APEM journal
Advances in Production Engineering & Management
Volume 17 | Number 3 | September 2022 | pp 381–393
https://doi.org/10.14743/apem2022.3.443
ISSN 1854-6250
Journal home: apem-journal.org
Original scientific paper

Multi-objective Intuitionistic Fuzzy Linear Programming model for optimization of industrial closed-loop supply chain network

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ABSTRACT

The urge to remanufacture and address environmental concerns in various industrial processes has drawn the attention of academics as well as practitioners towards Closed-loop Supply Chain Networks (CLSC). Although ever-changing and complex external factors including social and economic ones, adversely impact the sustainable development of closed-loop supply chain networks. The basic aim of the research is to optimize the functioning of CLSC networks. For the above-said, two objective functions are made. The first objective is to minimize the cost of production and assembly expenses of the forward and reverse logistics. Secondly, an endeavour has been made to reduce the fixed costs associated with plants and retailers. For the sake of achieving two objective functions, two methods are employed: triangular fuzzy numbers and triangular intuitionistic fuzzy numbers. Among the two methods, triangular intuitionistic fuzzy numbers achieved the said objectives with greater optimization substantiated by statistics. This method can deal with uncertain external factors without undermining the optimization of the CLSC networks.

ARTICLE INFO

Keywords:
Supply chain;
Closed-loop supply chain;
Multi-objective linear programming;
Modelling;
Optimization;
Fuzzy logic;
Intuitionistic fuzzy numbers

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Article history:
Received 7 March 2022
Revised 12 September 2022
Accepted 17 September 2022

1. Introduction

In human surroundings have a significant impact on daily routines. Environmental policies are associated with sustainable development. Clean environments have positive effects on mental and physical health. Technically and logically, policies are necessary to address environmental challenges. Currently, the reduction of pollution generated by industrial activities is under significant environmental and political pressure [1]. All developed and underdeveloped countries are developing strategies and modifying their plans of action so that their surplus can be recycled. Developing countries face challenges in finding ways out of poverty for their poorest citizens to provide better standards of living for their people. This necessitates providing opportunities for all by increasing industrial output through a series of changes, including the use of by-products

[2]. Most large corporations use their waste materials as raw materials for other processes rather than considering their residues as waste products. Waste management is key in any economy, but as the world shifts toward a more sustainable and circular economy, end-of-life options are begin enhanced [3]. The recognition that all wastes are resources and perhaps more appropriately referred to as by-products or non-product outputs is also notable [4].

Excessive return of product flow from consumers to suppliers over a wide range becomes a concern. A supply chain (SC) network is introduced to bring in raw materials and inventory of end products, and transform these materials for the utilisation of retailers. Returns have been viewed as annoyance for manufacturers, suppliers, and distributors. Successful policies and systems for inventory returns result in higher sales, reduced prices, better profitability, and improved consumer service levels [5]. Designing a supply chain network has become a necessity. Owing to government policies and societal appetites for environmental awareness, the supply chain network has acquired enormous importance. With the ongoing pressure to cut prices, environmental issues, high levels of uncertainty, and many other challenges can be successfully controlled by supply chains. The creation of a commodity delivery strategy for supply chain (SC) networks is also a dynamic activity [6]. The primary goal of the supply chain is to reduce costs and improve the efficiency of supply chain enterprises to maximise economic benefits. The traditional supply chain starts with the supplier and ends with users. Closed-loop Supply Chain (CLSC) pattern is divided into two main parts: (a) Forward flow and (b) Reverse Flow.

Integrating forward and reverse logistics delivers strong outcomes such as increasing customer loyalty and boosting revenue through change [7]. Internally, companies analyse logistics services on interest discernment using an appropriate model. Aleksic *et al.* [8] proposed a model which illustrates the failure mode and effects analysis (FMEA) and a case study technique to analyse the productivity of fuzzy logic, and many interdependent challenges related to the reverse supply chain (RSC) were resolved by implementing analysis for long-range production. Many successful organisations have realised that an effective product return strategy significantly enhances costs which is a major aspect of reverse logistics. Reverse logistics covers returns and various other operations pertaining to "backward" products in the supply chain [9]. Many countries have become increasingly aware of the role of handling reverse flows in supply chains along with forward flows. Multi-objective supply chain models are requisite variations of numerous objectives. Optimal supply chain models are essential for the success of industrial network [10]. The stock flow is circular and reversible throughout the closed-loop, and all goods are handled over the entire life cycle [11, 12]. The business environment is continuously changing because the diversification of returned products. This diversification of commodities is related to an increase in operating expenses and a reduction in revenue. Therefore, ensuring the profitability and long-term sustainability of the company, the proper use of returned goods is a key strategic decision [13]. For the competency and proper management of returned products, companies try their best to reduce production costs while keeping customer satisfaction in mind. Sustainable supply chain networks are used to address broad range of economic issues to overcome uncertainty. Fuzzy multi-objective models are ideally suited to solving supply chains [14].

A careful assessment is needed for plants and refurbishing centers that can maintain a CLSC process in a timely manner. Most of the time, supplier strengths and weaknesses vary, which highly affects the closed-loop supply chain process. Many studies on the closed-loop supply chain process have used mathematical programming under uncertain situations owing to societal demands for environmental consciousness [15]. Closed-loop supply chain viability aimed at promoting product circulation flow from production to marketing and then reutilisation and remanufacturing. Duan *et al.* [16] discussed that a large amount of waste material has a considerable impact on production. In pandemic Covid-19 the closed-loop supply chain models lead the entrepreneur to a more valuable and relatively well-balanced economic state. A smooth method of return is better for companies. Thus, returned products are productive for various purposes. In the real world, we deal with vagueness at a certain level, and the uncertainty of the remanufacturing system plays a strategic role in directing a product [17]. Therefore, we deal with such uncertainties using a fuzzy set, which was first introduced by Zadeh [18]. The fuzzy set is defined by the membership degree for all its intactness. The IFS is characterised by a membership function and a non-membership function, such that the sum of both values lies between zero and one. Any model parameter can only be approximately calculated in real-world problems.

Fuzzy models have the ability to model the subjective imagination of a maker as accurately as a decision-maker would describe them. Moreover, fuzzy models help to reduce information costs. The general model for fuzzy linear programming problems includes fuzziness in the coefficients and the accomplishment of the constraints. It is possible to reformulate fuzzy constraints in such a way that they can be solved as a normal linear programming problem. The concept of an intuitionist fuzzy set [19] was explored and introduced in various areas. The intuitionistic fuzzy set/number has also recently been applied in fuzzy optimization, and measures of possibility, precondition, and integrity have a significant role in the optimization of fuzzy theory [20]. Fuzzy linear programming was further examined in decision-making and management problems under uncertain circumstances to obtain an optimal solution [21]. The remaining paper is organised as follows. Section 2 presents all the basic and essential concepts used to develop the optimisation of fuzzy multi-objective linear programming. In Section 3, we formulate the general model of multi-objective fuzzy closed-loop supply chain network, and an interactive fuzzy approach to solve the problem is outlined in Section 4. Finally, concluding remarks and suggestions for further research are presented in Section 5.

2. Preliminaries

2.1 Fuzzy set

According to Zadeh [18], a fuzzy set presents a convenient point for the construction of a logical framework which might be parallel with respect to an ordinary set. In particular, the fuzzy framework provides a natural way to deal with uncertain situations. A fuzzy set μ of X is a function of X in the interval [0,1], that is, for each $x \in X$, $\mu(x)$ is a real number ranging between 0 and 1. Function $\mu(x)$ is a membership function. Mathematically, the fuzzy subset μ of X is expressed as $\mu = \{(x, \mu(x)) : x \in X\}$.

2.2 Triangular fuzzy number

The fuzzy number is a function in which the domain is any specified set, and whose range is the real number lies between 0 and 1, both inclusive. Generally, a triangular fuzzy number [22] is expressed as $TF_{\mu} = (q_1, q_2, q_3)$ with the respective membership function defined as

$$\mu(x) = \begin{cases} \frac{x-q_2}{q_2-q_1} & q_1 \le x < q_2 \\ 1, & x = q_2 \\ \frac{q_3-x}{q_3-q_2} & q_2 < x \le q_3 \\ 0, & \text{otherwise.} \end{cases} \tag{1}$$

2.3 Intuitionistic fuzzy set

An intuitionistic fuzzy set [19] (IFS) $\mathcal{N}$ of X can be described in set form as $\mathcal{N} = \{\langle x, \mu_{\mathcal{N}}(x), \nu_{\mathcal{N}}(x)\rangle : x \in X\}$ where the functions: $\mu_{\mathcal{N}}: X \to [0,1]$ and $\nu_{\mathcal{N}}: X \to [0,1]$ represents the degrees of membership and non-membership of each $x \in X$ respectively with

$$0 \le \mu_N(x) + \nu_{\mathcal{N}}(x) \le 1.$$

2.4 Triangular intuitionistic fuzzy number

A triangular intuitionistic fuzzy number (TrIFN) [23] $\tilde{X}^I$ is a pair of triplets written as $(x_1, x_2, x_3; x_1', x_2', x_3')$ where $x_1' \le x_1 \le x_2 = x_2' \le x_3 \le x_3'$ having membership and non-membership functions in the following manner:

$$\mu_{\tilde{X}^I}(x)=\begin{cases}\frac{x-x_1}{x_2-x_1} & ,x_1\leq x\leq x_2\\ 1 & ,x=x_2\\ \frac{x_3-x}{x_3-x_2} & ,x_2\leq x\leq x_3\\ 0 & ,\text{otherwise}\end{cases}\qquad \nu_{\tilde{X}^I}(x)=\begin{cases}\frac{x_2-x}{x_2-x_1'} & ,\ x_1'\leq x\leq x_2\\ 0 & ,x=x_2\\ \frac{x-x_2}{x_3'-x_2} & ,x_2\leq x\leq x_3'\\ 1 & ,\text{otherwise}\end{cases}\tag{2}$$

As $x_2 = x_2'$ so we can write TrIFN $(x_1, x_2, x_3; x_1', x_2', x_3')$ as $(x_1, x_2, x_3; x_1', x_3')$.

Arithmetic operations on TrIFN

Similar to numbers, several antiemetic operations can be defined on the TrIFNs [24]. Let $\tilde{X}^I = (x_1, x_2, x_3; x_1', x_3')$ and $\tilde{Y}^I = (y_1, y_2, y_3; y_1', y_3')$ be any two TrIFNs and k be a real number. Then

1. $\tilde{X}^I + \tilde{Y}^I = (x_1 + y_1, x_2 + y_2, x_3 + y_3; x_1' + y_1', x_3' + y_3')$.
2. $\tilde{X}^I - \tilde{Y}^I = (x_1 - y_3, x_2 - y_2, x_3 - y_1; x_1' - y_3', x_3' - y_1')$.
3. $k.\tilde{X}^I = k.(x_1, x_2, x_3; x_1', x_3') = (kx_1, kx_2, kx_3; kx_1', kx_3')$ if $k \geq 0$.
4. $k.\tilde{X}^I = k.(x_1, x_2, x_3; x_1', x_3') = (kx_3, kx_2, kx_1; kx_3', kx_1')$ if $k < 0$.
5. $\tilde{X}^I \times \tilde{Y}^I = (x_1y_1, x_2y_2, x_3y_3; x_1'y_1', x_3'y_3')$.

2.5 Linear programming

Linear programming problems [25] include the optimization of real-world problems, in which the quantity of the objective function must be maximized or minimized with some constraints. Constraints are linear equalities or inequalities. It consists of the following parts.

- Decision variables set X;
- Objective Function: A linear function $f(x)$ is maximized(minimized);
- Constraints: $g_i(x) \leq b_i$.

2.6 Multi-objective linear programming

In multi-objective linear programming [26], we have variations in the objective function as well as in the constraints. The mathematical representation of multi-objective linear programming is as follows:

Maximize

$$f_s(x) = a_{s1}.x_1 + a_{s2}.x_2 + \ldots + a_{sn}.x_n \text{ for all } s.$$

such that

$$a_{t1}.x_1 + a_{t1}.x_1 + \ldots + a_{t1}.x_1 \gtreqless b_t$$

In general, there is no single point $(x) = (x_1, x_2, \ldots, x_n)$ which optimizes each objective function individually. Many real-world problems can be modelled as multi-objective linear programming problems. A linear program with more than one objective function is known as a multi-objective linear program (MOLP).

2.7 Fuzzy linear programming

Fuzzy linear programming [27] represented as:

$$\begin{aligned} &\text{Max} \quad \tilde{Z}.x\\ \text{subject to}\quad &\textstyle\sum_{j=1}^{n} \tilde{X}_{ij}.x_j \geq \tilde{Y}_i,\ i = 1,2,\ldots m\\ &x_j \geq 0,\ j = 1,2,\ldots n \end{aligned}\tag{3}$$

where X_{ij} are decision variables in the constraints and x_j are non-negative fuzzy numbers. Fuzzy linear programming problems with decision variables and parameters play an important role in several applications in different areas, such as mathematical modelling, manufacturing and production, environment management, supply chain management, and transportation management. In fuzzy linear programming, fuzziness considers either the objective function or the constraint equations.

2.8 Linear programming with triangular intuitionistic fuzzy number

The linear programming model with triangular intuitionistic fuzzy numbers [21] can be expressed as

$$\begin{aligned} &\text{Minimize} \quad \sum_{j=1}^{n} \tilde{Z}_j^I . x_j \\ \text{subject to} \quad &\sum_{j=1}^{n} \tilde{X}_{ij}^I . x_j \geq \tilde{Y}_i^I, \ i = 1,2,\ldots m \\ &x_j \geq 0, \ j = 1,2,\ldots n \end{aligned} \tag{4}$$

where, $\tilde{Z}_j^I = (z_{j,1}, z_{j,2}, z_{j,3}; z'_{j,1}, z'_{j,2}, z'_{j,3})$, $\tilde{Y}_i^I = (y_{i,1}, y_{i,2}, y_{i,3}; y'_{i,1} y'_{i,2}, y'_{i,3})$ and $\tilde{X}_{ij}^I = (X_{ij,1}, X_{ij,2}, X_{ij,3}; X'_{ij,1}, X'_{ij,2}, X'_{ij,3})$; $i = 1,2\ldots, m$ and $j = 1,2,\ldots, n$ are TrIFN'S.

3. Model formulation

In a closed-loop supply chain network problem, our main purpose is to minimize overall costs, distribution time, or maximize profit; in general, objectives are usually uncertain due to unpredictable conditions in an evolving environment. In the proposed model, we first consider the raw materials and collect the initial parts. Suppliers send raw materials to the plants; in plants, the number of machines is working for proceeding with the products. These raw forms were further transformed into their final shapes. Retailers rack up commodities from plants and delivered them to customers. Collection centers collect customer previously purchased merchandise and returned goods. Further dispatch of these products to the disassembly center. The model is formulated as follows: after inspection, the reusable and manufacturable products are processed into refurbishing centers, and useless products of bad quality are disposed of. Refurbishing centers sent used parts to the plants to be used in the next period. Consequently, the CLSC problem was contrived, as shown in Fig. 1. The time and cost can be reduced by reducing the overall emissions. End-of-life vehicle (ELV) treatment is an example of a CLSC. Most European countries have had an existing ELV recycling system for decades. Parts of vehicles that are expected to have high re-sale value are first disassembled, and collection centers collect some parts in car accident and others from customers. Metal recycling and other components provide valuable product recovery which fulfils recycling targets at minimal cost [28]. Fig. 1 depicts the closed-loop supply chain network, forward flow from suppliers to plants, plants to retailers, and retailers to customers, and backward flow from customer to collection center, collection center to plant, collection center to disassembly center, disassembly center to refurbishing center, and refurbishing center to plant.

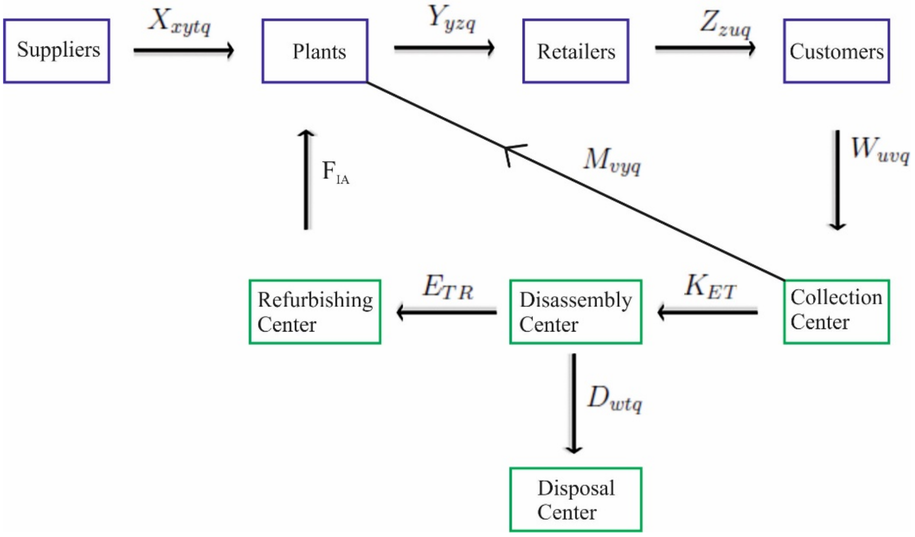

Fig. 1 Closed-loop supply chain network

Index sets

x	suppliers
y	plants
z	retailers
u	customers
v	collection centers
w	disassembly centers
h	refurbishing centers
t	number of parts
q	number of periods

Decision variables

X_{xytq}	supplier x shipped amount to plant y for part t in period q
Y_{yzq}	plant y shipped amount to retailer z for part t in period q
Z_{zuq}	retailer z shipped amount to customer u for part t in period q
W_{uvq}	customer u shipped amount to collection center v for part t in period q
M_{vyq}	collection center v shipped amount to plant y for part t in period q
K_{ET}	collection center v shipped amount to disassembly center w for part t in period q
D_{wtq}	disassembly center w shipped amount to disposal for part t in period q
E_{TR}	disassembly center w shipped amount to refurbishing center h for t in period q
F_{IA}	refurbishing center h shipped amount to plant y for part t in period q
A_{yq}	if plant y is open ,1 ; else 0.
B_{zq}	if retailer z is open ,1 ; else 0.

Parameters

$\tilde{l}_{xtq}$	fuzzy capacity in supplier x for part t in period q(ton)
$\tilde{m}_{yq}$	fuzzy capacity in plant y in period q(ton)
$\tilde{n}_{zq}$	fuzzy capacity in retailer z in period q(ton)
$\tilde{p}_{vq}$	fuzzy capacity in collection center v in period q(ton)
$\tilde{q}_{wtq}$	fuzzy capacity in disassembly center w for part t for period q(ton)
$\tilde{r}_{htq}$	fuzzy capacity in refurbishing center h for part t for period q(ton)
$\tilde{o}_{uq}$	fuzzy demand of customer u for period q
$\tilde{A}_q$	maximum availability in plants for period q
$\tilde{B}_q$	maximum availability in retailers for period q
t	unit cost of shipping
n_t	number of parts for the part t from disassembling one unit of product
l_{xt}	unit cost of purchasing of supplier x for part t
m_{ht}	unit cost of refurbishing of refurbishing center h for part t
μ_{yq}	fixed opening cost for plant y in period q
v_{zq}	fixed opening cost for retailer z in period q
$\tilde{\alpha}$	demand of fuzzy percentage that is composed by collection centers.
$\tilde{\beta}$	fuzzy percentage for collection of amount that is resent to plants
$\tilde{\theta}$	fuzzy percentage for disassembled amount that is disposed

Distances

d_{xy}	distance in the supplier x to plant y (kilometer)
d_{yz}	distance in the plant y to retailer z (kilometer)
d_{zu}	distance in the retailer z to customer u (kilometer)
d_{uv}	distance in the customer u to collection center v (kilometer)
d_{vy}	distance in the collection center v and plant y (kilometer)
d_{vw}	distance in the collection center v and disassembly center w (kilometer)
d_{wh}	distance in disassembly center w to refurbishing center h (kilometer)
d_{hy}	distance in the refurbishing center h to plant y (kilometer)
ds_p	distance between disassembly center w and disposal

3.1 Objective functions

Our main objectives ere to minimize the total costs. The first objective is to minimize the cost of production and assembly expenses for forward and reverse logistics, including transport system, buying, and renovation costs. The second goal is to reduce the fixed costs associated with the plants and retailers.

$$
\begin{aligned}
z_1 \cong t(&\sum_x \sum_y \sum_t \sum_q \tilde{X}^I_{xytq}.ds_{xy} + \sum_y \sum_z \sum_q \tilde{Y}^I_{yzq}.ds_{yz} + \sum_z \sum_u \sum_q \tilde{Z}^I_{zuq}.ds_{zu} \\
&+ \sum_u \sum_v \sum_q \widetilde{W}^I_{uvq}.ds_{uv} + \sum_v \sum_y \sum_q \widetilde{M}^I_{vyq}.ds_{vy} + \sum_v \sum_w \sum_q \widetilde{K}^I_{vwq}.ds_{vw} \\
&+ \textstyle\sum_w \sum_t \sum_q \widetilde{D}^I_{wtq}.ds_p + \sum_w \sum_h \sum_t \sum_q \tilde{E}^I_{whtq}.ds_{wh} + \sum_h \sum_y \sum_t \sum_q \tilde{F}^I_{hytq}.ds_{hy}) \\
&+ \textstyle\sum_x \sum_y \sum_t \sum_q \tilde{X}^I_{xytq}.l_{xt} + \sum_h \sum_y \sum_t \sum_q \tilde{F}^I_{hytq}.m_{ht}
\end{aligned}
\tag{5}
$$

$$
z_2 \cong \textstyle\sum_y \sum_q \tilde{A}^I_{yq}.\mu_{yq} + \sum_z \sum_q \tilde{B}^I_{zq}.v_{zq} \tag{6}
$$

3.2 Constraints

Supplier constraints

The shipped amount of plant y to supplier x in part t for q is less than or equal to the fuzzy space of supplier x in part t for period q. The supplier constraints converted into fuzzy triangular intuitionistic numbers (see Eq. 7) show that the supplier shipped amount is less than the fuzzy supplier capacities.

$$
\begin{aligned}
&\textstyle\sum_x X_{xytq,1} \le \tilde{l}_{xtq,1}, \qquad &&\textstyle\sum_x X_{xytq,2} \le \tilde{l}_{xtq,2} \\
&\textstyle\sum_x X_{xytq,3} \le \tilde{l}_{xtq,3}, &&\textstyle\sum_x X'_{xytq,1} \le \tilde{l}'_{xtq,1} \\
&\textstyle\sum_x X'_{xytq,2} \le \tilde{l}'_{xtq,2}, &&\textstyle\sum_x X'_{xytq,3} \le \tilde{l}'_{xtq,3}
\end{aligned}
\tag{7}
$$

Plant constraints:

The shipped amount of retailer z to plant y in period q is less than or equal to the fuzzy capacity of plant y in period q(ton). The plant constraints converted into fuzzy triangular intuitionistic numbers (see Eq. 8) show that the shipped amount to the retailer is less than the fuzzy plant capacities.

$$
\begin{aligned}
&\textstyle\sum_z Yyzq,1 \le \widetilde{m}_{yq,1}.A_{yq,1}, \quad &&\textstyle\sum_z Yyzq,2 \le \widetilde{m}_{yq,2}.A_{yq,2} \\
&\textstyle\sum_z Yyzq,3 \le \widetilde{m}_{yq,3}.A_{yq,3}, &&\textstyle\sum_z Y'_{yzq,1} \le \widetilde{m}'_{yq,1}.A_{yq,1} \\
&\textstyle\sum_z Y'_{yzq,2} \le \widetilde{m}'_{yq,2}.A_{yq,2}, &&\textstyle\sum_z Y'_{yzq,3} \le \widetilde{m}'_{yq,3}.A_{yq,3}
\end{aligned}
\tag{8}
$$

Retailer constraints

The shipped amount of customer u to retailer z in period q is less than or equal to the fuzzy space of retailer z for period q. The retailer constraints converted into fuzzy triangular intuitionistic numbers (see Eq. 9) show that the shipped amount to the customer is less than the fuzzy retailer capacities.

$$
\begin{aligned}
&\textstyle\sum_u z_{zuq,1} \le \tilde{n}_{zq,1}.B_{zq,1}\,, \quad &&\textstyle\sum_u z_{zuq,2} \le \tilde{n}_{zq,2}.B_{zq,2} \\
&\textstyle\sum_u z_{zuq,3} \le \tilde{n}_{zq,3}.B_{zq,3}, &&\textstyle\sum_u z'_{zuq,1} \le \tilde{n}'_{zq,1}.B_{zq,1} \\
&\textstyle\sum_u z'_{zuq,2} \le \tilde{n}'_{zq,2}.B_{zq,2}, &&\textstyle\sum_u z'_{zuq,1} \le \tilde{n}'_{zq,1}.B_{zq,1}
\end{aligned}
\tag{9}
$$

Collection center

The shipped amount of plant y and disassembly center w to collection center v for period q is less than or equal to the fuzzy space of collection center v for period q. The collection center constraints converted into fuzzy triangular intuitionistic numbers (see Eq. 10) show that the shipped amount to the plant and disassembly center is less than the fuzzy capacities of the collection center.

$$\begin{gathered}\sum_y M_{vyq,1} + \sum_w K_{vwq,1} \leq \tilde{P}_{vq,1},\ \sum_y M_{vyq,2} + \sum_w K_{vwq,2} \leq \tilde{P}_{vq,2}\\ \sum_y M_{vyq,3} + \sum_w K_{vwq,3} \leq \tilde{P}_{vq,3},\ \sum_y M'_{vyq,1} + \sum_w K_{vwq,1} \leq \tilde{P}'_{vq,1}\\ \sum_y M'_{vyq,2} + \sum_w K_{vwq,2} \leq \tilde{P}'_{vq,2},\ \sum_y M'_{vyq,3} + \sum_w K_{vwq,3} \leq \tilde{P}'_{vq,3}\end{gathered} \tag{10}$$

Disassembly center

The shipped amount disposal p to disassembly center w and refurbishing center h of part t for period q is less than or equal to the fuzzy space for disassembly center w of part t in period q. The disassembly center constraints converted into fuzzy triangular intuitionistic numbers (see Eq. 11) show that the shipped amount to the disposal and refurbishing center is less than the fuzzy capacities of disassembly center.

$$\begin{gathered}D_{wtq,1} + \sum_h E_{whtq,1} \leq \tilde{q}_{wtq,1},\ D_{wtq,2} + \sum_h E_{whtq,2} \leq \tilde{q}_{wtq,2}\\ D_{wtq,3} + \sum_h E_{whtq,3} \leq \tilde{q}_{wtq,3},\ D'_{wtq,1} + \sum_h E'_{whtq,1} \leq \tilde{q}'_{wtq,1}\\ D'_{wtq,2} + \sum_h E'_{whtq,2} \leq \tilde{q}'_{wtq,2}, D'_{wtq,3} + \sum_h E'_{whtq,3} \leq \tilde{q}'_{wtq,3}\end{gathered} \tag{11}$$

Refurbishing center

The shipped amount of plant y to refurbishing center h of part t for period q is less than or equal to the fuzzy capacity of refurbishing center h of part t for period q. The refurbishing center constraints converted into fuzzy triangular intuitionistic numbers (see Eq. 12) shows the shipped amount to the plant is less than the fuzzy capacities of the refurbishing center.

$$\begin{gathered}\sum_y F_{hytq,1} \leq \tilde{r}_{htq,1},\ \sum_y F_{hytq,2} \leq \tilde{r}_{htq,2}\\ \sum_y F_{hytq,3} \leq \tilde{r}_{htq,3}, \sum_y F'_{hytq,1} \leq \tilde{r}'_{htq,1}\\ \sum_y F'_{hytq,2} \leq \tilde{r}'_{htq,2}, \sum_y F'_{hytq,3} \leq \tilde{r}'_{htq,3}\end{gathered} \tag{12}$$

Retailers

The shipped quantity of customer u to retailers z for period q is greater than or equal to the fuzzy demand for customer u of period q. The retailer constraints converted into fuzzy triangular intuitionistic numbers (see Eq. 13) show that the shipped quantity from the retailer is greater than the fuzzy customer demand.

$$\begin{gathered}\sum_z Z_{zuq,1} \geq \tilde{O}_{uq,1},\ \sum_z Z_{zuq,2} \geq \tilde{O}_{uq,2}\\ \sum_z Z_{zuq,3} \geq \tilde{O}_{uq,3},\ \sum_z Z'_{zuq,1} \geq \tilde{O}'_{uq,1}\\ \sum_z Z'_{zuq,2} \geq \tilde{O}'_{uq,2}, \sum_z Z'_{zuq,3} \geq \tilde{O}'_{uq,3}\end{gathered} \tag{13}$$

Plant opening constraints

If plant y is open during period q the value is 1; otherwise, 0 is less than or equal to the maximum available set of plants for period q (see Eq. 14).

$$\begin{gathered}\sum_y H_{yq,1} \leq \tilde{A}_{q,1},\ \sum_y H_{yq,2} \leq \tilde{A}_{q,2}\\ \sum_y H_{yq,3} \leq \tilde{A}_{q,3}, \sum_y H'_{yq,1} \leq \tilde{A}'_{q,1}\\ \sum_y H'_{yq,2} \leq \tilde{A}'_{q,2}, \sum_y H'_{yq,3} \leq \tilde{A}'_{q,3}\end{gathered} \tag{14}$$

Retailer opening constraints

If retailer z is open during period q the value is 1; otherwise, 0 is less than or equal to the maximum available set of retailers z for period q (see Eq. 15).

$$\begin{gathered}\sum_z Z_{zq,1} \leq \tilde{B}_{q,1},\ \sum_z Z_{zq,2} \leq \tilde{B}_{q,2}\\ \sum_z Z_{zq,3} \leq \tilde{B}_{q,3},\ \sum_z Z'_{zq,1} \leq \tilde{B}'_{q,1}\\ \sum_z Z'_{zq,2} \leq \tilde{B}'_{q,2},\ \sum_z Z'_{zq,3} \leq \tilde{B}'_{q,3}\end{gathered} \tag{15}$$

Balance equations

Balance equations (see Eqs. 16 to 61) show that the shipped amounts that enter these capacities must be equal to the number of products that leave the places for forward and reverse flow, and Eq. 62 incites the non-negativity of the decision variables.

$$\sum_x X_{xytq,1} + \sum_n F_{hyt(q-1),1} + n_t \sum_v M_{vy(q-1),1} - n_t \sum_z Y_{yzq,1} = 0 \tag{16}$$

$$\sum_x X_{xytq,2} + \sum_n F_{hyt(q-1),2} + n_t \sum_v M_{vy(q-1),2} - n_t \sum_z Y_{yzq,2} = 0 \tag{17}$$

$$\sum_x X_{xytq,3} + \sum_n F_{hyt(q-1),3} + n_t \sum_v M_{vy(q-1),3} - n_t \sum_z Y_{yzq,3} = 0 \tag{18}$$

$$\sum_x X_{xytq,1} + \sum_n F_{hyt(q-1),1} + n_t \sum_v M_{vy(q-1),1} - n_t \sum_z Y_{yzq,1} = 0 \tag{19}$$

$$\sum_x X_{xytq,2} + \sum_n F_{hyt(q-1),2} + n_t \sum_v M_{vy(q-1),2} - n_t \sum_z Y_{yzq,2} = 0 \tag{20}$$

$$\sum_x X_{xytq,3} + \sum_n F_{hyt(q-1),3} + n_t \sum_v M_{vy(q-1),3} - n_t \sum_z Y_{yzq,3} = 0 \tag{21}$$

$$\sum_y Y_{yzq,1} - \sum_u Z_{zuq,1} = 0, \qquad \sum_y Y_{yzq,2} - \sum_u Z_{zuq,2} = 0 \tag{22}$$

$$\sum_y Y_{yzq,3} - \sum_u Z_{zuq,3} = 0, \qquad \sum_y Y'_{yzq,1} - \sum_u Z'_{zuq,1} = 0 \tag{23}$$

$$\sum_y Y'_{yzq,2} - \sum_u Z'_{zuq,2} = 0 \tag{24}$$

$$\sum_y Y'_{yzq,3} - \sum_u Z'_{zuq,3} = 0 \tag{25}$$

$$\tilde{\alpha} \sum_z Z_{zuq,1} - \sum_v W_{uvq,1} = 0 \tag{26}$$

$$\tilde{\alpha} \sum_z Z_{zuq,2} - \sum_v W_{uvq,2} = 0 \tag{27}$$

$$\tilde{\alpha} \sum_z Z_{zuq,3} - \sum_v W_{uvq,3} = 0 \tag{28}$$

$$\tilde{\alpha} \sum_z Z'_{zuq,1} - \sum_v W'_{uvq,1} = 0 \tag{29}$$

$$\tilde{\alpha} \sum_z Z'_{zuq,2} - \sum_v W'_{uvq,2} = 0 \tag{30}$$

$$\tilde{\alpha} \sum_z Z'_{zuq,3} - \sum_v W'_{uvq,3} = 0 \tag{31}$$

$$\tilde{\beta} \sum_u W_{uvq,1} - \sum_y M_{vyq,1} = 0 \tag{32}$$

$$\tilde{\beta} \sum_u W_{uvq,2} - \sum_y M_{vyq,2} = 0 \tag{33}$$

$$\tilde{\beta} \sum_u W_{uvq,3} - \sum_y M_{vyq,3} = 0 \tag{34}$$

$$\tilde{\beta} \sum_u W'_{uvq,1} - \sum_y M'_{vyq,1} = 0 \tag{35}$$

$$\tilde{\beta} \sum_u W'_{uvq,2} - \sum_y M'_{vyq,2} = 0 \tag{36}$$

$$\tilde{\beta} \sum_u W'_{uvq,3} - \sum_y M'_{vyq,3} = 0 \tag{37}$$

$$\left(1 - \tilde{\beta}\right) \sum_u W_{uvq,1} - \sum_w K_{vwq,1} = 0 \tag{38}$$

$$\left(1 - \tilde{\beta}\right) \sum_u W_{uvq,2} - \sum_w K_{vwq,2} = 0 \tag{39}$$

$$(1 - \tilde{\beta}) \sum_u W_{uvq,3} - \sum_w K_{vwq,3} = 0 \tag{40}$$

$$(1 - \tilde{\beta}) \sum_u W'_{uvq,1} - \sum_w K'_{vwq,1} = 0 \tag{41}$$

$$(1 - \tilde{\beta}) \sum_u W'_{uvq,2} - \sum_w K'_{vwq,2} = 0 \tag{42}$$

$$(1 - \tilde{\beta}) \sum_u W'_{uvq,3} - \sum_w K'_{vwq,3} = 0 \tag{43}$$

$$n_t(\tilde{\theta}) \sum_v K_{vwq,1} - D_{wtq,1} = 0 \tag{44}$$

$$n_t(\tilde{\theta}) \sum_v K_{vwq,2} - D_{wtq,2} = 0 \tag{45}$$

$$n_t(\tilde{\theta}) \sum_v K_{vwq,3} - D_{wtq,3} = 0 \tag{46}$$

$$n_t(\tilde{\theta}) \sum_v K'_{vwq,1} - D'_{wtq,1} = 0 \tag{47}$$

$$n_t(\tilde{\theta}) \sum_v K'_{vwq,2} - D'_{wtq,2} = 0 \tag{48}$$

$$n_t(\tilde{\theta}) \sum_v K'_{vwq,3} - D'_{wtq,3} = 0 \tag{49}$$

$$n_t\left(1 - \tilde{\theta}\right) \sum_v K_{vwq,1} - \sum_h E_{wtq,1} = 0 \tag{50}$$

$$nt(1 - \tilde{\theta}) \sum_v K_{vwq,2} - \sum_h E_{wtq,2} = 0 \tag{51}$$

$$n_t\left(1 - \tilde{\theta}\right) \sum_v K_{vwq,3} - \sum_h E_{wtq,3} = 0 \tag{52}$$

$$nt(1 - \tilde{\theta}) \sum_v K'_{vwq,1} - \sum_h E'_{wtq,1} = 0 \tag{53}$$

$$n_t(1 - \tilde{\theta}) \sum_v K'_{vwq,2} - \sum_h E'_{wtq,2} = 0 \tag{54}$$

$$n_t(1 - \tilde{\theta}) \sum_v K'_{vwq,3} - \sum_h E'_{wtq,3} = 0 \tag{55}$$

$$\sum_w E_{whtq,1} - \sum_y F_{hytq,1} = 0 \tag{56}$$

$$\sum_w E_{whtq,2} - \sum_y F_{hytq,2} = 0 \tag{57}$$

$$\sum_w E_{whtq,3} - \sum_y F_{hytq,3} = 0 \tag{58}$$

$$\sum_w E'_{whtq,1} - \sum_y F'_{hytq,1} = 0 \tag{59}$$

$$\sum_w E'_{whtq,2} - \sum_y F'_{hytq,2} = 0 \tag{60}$$

$$\sum_w E'_{whtq,3} - \sum_y F'_{hytq,3} = 0 \tag{61}$$

$$X_{xytq}, Y_{yzq}, Z_{zuq}, W_{uvq}, M_{vyq}, K_{vwq}, D_{wtq}, E_{whtq}, F_{hytq} \geq 0. \tag{62}$$

Binary variables

If plant y and retailer z in period q are open 1, then the binary variables $\tilde{A}^I_{yq}$ *and* $\tilde{B}^I_{zq}$ are 1; otherwise 0.

4. Application: Results and discussion

Closed-loop supply chain networks are primarily expressed as forward and reverse logistics. In this study the forward flow of the industrial CLSC contains five suppliers, four plants, four retailers, and five customers, as shown in Fig. 2. It is assumed that each supplier has three different components for the six periods, and each component has different rates depending upon its quality and demand.

In this study, reverse flow incorporates two collection centers which collect used products from customers. Two disassembly centers assemble the returned products, whether they are further recycled. If the product cannot be recycled, it is sent to one disposal center to be discarded, and the remaining items are further forwarded into two refurbishing centers, as shown in reverse logistic Fig. 3.

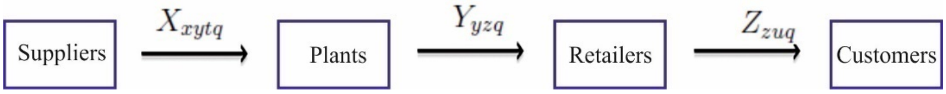

Fig. 2 Forward flow in closed-loop supply chain network

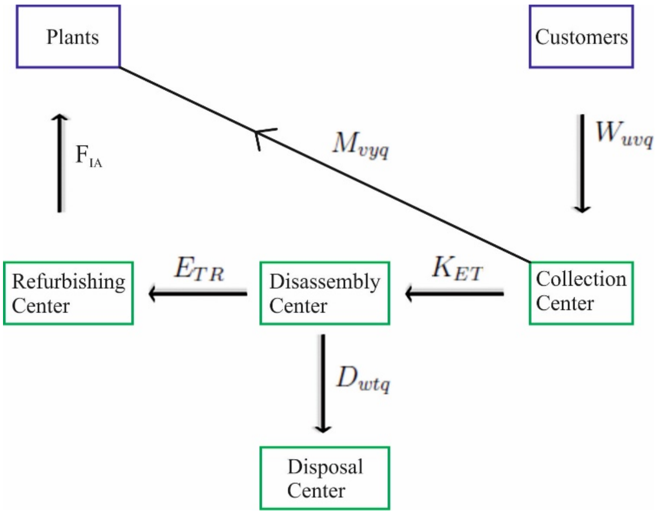

Fig. 3 Reverse flow in closed-loop supply chain network

Transportation cost t per unit is taken as 4.21 USD of one tonne goods over a distance of one kilometer for general loading vehicle. Purchasing and refurbishing unit costs named as l_{xt} and m_{ht} for all the three components are set as 15 USD per ton and 10 USD per ton respectively. Fixed cost for each plant μ_{yq} and retailer v_{zq} taken as 500 USD and 300 USD respectively for all the six periods. Maximum available plants A_{yq} and retailers B_{zq} both are four. The multi objective closed-loop supply chain model is used for transportation plan to control the expenses and maximize the profit. For optimising the model in fuzzy scenario, we apply the hypothetical values in proposed model in Section 3. The proposed model of closed-loop supply chain centralizes the envision to minimize total and fixed distribution cost on available capacities.

Now we generate some scenarios to get the optimum result. Consider the hypothetical values for amount shipped from one stage to the next and capacities according to the storage of products. Firstly, convert the data into triangular intuitionistic fuzzy numbers to maximize the profit in industrial closed-loop supply chain. Maximization of profit by using triangular intuitionistic fuzzy numbers is highly dependent upon the constraints and objective function. In this research we covert our constraints into fuzzy constraint by using weighted average method which minimize the total and fixed cost. For instance, the supplier constraints in Eq. 7 are modified as:

$$\begin{gathered}\sum_x X_{xytq,1} \leq w_1.\tilde{l}_{xtq,1},\ \ \sum_x X_{xytq,2} \leq w_2.\tilde{l}_{xtq,2}\\ \sum_x X_{xytq,3} \leq w_3.\tilde{l}_{xtq,3},\ \ \sum_x X'_{xytq,1} \leq w_4.\tilde{l}'_{xtq,1}\\ \sum_x X'_{xytq,2} \leq w_5.\tilde{l}'_{xtq,2},\ \ \sum_x X'_{xytq,3} \leq w_6.\tilde{l}'_{xtq,3}\end{gathered} \tag{63}$$

where $w_1 = 0.16$, $w_2 = 0.18$, $w_3 = 0.16$, $w_4 = 0.16$, $w_5 = 0.18$, $w_6 = 0.16$ with $w_1 + w_2 + w_3 + w_4 + w_5 + w_6 = 1$. For the application of presented model hypothetical numeric values are taken in Tables 1-5. The Table 4 and 5 shows the converted values in triangular intuitionistic fuzzy number by weighted sum method which provides the significant finding. Due to recognition of ecological challenges, authorizing legislation closed-loop supply chain is highly adoptable for industrial production. However, results from complex projects show that the proposed model can find an effective, adaptable, and suitable method for industrial closed-loop supply chain network. The formulated problem is solved through MATLAB2018a fuzzy technique gives the optimality result of total cost 2020800, in which the fuzziness and ambiguity of data is absorbed by using triangular fuzzy number. Second scenario generated by using triangular intuitionistic fuzzy concept and the modelling yields more accurate and flexible result 1012400, which depicts the cost is minimized with the noticeable difference of 1008400. Therefore, the triangular intuitionistic method is much appropriate for given closed-loop supply chain problem.

Table 1 Distance from suppliers to plants, plants to retailers and collection centers in km

Stages	Plant 1	Plant 2
1st supplier	150	200
2nd supplier	150	150
3rd supplier	160	110
1st Retailer	80	90
2nd Retailer	150	100
3rd Retailer	70	90
1st collection center	40	55
2nd collection center	70	50
3rd collection center	50	70

Table 2 Distance from retailers to customers and customers to collection centers in km

Stage	Customer A	Customer B	Customer C	Customer D
1st Retailer	100	60	150	80
2nd Retailer	150	90	90	60
3rd Retailer	100	80	80	30
1st collection center	150	60	30	90
2nd collection center	70	50	35	80
3rd collection center	30	80	40	50

Table 3 Distance from collection centers to disassembly centers and disassembly centers to refurbishing centers in km

Disassembly center	Collection center 1	Collection center 2	Collection center 3	Disposal	Refurbishing center 1	Refurbishing center 2	Refurbishing center 3
1	90	60	50	70	40	70	50
2	100	95	30	50	50	60	90
3	150	80	40	80	40	30	70

Table 4 Triangular intuitionistic fuzzy supplier capacity

Supplier	a_1	a_2	a_3	a'_1	a'_3	a_1	a_2	a_3	a'_1	a'_3	a_1	a_2	a_3	a'_1	a'_3	a_1	a_2	a_3	a'_1	a'_3	a_1	a_2	a_3	a'_1	a'_3	a_1	a_2	a_3	a'_1	a'_3
	Period 1					Period 2					Period 3					Period 4					Period 5					Period 6				
Component 1																														
1	90	110	120	80	150	160	170	180	150	200	240	250	260	210	270	130	140	160	110	180	100	130	150	80	180	160	180	200	130	210
2	70	80	90	60	100	180	200	210	160	230	220	230	240	200	250	60	90	130	40	150	120	140	180	100	200	220	230	240	200	250
3	70	75	80	60	90	170	180	200	140	210	210	230	240	180	300	60	70	100	30	110	90	100	120	70	150	210	200	220	180	240
Component 2																														
1	160	180	190	140	210	250	210	280	210	300	280	290	300	270	310	110	130	150	100	170	200	220	250	190	270	210	230	240	200	280
2	150	170	180	90	200	210	220	230	200	250	305	310	320	300	330	160	170	180	150	200	160	180	190	150	200	250	270	280	230	290
3	110	120	130	90	150	160	170	180	130	200	210	280	290	260	300	110	120	130	100	150	200	210	230	160	250	150	170	180	140	200
Component 3																														
1	210	230	250	200	300	80	90	100	60	120	160	180	200	140	210	200	210	220	180	230	260	280	290	240	300	120	130	140	100	150
2	150	170	190	120	200	70	80	90	50	100	150	160	170	130	180	110	150	200	100	210	270	290	300	250	310	130	150	170	120	180
3	180	200	220	160	250	100	110	130	70	150	120	130	150	110	90	120	130	150	90	180	220	250	270	200	280	140	150	160	115	170

Table 5 Triangular intitionistic fuzzy capacity

TIFNC	a_1	a_2	a_3	a_1'	a_3'	a_1	a_2	a_3	a_1'	a_3'	a_1	a_2	a_3	a_1'	a_3'
Stage	Period 1					Period 2					Period 3				
Plant1	150	160	170	130	180	310	320	350	300	380	270	280	290	250	300
Plant2	160	170	180	150	200	300	310	380	350	400	250	260	270	230	280
	Period 4					Period 5					Period 6				
Plant1	100	110	120	90	130	120	130	140	100	150	370	380	390	360	400
Plant2	140	150	170	130	180	150	170	180	140	190	410	420	430	400	450
	Period 1					Period 2					Period 3				
Retailer1	160	170	180	150	190	140	160	170	130	180	350	370	380	330	390
Retailer2	150	160	170	130	180	80	900	100	70	110	270	280	290	260	300
Retailer3	120	130	140	110	150	100	110	130	80	150	250	260	280	220	290
	Period 4					Period 5					Period 6				
Retailer1	250	260	270	240	280	230	270	280	200	300	230	260	270	210	280
Retailer2	160	170	180	130	190	190	200	210	180	220	220	230	240	200	250
Retailer3	200	220	230	180	250	210	220	230	200	240	260	280	300	240	310
	Period 1					Period 2					Period 3				
Customer1	200	210	220	190	230	260	270	280	250	290	370	380	400	350	410
Customer2	170	180	190	160	200	210	220	230	200	240	400	410	420	380	440
Customer3	120	130	140	110	150	270	280	290	250	300	370	380	390	360	400
Customer4	120	140	150	100	170	310	330	340	300	360	220	230	250	200	290
	Period 4					Period 5					Period 6				
Customer1	260	270	280	230	290	340	350	360	330	370	230	240	250	220	300
Customer2	210	240	250	200	260	350	370	380	340	390	200	220	230	200	250
Customer3	150	170	200	220	210	360	370	380	350	400	240	250	260	230	270
Customer4	230	240	250	210	280	420	430	440	410	450	230	240	250	210	260

5. Conclusion

Developing countries are striving to fight poverty and achieve sustainable development goals to improve the masses. In the current era, effective management of supply chain networks is imperative for reducing costs and maximizing optimization, thus contributing to the achievement of human capital development. This study chooses closed-loop supply chain (CLSC) networks for various industrial processes, as it integrates forward and backward logistics. The study relies on the triangular intuitionistic fuzzy number model to improve the output of CLSC networks in terms of reduced costs. This study contributes to the existing literature by using the chosen closed-loop supply chain model that comprehensively discusses forward and backward logistics in a systematic manner to address pricing issues more effectively under uncertain circumstances. Second, the employed method of triangular intuitionistic fuzzy numbers helped us to deal with a large dataset in a systematic and coordinated fashion, thus producing the desired results. Accounting for the catastrophes of Covid-19, and the ongoing financial turmoil in developing countries, the usage and implementation of CLSC networks alongside the employment of triangular intuitionistic fuzzy numbers for optimization of the linear programming model will effectively improve the efficiency of various supply chain networks, thus adding to human evolution. Moreover, the enhancement in software solutions would lead to more sustainable and efficient findings for further research.

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Appendix A

List of abbreviations

SC	Supply chain
RSC	Reverse supply chain
CLSC	Closed-loop supply chain
IFS	Intuitionistic fuzzy set
ELV	End of life vehicle
IFS	Intuitionistic fuzzy