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Fuzzy multi-objective programming to optimize closed-loop supply chain problem considering cloud management

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Abstract –Nowadays, competition is growing therefore, it is essential to try to form proper communications and reduce the price of the production along with increasing its quality. A supply chain, especially a closed-loop supply chain (CLSC) is a good solution in this situation since it has absorbed the attention of managers, manufacturers and researchers. In this paper, a new fuzzy multi-objective closed-loop supply chain is formulated. The first objective function increases profit, the second objective function increases cloud management of total centers of the supply chain, and the third objective function decreases total environmental impacts. The LP-metric method is used to solve the multi-objective model, validating it with numerical examples, and sensitivity analysis is done on demand and price parameters.

Keywords*– Cloud management, closed-loop supply chain, fuzzy programming, multi-objective.*

I. INTRODUCTION

Nowadays, expansion and variation of production and business in the world lead managers to new attitudes (Razmjooei et al., 2022). Supply chain, especially closed-loop supply chain (CLSC), has absorbed the attention of manufacturers, vendors, and researchers. Cost reduction, timely delivery, and environmental needs are significant to maintaining the satisfaction of customers and applying proper management techniques. CLSC was discussed as an activity for after-sales offices, a competitive region, returned faulty products, and warranty products (Goli and Golmohammadi, 2022).

Cloud computing is a cloud technology applied in online shopping platforms. Also, Amazon, Google, and Microsoft pursue this technology and their applications continue to expand their role in everyday's life (Hung, 2018). Cloud computing is very beneficial for the business sector, small and medium-sized enterprises (SMEs). Cloud computing can fulfill user requirements with on-demand services and low costs for SME departments. Certainly, SMEs have problems with the raw material procurement, on-time delivery, raw materials quality, low prices due to lack of contracted suppliers, and limited budgets (Chaising and Haasis, 2021). Cloud management is a composition of automation, software, diplomacy, governance, and people that specify how cloud computing services are made available. Informing the cloud strategy, measuring cloud performance, creating a more vigorous cloud security program, ensuring cloud compliance, and providing assurance of internal controls are done in cloud management (Mezzio et al., 2023). So, cloud management has benefits for managers and businessmen. Low prices, on-demand services, and troubleshooting of

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sourcing raw materials are benefits of firms with cloud management or cloud computing. Indeed, cloud computing is one of the suitable technologies that provides information services and helps companies settle problems. In the literature of CLSC, issues such as sale and leaseback agreements (Ameli et al., 2022), discount (Ghahremani-Nahr et al., 2020), sustainability (Battaïa et al., 2023), production planning (Scheller et al., 2023) and blockchain technology (Goli, 2023) have been studied. Cloud management is not addressed in recent studies. On the other hand, cloud management or cloud computing is used in complex networks to gain the issue of extensive data management in the business. Therefore, it seems essential to consider cloud management in CLSC. In Reality, paying attention to uncertainty is significant because of unforeseen events. The stochastic and fuzzy programming are two of the uncertainty addressing approaches. Stochastic methods need enough information to estimate the distribution of uncertain parameters whereas in the fuzzy methods, it is not the case (Razmjooei et al., 2022). The parameters are considered trapezoidal fuzzy numbers because of their uncertain nature. Accordingly, it was decided to formulate a new multi-objective CLSC, mixed-integer, multi-product, and fuzzy mathematical model in this paper. In addition to cloud management, this research considers the shortage and damaged products in transportation. The first objective function is to enhance profit (income minus total cost); the second objective function is to maximize the capability of cloud management of suppliers, manufacturers, distributions, collection centers, inspection centers, and disposal centers; the third object is to decrease total environmental impacts (environmental damage of suppliers, manufacturers, distributions, collection centers, inspection centers, and disposal centers). The Epsilon Constraint, LP-metric, and goal programming methods are the solution approaches for multi-objective problems. In this paper, the LP-metric method is used, which is a popular method. The relative deviations from the optimal solution of each function are minimized in the LP-metric method.

The remainder of this paper is arranged as follows. In the next part, the literature review is presented. The new MIP model is explained in the third section. The results of testing numerical examples and validating the new model are explained in Section 4. Finally, Section 5 mentions the conclusions and directions for future studies.

II. LITERATURE REVIEW

Many studies are done in the field of CLSC. The benefits of gathering and recycling the products lead to investigating them (Shahedi et al., 2021). On the other hand, it is vital to have access to real-time accurate information. Cloud computing helps managers enhance business and relations. Cloud management is not investigated in the literature of CLSC. The literature of the CLSC can be divided into uncertainty works and non-uncertainty works. In the field of uncertainty, Razmjooei et al. (2022) formulated a fuzzy programming problem to minimize delay time and the total cost of reverse logistics. Its supply chain network consists of manufacturers, processing centers, and returning centers. The Genetic Algorithm (GA) and Cuckoo Optimization Algorithm (COA) were used to solve the model. A fuzzy programming problem was applied to the automotive tire industry in the CLSC model to maximize the total profit and minimize environmental influences (Shahedi et al., 2021). A dynamic redesigning CLSC was formulated. They discussed establishing new organs, closing the existing organs, and enhancing discrete capacity levels of organs. It is noticeable that demand and returned products were considered stochastic (Ameli et al., 2022). Transportation cost and demand were considered uncertain in the other paper, which stated that the raw materials were purchased at a discount from the suppliers (Ghahremani-Nahr et al., 2020). Goli (2023) investigated blockchain technology in CLSC which stated that the product portfolio was designed under robust optimization.

The competition between existing and new supply chains was discussed in the CLSC literature. The critical issues were the selling price of new products and the purchasing price of returned products in reverse logistics. Also, the demand and the amount of returned products depended on the suggested price of the competitors (Keshavarzfard and Zamani, 2022).

The novelty was seen in the solution methods. In one study, the robust non-linear model was developed using the budget of uncertainty which was solved by a new hybrid heuristic algorithm considering dynamic programming, tabu search, and ant colony optimization (Moubed and Mehrjerdi, 2015).

In line with the significance of disruptions, Yousefi-Babadi et al. (2021) considered the resilience and sustainability in the proposed p-robust model that was solved by a heuristic algorithm depending on strategic variables relaxation. Afshar et al. (2022) propounded distributors based on disruptions, which can be the reason for plants to lose part of their capacity in production or human resources and delay in requirements of customers. Considering sustainability and resilience, the quality of the manufactured and transported products, and environmental effects in CLSC in Boom Scenario and Bust Scenario was obtained using the Epsilon Constraint and NSGA-II methods. In the other study, disruption is considered in distribution centers. This is because possible partial disruption influences the maximizing of the reliability of the system and minimizing the total cost (Mirmajlesi et al., 2022).

For the deterministic literature of CLSC, Goli and Golmohammadi (2022) developed a bi-objective model to maximize the profit and market share of a network that included production, customers, collection, recovery, and sales centers. In comparing the results of LP-metric and goal programming, LP-metric provided better results. Alinezhad (2019) developed a mixed-integer problem to enhance profit based on inspiration from the dairy industry. The quality of returned products is the other issue considered in CLSC literature. Jolai et al. (2021) investigated the consumers' willingness based on taking back the price in reverse logistics. Taking back price depended on various quality levels influencing the processed cost of the collected products. The disruption was another important issue in this field. A multi-objective green CLSC problem developed with propounding disruption in centers that used the Epsilon Constraint approach for small-scale examples and the non-dominated sorting genetic algorithm for large-scale problems was proposed (keshmiry zadeh et al., 2021). Aghagolnezhad Gerdrodbari et al. (2021) propounded the perishable products to minimize total cost and pollution emissions that solved the model by the ε-constraint method. Customer satisfaction depended on delivery time with using a multi-level system for the distributions was an operational decision. Saffarian et al. (2021) formulated a two-level pricing-inventory-routing CLSC model. The leader minimized greenhouse gas and the follower maximized profit. Scheller et al. (2023) proposed a production planning for CLSC of lithium-ion batteries, the efficacy of different network structures was investigated.

In the field of solution methods, exact, meta-heuristic, and heuristic methods were evaluated. The bi-objective problem was developed to maximize the utilization of eco-friendly materials and minimize the cost. The exact methods consisted of modified Epsilon-Constraint, LP-metric. The heuristic method included the lagrangian relaxation algorithm. The meta-heuristic methods included NSGA-II, MOPSO, SPEA-II, and MOEA/D (Abdolazimi et al., 2020).

Integrated reliability and sustainability were discussed in the multi-objective CLSC model, which was applied the normalized normal constraint (NNC) approach to solve the model (Amirian et al., 2022). Sustainability is one of the best issues in the CLSC literature. Bahrampour et al. (2023) proposed a multi-objective fuzzy model, they considered three aspects of sustainability. Battaïa et al. (2023) considered sustainability in CLSC, which investigated the evaluation of environmental and social equity in the network design of CLSC. They understood that environmental and social fairness and paradoxically -these are related to the sustainable development goals (SDGs)- have not been considered in the network design of sustainable supply chains. Khorshidvand et al. (2021) presented a two-stage sustainable CLSC in which the price was derived in the first stage, and then the multi-objective model was solved to minimize the total cost and CO_2 emissions and maximize employee safety. Wang et al. (2023) suggested the Stackelberg model, which consisted of the retailer and the manufacturer. Responsibility sharing ratios were investigated. Also, the environmental impacts of the proposed models with and without responsibility sharing were investigated based on the optimal sharing ratios. Yang et al. (2023) studied product recovery options. The poor dynamic behavior (which resulted in inventory variance and bullwhip effect) could be reduced in CLSC compared with a traditional open-loop supply chain.

Javadi Gargari et al. (2021) considered cloud management for suppliers to optimize the supply chain, which was a multi-objective problem. Chaising and Haasis (2021) considered cloud computing in SMEs to help with logistics services and procurement services.

A. Research gap

The research gap can be summarized as follows according to the subject literature:

1. Little attention was paied to the shortage of products in CLSC literature.
2. The damaged products in transportation in CLSC has not been considered.
3. The cloud management in CLSC has not received enough attention.

B. Research innovations

1. The shortage is considered in the developed model.
2. Shipping the unaccepted products (which are damaged in transportation or other defects of products) from distribution centers to collection centers is a good idea for better customer satisfaction and cost reduction.
3. It is noticeable that cloud management is a novel issue in CLSC. Cloud management (especially in CLSC) can provide a suitable situation for managers and profit. Also, considering the above-mentioned issues simultaneously is another contribution of this paper.

Table 1. Literature Review

Authors	Considered subjects							Objective function					Uncertain			
	time	Sustainability, disruption	comptition	blockchain technology	Price, Quality	Budget and discount	Sale and leaseback	Cost or profit	Environmenand, social	market share, customer satisfaction	Cloud management	certain	Fuzzy progrmming	stochastic	robust	Scenario-based
Razmjooei et al. (2022)	*							*					*			
Shahedi et al. (2021)								*	*				*			
Ameli et al. (2022)							*	*	*					*		
Ghahremani-Nahr et al. (2020)						*		*							*	
Goli and Golmohammadi (2022)			*					*		*						
Keshavarzfard and Zamani, (2022)			*		*			*					*			
Moubed and Mehrjerdi (2015)						*		*							*	
Yousefi-Babadi et al. (2021)		*						*							*	
Afshar et al. (2022)		*						*	*							*
Mirmajlesi etal. (2022)		*						*				*				
Jolai et al. (2021)					*			*				*				
Keshmiry zadeh et al. (2021)		*						*	*	*		*				
Aghagolnezhad Gerdrodbari et al. (2021)	*							*	*			*				
Saffarian et al. (2021)					*			*	*			*				
Abdolazimi et al. (2020)		*						*	*			*				
Amirian et al. (2022)		*						*	*			*				
Battaïa et al. (2023)		*							*							
Khorshidvand et al. (2021)		*			*			*	*			*				
Wang et al. (2023)			*						*			*				
Presented lecture					*			*	*		*		*			

III. MODEL DESCRIPTION

A multi-objective CLSC is formulated. It is multi-period, multi-products, multi-echelon. The network consists of suppliers, manufacturers, distributions, and clients in the forward chain. Also, the network consists of collection centers, inspection centers, and disposal centers in the backward chain. The first objective function maximizes profit (income minus total cost), the second object maximizes the cloud management capability of each echelon, and the third object minimizes total environmental impacts (environmental damage of each echelon). The demand, price, cloud management capability, costs, and environmental influence are propounded uncertain in the model produced by trapezoidal fuzzy numbers.

A. Assumptions

- The CLSC design model is multi-products and multi-periods.
- The position of all zones is fixed.
- The inventory holding cost of raw materials is considered in plants.
- The transfer cost between the production center and the inspection center is neglected.
- Shortage (demand backlog) is allowed.
- The unaccepted products (which are damaged in transportation or other difficulties) are shipped from distribution centers to collection centers.

B. Model formulation

Symbols of the model:

r	The index of raw materials	c	The index of clients
p	The index of products	d	The index of collection zones
j	The index of suppliers	n	The index of inspection zones
m	The index of plants	l	The index of disposal zones
k	The index of distributions	t	The index of period

Model parameters :

$\widetilde{dem}_{pct}$	Demand of client c for product p in period t
$\widetilde{pric}_{pt}$	Price of product p in period t
$\widetilde{bp}_{pct}$	Shortage cost of client c for product p in period t
$\widetilde{cp}_{pmt}$	Producing cost of product p for plant m in period t
$\widetilde{cs}_{rjt}$	Supplying cost of raw material r for supplier j in period t
hr_{rmt}	Holding cost of raw material r for planet m in period t
$\widetilde{cpr}_{pmt}$	Remanufacturing cost of p product for m plant in period t

$\widetilde{cn}_{pnt}$	Inspection cost of p product for n inspection zone in period t
$\widetilde{cl}_{plt}$	Disposal cost of p product for n disposal zone in period t
$\widetilde{tcm}_{pmkt}$	Shipment cost of p product from m plant to k distribution in period t
$\widetilde{tck}_{pkct}$	Shipment cost of product p from distribution zone k to client c in period t
$\widetilde{tcc}_{pcdt}$	Shipment cost of product p from client c to collection zone d in period t
$\widetilde{tcd}_{pdnt}$	Shipment cost of product p from collection zone d to inspection zone n in period t
$\widetilde{tcn}_{pnmt}$	Shipment cost of product p from inspection zone n to plant m in period t
$\widetilde{tcl}_{pnlt}$	Shipment cost of product p from inspection n to disposal zone l in period t
mr_{rjt}	Maximum capacity of providing raw material r from supplier j in period t
mk_{pkt}	Maximum capacity of distributing product p for distribution zone k in period t
md_{pdt}	Maximum capacity of collecting product p for collection zone d in period t
mn_{pnt}	Maximum capacity of inspecting product p for inspection zone n in period t
ml_{plt}	Maximum capacity of disposing product p for disposal zone n in period t
$\widetilde{clm}_{pmt}$	Capability of cloud management of product p for plant m in period t
$\widetilde{cld}_{pdt}$	Capability of cloud management of product p for collection zone d in period t
$\widetilde{cls}_{rjt}$	Capability of cloud management of raw material r for supplier j in period t
$\widetilde{clk}_{pkt}$	Capability of cloud management of product p for distribution zone k in period t
$\widetilde{cln}_{pnt}$	Capability of cloud management of product p for inspection zone n in period t
$\widetilde{cll}_{plt}$	Capability of cloud management of product p for disposal zone l in period t
$\widetilde{clJ}_{rjt}$	Capability of cloud management of supplier J for raw material r in period t
$\widetilde{cvm}_{pmt}$	Environmental influences of product p for plant m in period t
$\widetilde{cvd}_{pdt}$	Environmental influences of product p for collection zone d in period t
$\widetilde{cvs}_{rjt}$	Environmental influences of supplier j for raw material r in period t
$\widetilde{cvk}_{pkt}$	Environmental influences of product p for distribution zone k in period t
$\widetilde{cvn}_{pnt}$	Environmental influences of product p for inspection zone n in period t
$\widetilde{cvJ}_{rjt}$	Environmental influences of supplier J for raw material r in period t

u_{rp}	The amount of raw material r needed for product p
R_{pct}	Return rate of product p from client c in period t
φ_{pt}	Probability that product p is usable after inspection in period t

Decision variables:

b_{pct}	Shortage amount of product p for client c in period t
qj_{rjmt}	Amount of raw materials r shipped from supplier j to plant m in period t
qm_{pmkt}	Amount of product p shipped from plant m to distribution k in period t
qk_{pkct}	Amount of product p shipped from distribution k to client c in period t
qr_{pcdt}	Amount of product p shipped from client c to collection d in period t
qrd_{pdnt}	Amount of product p shipped from collection d to inspection n in period t
qru_{pnmt}	Amount of product p shipped from inspection n to plant m in period t
$qrdi_{pnlt}$	Amount of product p shipped from inspection n to disposal l in period t
I_{rmt}	Inventory of raw material r at plant m in period t
y_{pkt}	$\begin{cases} 1 & \text{if product } p \text{ is accepted in distribution zone } k \text{ in period } t \\ 0 & otherwise \end{cases}$

$$
\begin{aligned}
\text{Min } Z_1 = & \sum_p^P \sum_k^K \sum_c^C \sum_t^T \widetilde{\text{pric}}_{pt} . qk_{pkct} \\
& - \sum_r^R \sum_j^J \sum_m^M \sum_t^T \widetilde{cs}_{rjmt} . qj_{rjmt} + hr_{rmt} . I_{rmt} \\
& - \sum_p^P \sum_m^M \sum_k^K \sum_t^T \widetilde{cp}_{pmt} . qm_{pmkt} + \widetilde{bp}_{pct} . b_{pct} + \widetilde{tcm}_{pmkt} . qm_{pmkt} \\
& - \sum_p^P \sum_k^K \sum_c^C \sum_t^T \sum_d^D \widetilde{tck}_{pkct} . qk_{pkct} + \widetilde{tcc}_{pcdt} . qr_{pcdt} \\
& - \sum_p^P \sum_d^D \sum_n^N \sum_t^T \widetilde{tcd}_{pdnt} . qrd_{pdnt} + \widetilde{cn}_{pnt} . qrd_{pdnt} \\
& - \sum_p^P \sum_n^N \sum_m^M \sum_t^T \widetilde{tcn}_{pnmt} . qru_{pnmt} + \widetilde{cpr}_{pmt} . qru_{pnmt} \\
& - \sum_p^P \sum_n^N \sum_l^L \sum_t^T \widetilde{tcl}_{pnlt} . qrdi_{pnlt} + \widetilde{cl}_{plt} . qrdi_{pnlt}
\end{aligned} \tag{1}
$$

$$\text{Max } Z_2 = \sum_p^P \sum_m^M \sum_k^K \sum_c^C \sum_d^D \sum_n^N \sum_r^R \sum_j^J \sum_t^T \widetilde{clm}_{pmt}.qm_{pmkt} + \widetilde{cls}_{rjt}.qj_{rjmt} + \widetilde{clk}_{pkt}.qk_{pkct} + \widetilde{cld}_{pdt}.qr_{pcdt} + \widetilde{cll}_{plt} * qrdi_{pnlt} + \widetilde{cln}_{pnt}.qrd_{pdnt} + \widetilde{clJ}_{rjt}.qj_{rjmt} \quad (2)$$

$$\text{Min } Z_3 = \sum_p^P \sum_m^M \sum_k^K \sum_c^C \sum_d^D \sum_n^N \sum_r^R \sum_j^J \sum_t^T \widetilde{cvm}_{pmt}.qm_{pmkt} + \widetilde{cvs}_{rjt}.qj_{rjmt} + \widetilde{cvk}_{pkt}.qk_{pkct} + \widetilde{cvd}_{pdt}.qr_{pcdt} + \widetilde{cvn}_{pnt}.qrd_{pdnt} + \widetilde{cvJ}_{rjt}.qj_{rjmt} \quad (3)$$

$$b_{pct} = b_{pct-1} + \widetilde{dem}_{pct} - \sum_k^K qk_{pkct} \quad (4)$$

$$I_{rmt} = I_{r\,m\,t-1} + \sum_j^J qj_{rjmt} + \sum_n^N qru_{pnmt}.\ \mu_{rp} - \sum_k^K qm_{pmkt}.\ \mu_{rp} \quad (5)$$

$$\sum_m^M qm_{pmkt} = \sum_c^C qk_{pkct} + \sum_d^D qkd_{pkdt} \quad (6)$$

$$\sum_c^C qk_{pkct} \le M.y_{pkt} \quad (7)$$

$$\sum_c^C qkd_{pkdt} \le M.(1 - y_{pkt}) \quad (8)$$

$$\sum_d^D qr_{pcdt} \le R_{pct}.\sum_k^K qk_{pkct} \quad (9)$$

$$\sum_k^K qkd_{pkdt} + \sum_c^C qr_{pcdt} = \sum_n^N qrd_{pdnt} \quad (10)$$

$$\sum_d^D qrd_{pdnt} = \sum_m^M qru_{pnmt} + \sum_l^L qrdi_{pnlt} \quad (11)$$

$$\sum_m^M qru_{pnmt} = \sum_d^D qrd_{pdnt}.\varphi_{pt} \quad (12)$$

$$\sum_m^M qj_{rjmt} \le \mathrm{mr}_{rjt} \quad (13)$$

$$\sum_k^K qm_{pmkt} + \sum_n^N qru_{pnmt} \le mm_{pmt} \quad (14)$$

$$\sum_c^C qr_{pcdt} + \sum_k^K qkd_{pkdt} \le md_{pdt} \quad (15)$$

$$\sum_{d}^{D} qrd_{pdnt} \leq mn_{pnt} \tag{16}$$

$$\sum_{l}^{L} qrdi_{pnlt} \leq ml_{plt} \tag{17}$$

$$\sum_{m}^{M} qm_{pmkt} \leq mk_{pkt} \tag{18}$$

$$b_{pct} \leq (1-sat).\widetilde{dem}_{pct} \tag{19}$$

$$b_{pct}, I_{rmt}, qj_{rjmt}, qm_{pmkt}, qk_{pkct}, qru_{pnmt}, qkd_{pkdt}, qr_{pcdt}, qrd_{pdnt}, qrdi_{pnlt} \geq 0 \tag{20}$$

$$y_{pkt} = 0, 1 \tag{21}$$

The first objective function maximizes the profit (income minus total cost) (Eq. 1). The second objective function maximizes the total capability of cloud management (Eq. 2). The third objective function minimizes the total environmental influences (Eq. 3). Equation (4) displays the balance between shortage, customer demand and amount of products that are shipped to customers. Equation (5) is related to the inventory level balance for raw materials. The products delivered to the distributors must equal the products sent to the customers and those sent to the collection zones, which is illustrated in equation (6). If variable qk_{pkct} is positive, then the variable qkd_{pkdt} must be zero and vice versa (Eq. 7, 8). These two equations illustrate that in the case of acceptance of each product at each distributor, it will be shipped to the customers. Otherwise, it will be shipped to the collection centers. The quantity of returned products from each customer is shown in equation (9). The products shipped to inspection from customers and distributions (Eq. 10) are equal to the reusable products shipped to plants plus the products shipped to disposal zones (Eq. 11). Equation (12) shows the reusable products. Equation (13) – (18) explain capacity limitations in each supplier, manufacturer, distributor, collection, inspection, and disposal center. Equation (19) assures that the related decision variables are non-negative.

IV. SOLUTION APPROACH

A. Fuzzy programming

Fuzzy programming is a popular and good method when there is not sufficient and exact information about the problem. This approach has many benefits in situations of uncertainty of parameters. Fuzzy programming and probabilistic methods are methods in uncertain conditions, but the probabilistic method needs enough information to estimate the distribution of uncertain parameters. Compared with the fuzzy method, the probabilistic method is very problematic because it determines the distribution of uncertain parameters (Razmjooei et al., 2022). There are multiple patterns such as trapezoidal, triangular, and bell-shaped patterns to explain fuzzy numbers. In this paper, trapezoidal numbers are employed to demonstrate the fuzzy parameters (Bahrampour et al., 2023). The fuzzy set Ñ from the reference *Y* is a set of ordered pairs and is defined as follows (Razmjooei et al., 2022):

$$\tilde{N} = \{(y, \mu_{\tilde{N}}(y))/y \in Y\} \tag{22}$$

Where $\mu_{\tilde{N}}(y)$ is acquired as (23).

$$\mu_{\tilde{N}}(y) : Y \to [0, 1] \tag{23}$$

The membership function of a trapezoidal fuzzy numbers is denoted as follows:

$$\mu(y) = \begin{cases} \frac{y-a}{b-a} & a \leq y \leq b, \\ 1 & b \leq y \leq c, \\ \frac{d-y}{d-c} & c \leq y < d, \\ 0 & otherwise \end{cases} \tag{24}$$

According to Eq. (25), the average of four fuzzy numbers is applied to de-fuzzify the parameters discussed in the form of the fuzzy objective function. Depending on the type of constraint, Eqs. (26) and (27) are used for de-fuzzifying parameters in the constraints of the model.

$$\tau = \frac{(a+b+c+d)}{4} \tag{25}$$

$$Cr\{\tau \leq y\} \geq a \leftrightarrow y \geq (2-2a)c + (2a-1)d \tag{26}$$

$$Cr\{\tau \geq y\} \geq a \leftrightarrow y \geq (2a-1)a + (2-2a)b \tag{27}$$

B. LP-metric

The relative deviations from the optimal solution of each function are minimized in the LP-metric method. First, the optimal value of each function should be achieved independently from other objective functions. It is noticeable that in the optimal value gained separately for each objective, the constraints have no variations. The objective functions that are nearer to their optimal solutions are better. Then, the sum of the relative deviations of the objectives from their optimal solution should be minimized. The objective function is shown in Eq. (28) (Goli and Golmohammadi, 2022; Ameli et al., 2022).

$$\min z = \left[\sum_{i=1}^{n} \left(\frac{f_i^* - f_i}{f_i^*}\right)^p\right]^{1/p} \tag{28}$$

The proposed CLSC model is a multi-objective possibilistic mixed-integer linear programming. Since uncertainty is an unavoidable factor in the real world, most of the parameters are considered trapezoidal fuzzy numbers because of their uncertain nature. In general, the fuzzy programming problem must first be changed into a deterministic equivalent problem and then be solved with exact methods so that its optimal answer would be gained (Shahedi et al., 2021). This two-stage approach is used to solve the model. In the first stage, the developed model with fuzzy parameters is changed into a deterministic model using Razmjooei et al.'s (2022) method.

All objective functions have fuzzy parameters (Eq. (1-3)). Hence, according to the presented approach by Razmjooei et al. (2022), these terms are transferred into crisp numbers, as (Eq. (29-31)). The first and last constraints (Eq. 4, Eq. 19) are transferred to crisp numbers, as (Eq.32, Eq.33). In the second stage, the LP-metric method illustrated in Eq. (28) (Goli and Golmohammadi, 2022; Ameli et al., 2022)) is used and the obtained crisp model is solved.

According to the above explanation, the equivalent crisp model of the CLSC model is formulated as follows:

$$
\begin{aligned}
\text{Max } Z_1 = & \sum_{p}^{P}\sum_{k}^{K}\sum_{c}^{C}\sum_{t}^{T}\left(\frac{pric_{pt}^{1}+pric_{pt}^{2}+pric_{pt}^{3}+pric_{pt}^{4}}{4}\right).\,\mathrm{qk}_{\mathrm{pkct}} \\
& -\sum_{r}^{R}\sum_{j}^{J}\sum_{m}^{M}\sum_{t}^{T}\left(\frac{cs_{rjmt}^{1}+cs_{rjmt}^{2}+cs_{rjmt}^{3}+cs_{rjmt}^{4}}{4}\right).\,qj_{rjmt}+\ hr_{rmt}.\,I_{rmt} \\
& -\sum_{p}^{P}\sum_{m}^{M}\sum_{k}^{K}\sum_{t}^{T}\left(\frac{cp_{pmt}^{1}+cp_{pmt}^{2}+cp_{pmt}^{3}+cp_{pmt}^{4}}{4}\right).\,qm_{pmkt}+\left(\frac{bp_{pct}^{1}+bp_{pct}^{2}+bp_{pct}^{3}+bp_{pct}^{4}}{4}\right).\,b_{pct} \\
& \quad +\left(\frac{tcm_{pmkt}^{1}+tcm_{pmkt}^{2}+tcm_{pmkt}^{3}+tcm_{pmkt}^{4}}{4}\right).\,qm_{pmkt} \\
& -\sum_{p}^{P}\sum_{k}^{K}\sum_{c}^{C}\sum_{t}^{T}\sum_{d}^{D}\left(\frac{tck_{pkct}^{1}+tck_{pkct}^{2}+tck_{pkct}^{3}+tck_{pkct}^{4}}{4}\right).\,qk_{pkct} \\
& \quad +\left(\frac{tcc_{pcdt}^{1}+tcc_{pcdt}^{2}+tcc_{pcdt}^{3}+tcc_{pcdt}^{4}}{4}\right).\,qr_{pcdt} \\
& -\sum_{p}^{P}\sum_{d}^{D}\sum_{n}^{N}\sum_{t}^{T}\left(\frac{tcd_{pdnt}^{1}+tcd_{pdnt}^{2}+tcd_{pdnt}^{3}+tcd_{pdnt}^{4}}{4}\right).\,qrd_{pdnt} \\
& \quad +\left(\frac{cn_{pnt}^{1}+cn_{pnt}^{2}+cn_{pnt}^{3}+cn_{pnt}^{4}}{4}\right).\,qrd_{pdnt} \\
& -\sum_{p}^{P}\sum_{n}^{N}\sum_{m}^{M}\sum_{t}^{T}\left(\frac{tcn_{pnmt}^{1}+tcn_{pnmt}^{2}+tcn_{pnmt}^{3}+tcn_{pnmt}^{4}}{4}\right).\,qru_{pnmt} \\
& \quad +\left(\frac{cpr_{pmt}^{1}+cpr_{pmt}^{2}+cpr_{pmt}^{3}+cpr_{pmt}^{4}}{4}\right).\,qru_{pnmt} \\
& \quad -\sum_{p}^{P}\sum_{n}^{N}\sum_{l}^{L}\sum_{t}^{T}\left(\frac{tcl_{pnlt}^{1}+tcl_{pnlt}^{2}+tcl_{pnlt}^{3}+tcl_{pnlt}^{4}}{4}\right).\,qrdi_{pnlt} \\
& \quad +\left(\frac{cl_{plt}^{1}+cl_{plt}^{2}+cl_{plt}^{3}+cl_{plt}^{4}}{4}\right).\,qrdi_{pnlt}
\end{aligned}
\tag{29}
$$

$$
\begin{aligned}
\text{Max } Z_2 = & \\
& \textstyle\sum_{p}^{P}\sum_{m}^{M}\sum_{k}^{K}\sum_{c}^{C}\sum_{d}^{D}\sum_{n}^{N}\sum_{r}^{R}\sum_{j}^{J}\sum_{t}^{T}\left(\frac{clm_{pmt}^{1}+clm_{pmt}^{2}+clm_{pmt}^{3}+clm_{pmt}^{4}}{4}\right).\,qm_{pmkt}+ \\
& \left(\frac{clk_{pkt}^{1}+clk_{pkt}^{2}+clk_{pkt}^{3}+clk_{pkt}^{4}}{4}\right).\,qk_{pkct} \\
& +\left(\frac{cls_{rjt}^{1}+cls_{rjt}^{2}+cls_{rjt}^{3}+cls_{rjt}^{4}}{4}\right).\,qj_{rjmt}+ \\
& +\left(\frac{cld_{pdt}^{1}+cld_{pdt}^{2}+cld_{pdt}^{3}+cld_{pdt}^{4}}{4}\right).\,qr_{pcdt} \\
& +\left(\frac{cln_{pnt}^{1}+cln_{pnt}^{2}+cln_{pnt}^{3}+cln_{pnt}^{4}}{4}\right).\,qrd_{pdnt} \\
& \left(\frac{cll_{plt}^{1}+cll_{plt}^{2}+cll_{plt}^{3}+cll_{plt}^{4}}{4}\right).\,qrdi_{pnlt}+ \\
& +\left(\frac{clj_{rjt}^{1}+clj_{rjt}^{2}+clj_{rjt}^{3}+clj_{rjt}^{4}}{4}\right).\,qj_{rjmt}
\end{aligned}
\tag{30}
$$

$$\text{Min } Z_3 = \sum_p^P \sum_m^M \sum_k^K \sum_c^C \sum_d^D \sum_n^N \sum_r^R \sum_j^J \sum_t^T \left(\frac{cvm_{pmt}^1+cvm_{pmt}^2+cvm_{pmt}^3+cvm_{pmt}^4}{4}\right).\, qm_{pmkt} + \left(\frac{cvk_{pkt}^1 + cvk_{pkt}^2 + cvk_{pkt}^3 + cvk_{pkt}^4}{4}\right).\, qk_{pkct} \left(\frac{cvs_{rjt}^1 + cvs_{rjt}^2 + cvs_{rjt}^3 + cvs_{rjt}^4}{4}\right).\, qj_{rjmt} + \left(\frac{cvd_{pdt}^1 + cvd_{pdt}^2 + cvd_{pdt}^3 + cvd_{pdt}^4}{4}\right).\, qr_{pcdt} + \left(\frac{cvn_{pnt}^1 + cvn_{pnt}^2 + cvn_{pnt}^3 + cvn_{pnt}^4}{4}\right).\, qrd_{pdnt} + \left(\frac{cvj_{rjt}^1 + cvj_{rjt}^2 + cvj_{rjt}^3 + cvj_{rjt}^4}{4}\right).\, qj_{rjmt} \quad (31)$$

$$b_{pct} - b_{pct-1} + \sum_k^K qk_{pkct} \geq (2-2a).\, dem_{pct}^3 + (2a-1).\, dem_{pct}^4 \quad (32)$$

$$\frac{b_{pct}}{(1-\text{sat})} <= (2a-1).\, dem_{pct}^1 + (2-2a).\, dem_{pct}^2 \quad (33)$$

All the the constraints are the same in the uncertain and crisp model except the first and last one (Eq. 4, Eq. 19), which are converted into crisp numbers, as Eqs. (32-33).

V. ILLUSTRATIVE EXAMPLE

In this part, a numerical example is shown to validate the proposed model. The prepared data set is shown in Tables 2 to 6. Table 2 presents the costs of the supply chain network. The amounts of transportation costs between each node are shown in Table 3. Table 4 presents the capability of cloud management of each center. The environmental impacts of each center are shown in Table 5. Table 6 presents the maximum capacity of each node.

Table 2. Supply chain network costs

Parameters	Value
bp_{pct}	Uniform (20, 65)
cn_{pnt}	Uniform (60, 105)
cpr_{pmt}	Uniform (100, 190)
cl_{plt}	Uniform (60, 105)
cp_{pmt}	Uniform (1000, 1415)
cs_{rjmt}	Uniform (500, 910)

Table3. Transportation costs

tck_{pkct}	Uniform (11, 19.9)
tcc_{pcdt}	Uniform (11, 19.9)
tcd_{pdnt}	Uniform (10, 18.9)
tcn_{pnmt}	Uniform (10, 18.9)
tcl_{pnlt}	Uniform (15, 24)
tcm_{pmkt}	Uniform (20, 65)

Table4. Capability of cloud management of each center

clj_{rjt}	Uniform (40, 85)
clm_{pmt}	Uniform (30, 75)
cld_{pdt}	Uniform (30, 75)
clk_{pkt}	Uniform (10, 96)
cln_{pnt}	Uniform (10, 98)
cll_{plt}	Uniform (30, 75)

Table5. Environmental impacts of each center

cvj_{rjt}	Uniform (60, 105)
cvm_{pmt}	Uniform (30, 120)
cvd_{pdt}	Uniform (20, 63)
cvk_{pkt}	Uniform (50, 93)
cvn_{pnt}	Uniform (80, 124)
cvl_{plt}	Uniform (40, 85)

Table 6. Maximum capacity of each center

mm_{pmt}	Uniform (90000, 100000)
mr_{rjt}	Uniform (90000, 100000)
md_{pdt}	Uniform (90000, 100000)
mk_{pkt}	Uniform (90000, 100000)
mn_{pnt}	Uniform (90000, 100000)
ml_{plt}	Uniform (90000, 100000)

The model is solved to validate the performance of the presented new model using GAMS win64 24.7.3 optimization software. As said before, the LP-metric method converts the multi-objective model to a single object. The objective functions are shown in Table 7. Also, a total weighted objective function method is used to solve the new model (Razmjooei et al., 2022). Table 8 shows different values of objective functions with different values of weights. According to Tables 7 and 8, the total weighted objective functions method is better since different values of objective functions are obtained simply.

Table 7. Objective functions value with LP-metric method

Objective Function (OF)	value
OF1	1106332000
OF2	28781500000
OF3	44315900000
LP-metric OF	-890.931

Table 8. Objective functions value with total weighted objective functions method

weights	OF1	OF2	OF3	total weighted OF
W1=0.3, W2=0.4, W3=0.3	10073200000	1310330000	20763400000	2034267000
W1=0.2, W2=0.2, W3=0.6	24007020	31354220	49812700	-18815400
W1=0.05, W2=0.05, W3=0.9	23657990	30884250	49735000	-42034400
W1=0.1, W2=0.75, W3=0.05	1194124000	28780200000	44295300000	19489800000
W1=0.5, W2=0, W3=0.5	24006980	31334810	49806700	-12899900
W1=0, W2=0.5, W3=0.5	24007020	31354220	49812700	-9229240
W1=0.5, W2=0.5, W3=0	1202323000	28775500000	44288000000	14988900000

VI. SENSITIVITY ANALYSIS

In this part, sensitivity analysis has been performed to display the confirmation of the proposed model. So, sensitivity analysis is performed on two parameters: the total customers' demand and the price of the final product. To this end, the first test problem, considered in the previous section, is used. A range of alterations in this parameter is tested, from a reduction of 20% to an enhancement of 20%. The results are shown in Tables 8 and 9.

Table 8. Sensitivity analysis of customer's demand parameter

Objectives	Parameter alteration percentage				
	-0.2	-0.1	0	$+0.1$	$+0.2$
OF1	13932170	15673700	17415220	19156740	20898260
OF2	30143690	33911650	37679610	41447570	45215530
OF3	55022850	61900700	68778560	75656410	82534270

Table 9. Sensitivity analysis of product's price parameter

Objectives	Parameter alteration percentage				
	-0.2	-0.1	0	$+0.1$	$+0.2$
OF1	10686090	15102100	17415220	23934100	26246990
OF2	36204260	36204260	37679610	36204260	37679610
OF3	66449360	66449360	68778560	66449360	68778560

When the demand parameter increases, the objectives increase, too. However, the enhancement slope of the first objective function is higher than the other two objective functions, meaning that the second objective function increases at a slower rate, and the enhancement speed of the third objective function is lower than that of the other two objective functions. These variations are reasonable. Since the first objective function is income minus cost, the demand changes influence the first objective function more than other objective functions (Figure 1). The objective function’s variations according to price variations are shown in Figure 2.

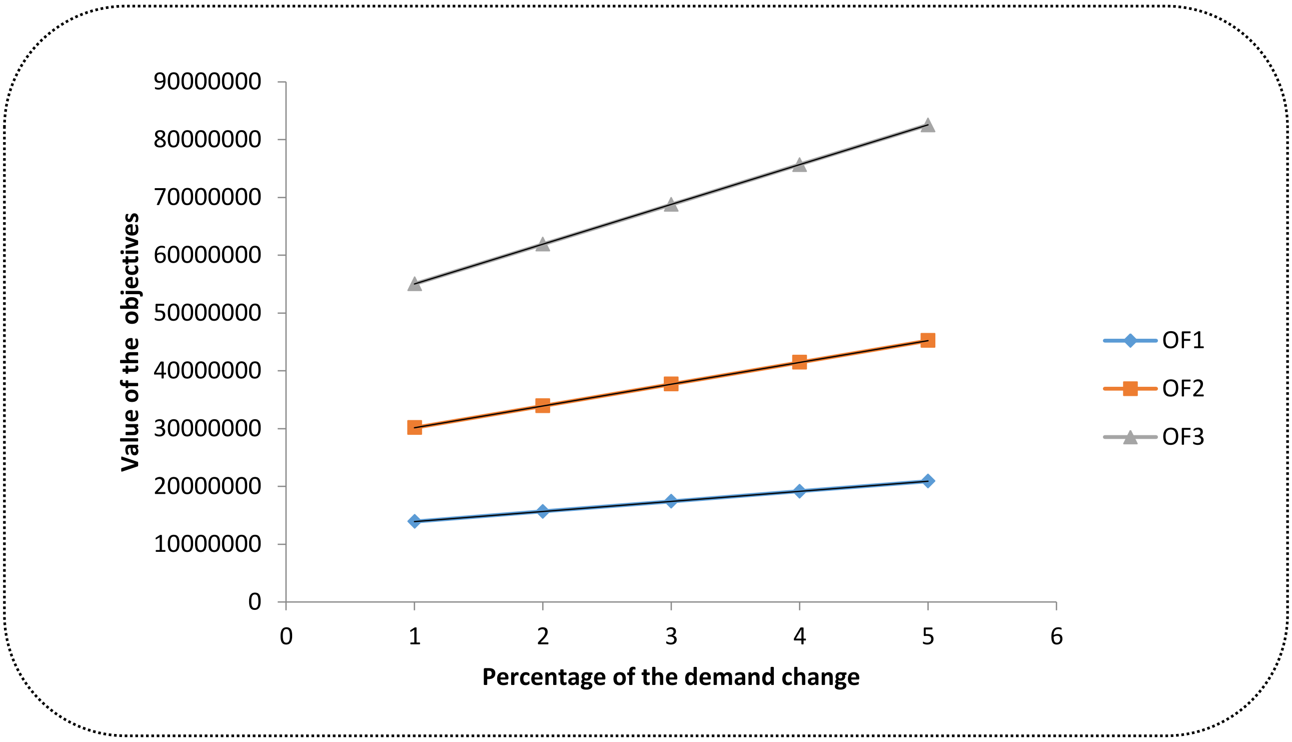

Fig. 1. The values of the objectives function according to the increase in the demand parameter

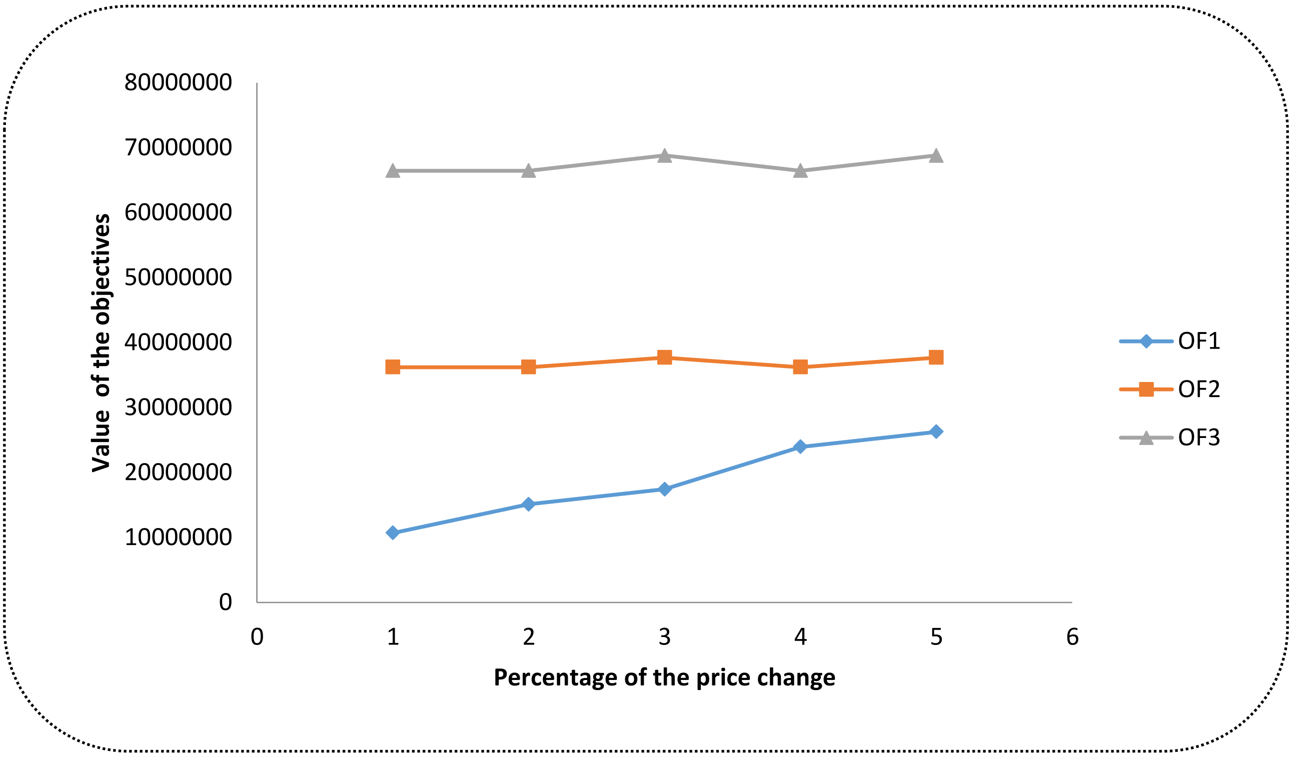

Fig. 2. The values of the objectives function according to the increase in the price parameter

VII. CONCLUSION

A fuzzy multi-objective CLSC is presented, which is multi-period, multi-products, and multi-echelon. The network includes suppliers, manufacturers, distributions, and clients in the forward chain and collection centers, inspection centers, and disposal centers in the backward chain. The first objective function maximizes profit (income minus total cost), the second one maximizes the cloud management. capability, and the third one minimizes the total environmental impacts. Because of the growth of technology, cloud management capability is an essential approach for managers to reduce cost, time, and product quality. So, discussing this ability is important for customers in selecting suppliers, manufacturers, distributions, collections, inspections, and disposal centers. Also, because of globalization and industrialization, the environmental influences of the zones of the echelons of CLSC are an important issue for customers. The trapezoidal fuzzy numbers are considered to change the uncertain model to the crisp model. A numerical example was used to validate the performance of the proposed model. The LP metric method converted the muli-objective model to a single-objective model. The sensitivity analysis on demand and price parameters shows that demand influences the first objective function more. If the first objective value is more important for managers, they must focus on the demand value. The price has a lower influence on the first objective function. One of the limitations of this study is applying the proposed model with numerical examples. Hence, it is highly suggested in future studies to perform this model for the actual industrial cases. Also, the researchers could solve the model on large-scale problems by exact methods or meta-heuristics approaches for future research. The other suggestion is to investigate robust optimization or other uncertainty methods.

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