathrm{DR}_{irt(4)}}{2}).\beta 2_{it}$$

$$\sum_c X'_{irct} \geq (1 - \frac{\tau_3}{2})(\frac{\mathrm{DR}_{irt(3)} + \mathrm{DR}_{irt(4)}}{2}) + (\frac{\tau_3}{2})(\frac{\mathrm{DR}_{irt(1)} + \mathrm{DR}_{irt(2)}}{2}).\beta 2_{it}$$

$$ILR_{ir(t-1)} + \sum_w X_{iwrt} - ILR_{irt} \geq (1 - \frac{\tau_4}{2})(\frac{DR_{irt(1)} + DR_{irt(2)}}{2}) + (\frac{\tau_4}{2})(\frac{DR_{irt(3)} + DR_{irt(4)}}{2})$$

$$ILR_{ir(t-1)} + \sum_w X_{iwrt} - ILR_{irt} \leq (1 - \frac{\tau_4}{2})(\frac{DR_{irt(3)} + DR_{irt(4)}}{2}) + (\frac{\tau_4}{2})(\frac{DR_{irt(1)} + DR_{irt(2)}}{2})$$

$$0.5 \leq \alpha_j \leq 1$$

Equations (5) and (8)-(17) and (19)-(27)

3. Solution Procedure

Since MILP model is a multi-objective, mixed integer linear programming model whose objective functions are completely inconsistent, the LP-metrics method is used which is one of the famous Multi-Criteria Decision-Making (MCDM) methods for solving multi-objective problems with conflicting objectives simultaneously. According to this method, a multi-objective problem is solved by considering each objective function separately and, then, a single objective is reformulated which aims to minimize the summation of normalized differences between each objective and the optimal values of them. In the proposed model, it can be assumed that three objective functions are named as Z_1, Z_2, Z_3 . Based on LP-metrics method, MILP should be solved for each one of these three objectives separately. Assume that the optimal values of these three problems are Z_1^*, Z_2^*, Z_3^* . Now, the LP-metrics objective function can be formulated as follows:

$$Z_4 = [w_1 . \frac{Z_1 - Z_1^*}{Z_1^*} + w_2 . \frac{Z_2 - Z_2^*}{Z_2^*} + w_3 . \frac{Z_3^* - Z_3}{Z_3^*}] \tag{36}$$

where $0 \leq w \leq 1$ is the relative weight of components of the objective function (36) as given by the decision-maker(s). Using LP-metrics objective function and considering MILP model constraints, we have a single-objective mixed integer programming model which can be efficiently solved by linear programming solvers.

4. Computational Results

In this section, numerical experiments are conducted to investigate the performance of the proposed model.

4.1. Report of result

In this section, results of solving five test problems are reported and analyzed. It should be noted that necessary data are taken from the similar research in this field (like Yavari et al. [15]). Table 1 shows the results of experiments.

Tab. 1. Results of experiments

T.P	|i|×|s|×|m|×|w|×|r|×|c|×|t|	F.O.V	S.O.V	T.O.V	CPU time (s)
1	|1|×|2|×|1|×|1|×|2|×|1|×|1|	4741904.68	75764380	0.1	21.48
2	|2|×|3|×|1|×|1|×|4|×|2|×|2|	6220507.39	152837400	0.18	33.67
3	|3|×|5|×|2|×|2|×|7|×|2|×|3	8642172.41	161476000	0.25	45.069
4	|4|×|7|×|3|×|3|×|9|×|2|×|3|	13270350	171251200	0.4	77.42
5	|5|×|10|×|3|×|5|×|10|×|2|×|4|	47932896	190812400	0.61	81.03

in Table 1, T. P denote the number of test problems, second column shows the size of the problem, F. O. V. is the first objective function value, S. O. V. denotes the second objective function value, T.O.V is the third objective function value, and the last column shows computational times of solving model. The CPU times of the test problems are given in Figure 2. According to Figure 2, the CPU time of solving the model increased with an increase in size of the problem.

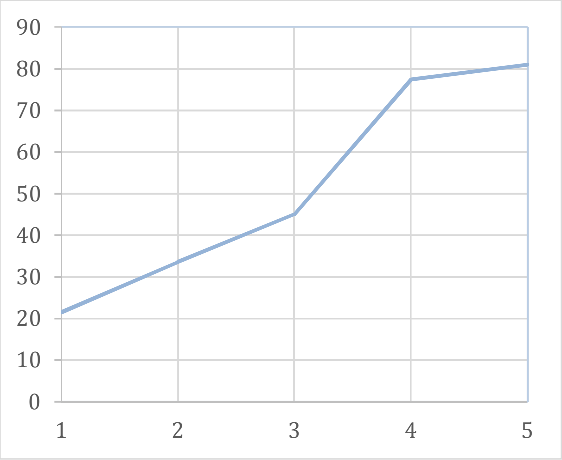

Fig. 2. CPU time of the problem

4.2. Sensitivity analysis of product demands

This study examined the values of the objective function in five different modes for product demands (Based case, -20%, -10%, +10%, and +20%). The results of sensitivity analysis are shown in Figure 3.

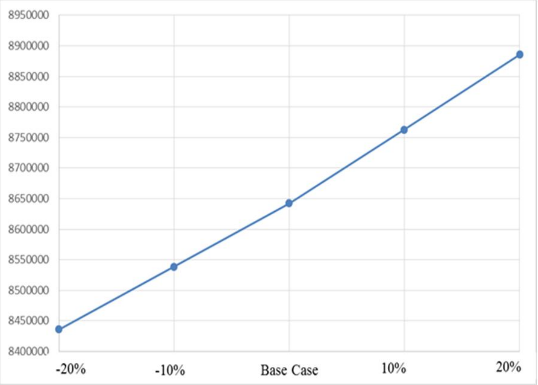

Fig. 3. Sensitivity analysis of the first objective function on demand

According to Figure 3, with increasing the quantity of demands, the value of the first objective function increased.

4.3. Sensitivity analysis of the rate of returned products β_{it}

This study examined the values of the objective function in five different modes for the rate of returned products. The sensitivity analysis results are illustrated in Figure 4.

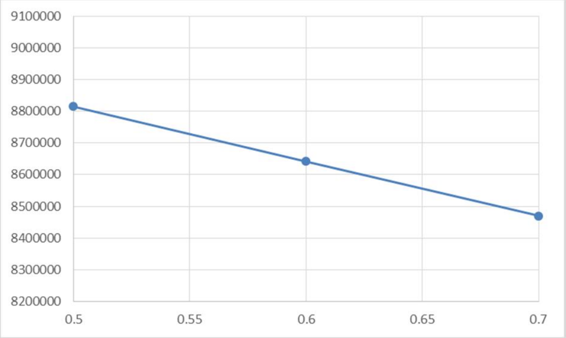

Fig. 4. Sensitivity analysis of the first objective function on rate of return

According to Figure 4, with increasing the quantity of rate of returned products, the value of first objective function decreased.

4.4. Sensitivity analysis of transportation cost

The values of the objective function are examined in five different modes for transportation costs. The sensitivity analysis results are illustrated in Figure 5.

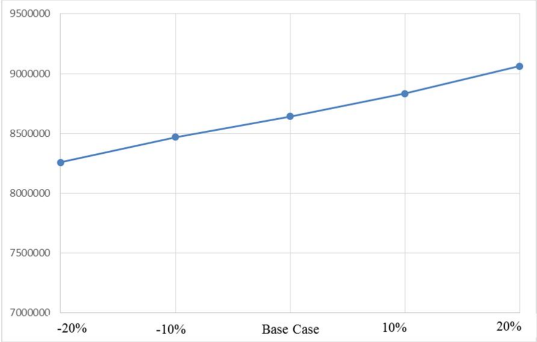

Fig. 5. Sensitivity analysis of the first objective function on transportation cost

According to Figure 5, with increasing transportation costs, the value of the first objective function increased.

5. Conclusions and Future Work

This study presented an approach that combined sustainability criteria (i.e., economic, environmental, and social) with the supply chain decisions in the context of supply chain management. By linking this approach to mathematical programming, the environmental, economic, and social impacts could all be simultaneously combined. Indeed, for a multi-product, multi-echelon, multi-period supply chain planning, a multi-objective mixed integer linear programming model was formulated. The first objective function aimed to minimize the total cost of the supply chain network; the second objective function aims to minimize the environmental pollutants; the third objective function uses the level of customer satisfaction for measuring social objectives. Due to changes in the business environment, the uncertainty exists in parameters of problem (like demand and transportation cost). In this study, the chance-constrained fuzzy programming was applied in order to tackle these uncertainties. Then, the multi-objective model was solved using LP-metric method whose results were reported.

Future research can develop heuristic or meta-heuristic algorithms in order to solve the proposed model in the case of large-sized problems. Moreover, considering the concept of resiliency in the proposed model is another suggestion for future researches.

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