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A novel interactive approach for solving uncertain bi-level multi-objective supply chain model

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ABSTRACT

In this paper, we adopt an interactive approach for bi-level multi-objective supply chain model (BL-MOSCM). The essential target is to decide the ideal request designation of items where the client's demands and supply for the items are vague demand. This study considers two decision-makers (DMs) operating at two separate groups of supply chain network (SCN), that is, a bi-level decision-making process. In the current BL-MOSCM, the leader locates quantities dispatched to retailers, and afterward, the follower chooses his amounts reasonably. The pioneer's goal is to reduce the all-out conveyance expenses, also, the follower's goal is to reduce the all-out conveyance time of the SCN and simultaneously adjusting the optimal request allotment from each source, plant, retailer, and distribution center, respectively. The BL-MOSCM is defuzzified and changed into a valent crisp structure based on the α-level methodology. Then the interactive methodology works on the α-(BL-MOSCM) by changing it into discrete multi-objective programming problems (MOPP). Also, each separate MOPP thinks through the ϵ-constraint methodology and the idea of satisfactoriness. The ϵ-constraint method aims at optimising one objective function, while considering all other objective functions as constraints. By obtaining the solution of the first level SCN utilizing the ϵ-constraint method, the second level SCN is also optimized considering the controlled variables of the first level. A novel test function is introduced to decide the compromise solution of the BL-MOSCM. Procedures for solving the uncertain BL-MOSCM via the interactive approach are introduced. A real-life case study was used to illustrate the proposed interactive methodology for the BL-MOSCM with fuzzy parameters. The obtained result shows the optimal quantities transported from the various sources to the various destinations that could enable managers to detect the optimum quantity of the product when hierarchical decision-making involving two levels. Finally, a comparison with the past studies is used to display the practicality and efficiency of the suggested methodology.

1. Introduction

Supply chain management (SCM) has been progressively highlighted over the latest decennium. The concentration has been set to maximize the profit-making execution, purse profiteering, and sustainability through joining holistic decision-making on both onward and inverse logistics (Amin and Zhang, 2013; Jolai et al., 2011).

A supply chain network (SCN) is a regulation of organizations, individuals, technologies, activities, data, and assets engaged with moving an item or administration from provider to client. Organizations are doing designing, buying, industrialization, marketing, and allotment via SCN, work freely with their targets which predominating guided to clashes and consequently there is a requirement for a system out of which these various tasks can be incorporated. SCN is a system to accomplish such combination among the autonomous organizations (Yu and Solvang, 2020; Amin and Zhang, 2013).

These days, SCNs are pull faced with environmental changes, social enactments, and disturbance chances; so, they should figure out how to be totally ready in confrontation of uncertain proceedings and novel variation in the planet (Charles et al., 2019; Gupta et al., 2021; Cancinoa et al., 2019). Uncertainty is inevitable and tending to the equivalent is inescapable. That everything is accessible at our doorstep is because of an all-around oversaw current worldwide supply chain (SC), which happens regardless of its productivity and viability being undermined by

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different wellsprings of uncertainty beginning from the desire side, supply side, producing cycle, designing and control frameworks.

Today we live in a highly interconnected world economy that organizes millions of businesses operating across different regions or countries. Given smooth economic coordination is a pre-condition for the successful functioning of the global economy, SCM offers the most needed service to ensure a strong network between a company and its suppliers to manufacture or produce, then to distribute goods to customers (www.statista.com, xxxx). As a commercial system of organizations, resources, information, and people, the SCN forms a complex and dynamic supply and demand network between a multitude of economic agents. The expansion of international trade triggered the importance of SCM further (www.statista.com, xxxx). For instance, the global SCM market was worth roughly 16 billion U.S. dollars in 2020. Over the last decade, SCM software and procurement market expanded more than twice (www.statista.com, xxxx). These networks of supply chains form the so-called global value chains, which is the prevailing method of interaction in international trade relations. Fig. 1 indicates the biggest supply chain challenges worldwide on 2017–2018 (www.statista.com, xxxx).

To explore SC uncertainty, we must initially characterize the connected key ideas. SCN, Fig. 2., comprises of a dispersion organization of the item equipping from origin to objective, i.e., the commute of the crude item from providers to producers, from makers to wholesalers, then, at that point from merchants to retailers, lastly, from retailers to clients. The industrialist gets the crude item from the providers and after handling it into completed products, he stocks the last to various distribution centers and retailers to ready them effectively accessible for the clients (Charles et al., 2019; Cancinoa et al., 2019).

All through the 20^{th} century, the SCN issue has been acquiring significance because of market globalization, which has expanded the opposition among the organizations. During the formularization operation of genuine world issues, the possible rate of these coefficients is dubious or equivocally known to the decision-makers (DMs) (Aliev et al., 2007; Charles et al., 2019; Jiménez et al., 2007; Liu and Kao, 2004; Liang, 2006). Consistently, it would be more helpful for these coefficients to be addressed as fuzzy mathematical information (Çalık et al.). The resulting SCN which joins obscure coefficients would be seen as more genuine than the standard one. According to this point of view, the coefficients exist in the proposed BL-MOSCM are believed to be characterized by fuzzy numbers (Elsisy and El Sayed, 2019; El Sayed and Abo-Sinna, 2021).

The bi-level programming problem (BLPP) is the most utilized demonstrating strategy in decentralized associations. The BLPP has two players; every one of the players knows their scenario and decides their own technique as per the other player's procedure (Amirtaheri et al., 2018; Çalık et al.; Sakawa and Nishizaki, 2009). However, in this model, players don't help one another.

In genuine world models, top administration or a leader board should think other players' procedure in by and large administration strategy. Interactive fuzzy programming (IFP) has been proposed by Sakawa et al. (Sakawa et al., 1998; Sakawa et al., 2000) to cope with this problem. Also, BLPP were solved in view of IFP to overcome such problem (Sakawa et al., 1998).

To contend with different types of uncertainty, different uncertainty programming approaches have been introduced, among them, fuzzy programming (FP), stochastic programming (SP), and robust optimization (RO) are the most applied ones. When randomness is the main source of uncertainty in the input coefficients of a decision model and there are enough historical data to estimate their probability distributions reliably, SP approach is a suitable candidate to cope with such uncertain data.

However, in most real cases, as there is not enough historical data, obtaining the exact random distribution of uncertain input data is difficult. Also, some cases may deal with elasticity (softness) in constraints or/and flexibility on the goals' target values. FP method can deal with both the epistemic uncertainty in input data and soft constraints using the two well-known categories of FP approach. The main assumption in this study is that the coefficients of the objective functions and the constraints in the BL-MOSCM are fuzzy parameters. To bridge the gap between the industrial practices and the lack of corresponding research, we propose an approach that directly captures their multi-level and uncertainty aspects based on BLPP principles.

In this paper we developed an interactive approach for BL-MOSCM with fuzzy parameters. The main aim is to decide ideal required assignment of items where the client's requests and supply for the items have a vague nature. In the created model the gross transportation costs are minimized at the first level, and the second level aim is to minimize the entire conveyance era of the SC and simultaneously adjusting the ideal request allotment from each source, plant, retailer, and distribution center, respectively. Considering the α-level methodology, the desired α-(BL-MOSCM) is developed. Then, at that point, the interactive

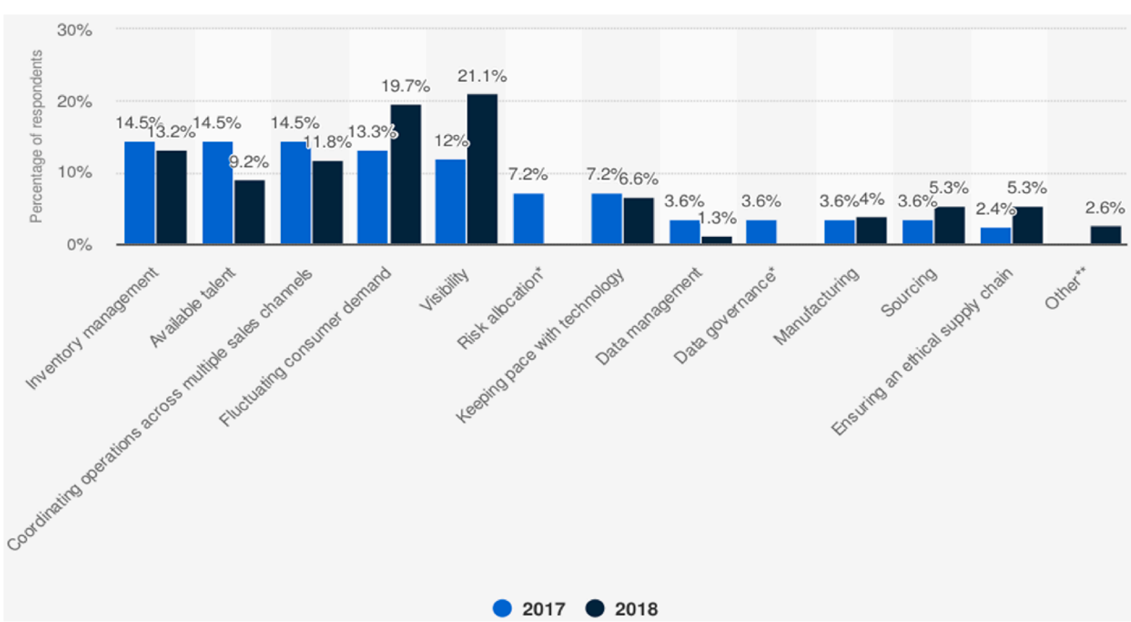

Fig. 1. The biggest supply chain challenges worldwide on 2017–2018.

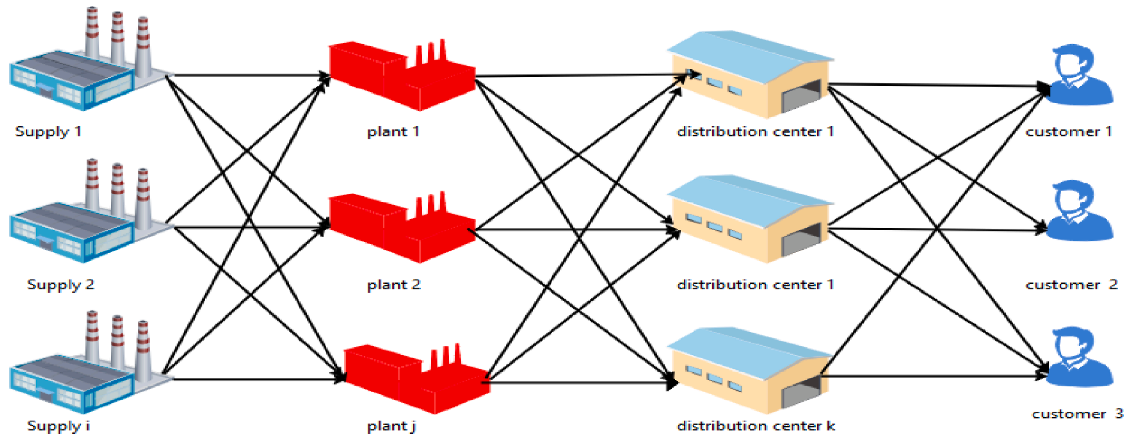

Fig. 2. Supply Chain Network.

methodology improves the α-(BL-MOSCM) by changing it over into discrete MOPPs. Additionally, each separate MOPP is settled by the ϵ-constraint methodology and the idea of satisfactoriness. At last, mathematical epitome and rapprochements with the past research are used to show the achievability and efficiency of the suggested methodology.

2. Literature review

Over the years, comprehensive exploration articles have been directed for the evolution of several optimization models for SCN (Bredstrom and Ronnqvist, 2002; Fahimnia et al., 2013; Gumus et al., 2009; Selim et al., 2008). Among these studies Feili and Khoshdooni (Feili and Khoshdoon, 2011), introduced A fuzzy optimization type for SC production designing with overall portion of decision making. Liang used fuzzy goal programming (FGP) to manufacturing/transportation arranging choices in a SC (Liang, 2007). FP for revenue and cost allotment to a fabrication and transportation issue has been studied by Sakawa et al. (Sakawa et al., 2001). Aliev et al. (Aliev et al., 2007) exhibited fuzzy-genetic way to deal with production–distribution designing in SCM. Mathematical programming and solution approaches for minimizing tardiness and transportation costs in the supply chain scheduling problem has been studied by Tamannaei and Rasti-Barzoki (Tamannaei and Rasti-Barzoki, 2019).

A mathematical programming approach to SCM under fuzziness has been studied by Chen and Chang (Chen and Chang, 2006). SC planning under uncertainty established on a FP approach was presented by Peidro et al. (Peidro et al., 2007). Application of FP technique to deal with the production allotment and distribution SCN issue has been proposed by Bilgen (Bilgen, 2010). A linear FP pattern for the optimization of multiphase SCNs via different membership functions was also, introduced by Paksoy and Pehlivan (Paksoy and Pehlivan, 2012). Multi-agent supply chain scheduling problem by considering resource allocation and transportation was studied by Aminzadegan et al. (Aminzadegan et al., 2019). Budiman and Rau presented a mixed-integer model for the implementation of postponement strategies in the globalized green supply chain network (Budiman and Rau, 2019). Pishvaee et al. (Pishvaee et al., 2011) sophisticated a mixed-integer linear type for closed loop SCN purpose. Effects of power structure on manufacturer encroachment in a closed-loop supply chain was considered by Zheng et al. (Zheng et al., 2019). To deal with uncertainty, a strong optimization paradigm is suggested by researchers in (Pishvaee and Torabi, 2010). Pishvaee and Razmi (Pishvaee and Razmi, 2012) exhibited a multi-objective FP paradigm for ecological SCN planning. Mula et al. (Mula et al., 2010) introduced a survey of various methods for SCM and arranged them dependent on linear, non-linear, multi-objective, fuzzy, stochastic programming, and metaheuristics.

Numerous academics and professionals have been ceaselessly zeroing in on addressing dubious SCNs. Sabri and Beamon, (Sabri and Beamon, 2000) fostered an integrated technique for tackling multi-objective SCN (MO-SCN) that incorporates synchronous vital and functional arranging together, i.e., manufacturing cost, submission time with dubious demand. Selim and Ozkarahan (Selim and Ozkarahan, 2008) fostered a MO-SCM to acquire the ideal numbers, areas, and ability levels of plants and distribution centers to convey the items to the retailers basically cost while fulfilling the ideal service level. Yeh and Chuang (Yeh et al., 2011) suggested MO-SCM for accomplice choice in green SC issues. Charles et al. (Charles et al., 2019) incorporated the different phases of SCN and figured it as a MOPP. Likewise, Gupta et al. (Gupta et al., 2021) showed the Significance of MOPP in coordination for multi-product SCN under intuitionistic fuzzy area. An intuitionistic fuzzy T-sets established optimization procedure for manufacturing-allocation arranging in SCM has been developed by Garai et al. (Garai et al., 2016).

A possibilistic linear programming model for supply chain network design (SCND) under uncertainty has been introduced by Bouzembrak (Bouzembeak, 2013). A comprehensive review and future research directions in SCND under uncertainty was exhibited by Govindan et al. (Govindan et al., 2017). Baidya suggested stochastic SC transportation models implementations and benefits (Baidya, 2019). Boronoos et al. proposed a robust mixed flexible-possibilistic programming approach for multi-objective closed-loop green SCND (Boronoos et al., 2021). Recently, Salehi-Amiri et al., designed a closed-loop SCN considering social factors with a case study on Avocado industry (Salehi-Amiri et al., 2022). Developing a bi-objective mathematical model to design the fish closed-loop supply chain introduced by Fasihi et al. (Fasihi et al., 2021). Sustainability in designing agricultural supply chain network: A case study on palm date proposed by Hamdi-Asl et al. (Hamdi-Asl et al., (2021)).

Robust SCND with service level against disruptions and demand uncertainties with a real-life case has been introduced by Baghalian et al. (Baghalian et al., 2013). Farahani et al. (Farahani et al., 2014) gave an audit of serious climate on SCN plan. They classified the connected writing in SCN plan that thought about rivalry in demonstrating such issue. Cheraghalipour et al. exhibited Pareto-based algorithms for a bi-objective optimization of citrus closed-loop SCN Cheraghalipour et al. (2018). Samadi et al. suggested heuristic-based metaheuristics to address a sustainable SCND problem (Samadi et al., 2018). Integrated design of sustainable supply chain and transportation network using a fuzzy bi-level decision support system for perishable products studied by Tirkolaee and Aydin (Tirkolaee and Aydin, 2022). Optimization of multi-period three-echelon citrus SC problem was introduced by Sahebjamnia et al. (Sahebjamnia et al., 2020). A distribution planning model for natural gas SC was studied by Hamedi et al. (Hamedi et al., 2009). Benders' decomposition for concurrent redesign of forward and closed loop SCN with demand and return uncertainties has been suggested by Khatami et al. (Khatami et al., 2015).

2.1. Research gap

Even though SCN issue has been concentrated broadly, truth be told, seldom consideration has been designated to use BLPP as the modeling approach. SCN issue can be addressed as a Leader-Follower where superior choice directors are the pioneers, and the constructing agents are the adherents who settle on choices about their exercises by thinking about high scale choices (El Sayed et al., 2020; Sakawa and Nishizaki, 2009).

The integrated problem of buying, production, and delivery planning in an SC is demanding as businesses push into higher collaboration and competitive situations. Prominent work related to the BLPP in the SCN is discussed in studies by Hajiaghaei-Keshteli and Fathollahi-Fard (Hajiaghaei-Keshteli and Fathollahi-Fard, 2018). They solved the distribution network problem using the two-stage stochastic BLPP under efficient heuristics and *meta*-heuristics approaches. Sun et al. (Sun et al., 2008) exhibit a BLPP to acquire the optimal area for logistics allocation focuses. The leader provides the optimal area, and the follower decides a balance request dispersion.

Roghanian et al. (Roghanian et al., 2007) treat a stochastic multi-objective BLPP and its implementation in big business vast SCN where a few parameters are random variables. A decentralized multi-objective maintainable SCM under an intuitionistic fuzzy climate was introduced by Kamal et al. (Kamal et al., 2020). Ryu et al. (Ryu et al., 2004) recommended a BLPP involving two models with questionable demand, one for creative designing and one for circulation designing. Kolak et al. (Kolak et al., 2018) outlined a BLPP for the traffic network optimization under maintainability. Karimi et al. (Karimi et al., 2018) introduced a BLPP for evaluating demand reaction continuously retail markets. Amirtaheri et al. (Amirtaheri et al., 2018) utilized a BLPP for a decentralized industrialist and wholesaler of SC by thinking about helpful advertising.

Gupta et al. (Gupta et al., 2018) developed a SCN as a BLPP wherein the optimal demand allotment of items is the DM's essential objective, accepting that the items' demands, and supply are vague. Hsueh (Hsueh, 2015) accessed BLPP in sustainable SCM for collaboration with corporate social responsibility. Rowshannahad et al. (Rowshannahad et al., 2018) formulated a multi-item commodity problem of SCN as a BLPP having multiple by products that can be remanufactured and reused. Chalmardi and Camacho-Vallejo (Chalmardi and Camacho-Vallejo, 2019) fostered a BLPP for a reasonable SCN plan that thinks about the public authority's monetary impetuses.

None of the past examinations present the hole between the industrial practices and the lack of corresponding research, so we propose an approach that directly captures their multi-level and uncertainty aspects based on BLPP principles. In the presented BL-MOSCM all the parameters have a fuzzy nature. Moreover, an interactive approach is presented to solve such uncertain BL-MOSCM which has not presented in literature before.

The rest of this work is coordinated as: Notions and definitions were presented in Sect. 3. Sect. 4 portrays problem definition and model formularization. A novel interactive approach for the α-(BL-MOSCM) was setup in Sect. 5. The next section presents detailed procedures to cope with the fuzzy BL-MOSCM. Numerical results were given in Sect. 7. At last, we conclude the research and give some future bearings.

3. Notions and definitions

This segment is committed to a prologue to trapezoidal fuzzy number and ϵ-constraints notations (Baky et al., 2014; Charles et al., 2019; Emam, 2013; Osman et al., 2018):

Definition 1. *Let E be a universal set, A mapping $\mu : E \rightarrow [0,1]$ is a membership function, if $\mu(x) \in [0,1]$. A fuzzy set $\widetilde{A}$ is the pair (E,μ).*

Definition 2. *Let $E \in R^n$. Then the fuzzy set $\widetilde{A} = (E,\mu)$ is convex, if $\forall x, y \in E$ and $\lambda \in [0,1]$ such that $\mu(\lambda x + (1-\lambda)y) \geq min\{\mu(x),\mu(y)\}$.*

Definition 3. *A fuzzy set $\widetilde{A} = (E,\mu)$ for $E \in R$ is called a fuzzy number if $\widetilde{A}$ is convex and normal, μ is piecewise continuous, A_α is a closed interval for all $\alpha \in (0,1]$, and support is bounded* (Gen et al., 1992).

Definition 4. *for $\widetilde{A} = (E,\mu)$ and $\alpha \in [0,1]$: The α-cut or α-level set is $A \geq \alpha$, $A_\alpha = \{x \in E | \mu(x) \geq \alpha\}$ and the strong α-cut $A > \alpha$, $A_\alpha^{'} = \{x \in E | \mu(x) > \alpha\}$.*

Definition 5. *A trapezoidal fuzzy number (TFN) $\widetilde{A} = (R,\mu)$ is a fuzzy number whose $\mu(x)$ is defined as* (Charles et al., 2019; Jiménez et al., 2007):

$$\mu(x) = \begin{cases} \dfrac{(x-a)}{(b-a)} if a \leq x \leq b \\ 1, if b \leq x \leq c \\ \dfrac{(d-x)}{(d-c)} if c \leq x \leq d \\ 0, otherwise \end{cases} \tag{1}$$

Where $a,b,c,d \in R$ with $a \leq b \leq c \leq d$. Note that $\mu(x)$ is a piecewise continuous and $\widetilde{A}$ is normal. Further, the quadruple (a,b,c,d) is suffient to describe $\widetilde{A}$. The α-cut of the TFN $\widetilde{A} = (a,b,c,d)$ is the closed interval.

$$\widetilde{A}_\alpha = \left[\widetilde{A}_\alpha^L, \widetilde{A}_\alpha^U\right] = [a + (b-a)\alpha, d - (d-c)\alpha] \tag{2}$$

The TFN $\widetilde{A} = (m,n,\gamma,\delta)$, with defuzzifiers m,n, left and right fuzziness $\gamma > 0; \delta > 0$, is given as (Gen et al., 1992; Gumus et al., 2009):

$$\mu(x) = \begin{cases} \dfrac{1}{\gamma}(x - m + \gamma) if m - \gamma \leq x \leq m \\ 1, if m \leq x \leq n \\ \dfrac{1}{\delta}(n - x + \delta) if n \leq x \leq n + \delta \\ 0, otherwise \end{cases} \tag{3}$$

The α-cut of the TFN $\widetilde{A} = (m,n,\gamma,\delta)$ is the closed interval.

$$\widetilde{A}_\alpha = \left[\widetilde{A}_\alpha^L, \widetilde{A}_\alpha^U\right] = [(m-\gamma) + \alpha\gamma, (n+\delta) - \alpha\delta] \tag{4}$$

ϵ-constraint method

This methodology converts the MOPP into a single objective decision-making (SO-DM) issue with extra constraints. The function with a high need is considered as an objective. Different objectives are composed as constraints by utilizing a constrain vector ϵ_i. The changed issue is composed as (Osman et al., 2018):

$$min f_l(x) \tag{5}$$

$$subject to$$

$$f_i(x) \leq \epsilon_i \forall i = 1,2,\cdots,k, i \neq l \tag{6}$$

$$x \in X, \quad x \geq 0 \tag{7}$$

where $l \in \{1,2,\cdots,k\}$. The selection of $f_l(x)$ and ϵ_i of this strategy rely upon the issue viable.

4. Mathematical model

In most practical situations, the parameters might take loose qualities because of some potential reasons as recorded underneath (El Sayed and Abo-Sinna, 2021; Gupta et al., 2018; Gupta et al., 2021; Tirkolaee and Aydin, 2022):

Table 1
Documentations and Nomenclature.

Documentations and Nomenclature	
The notations and Nomenclature utilized are:	
Indices	
i	Indicator of retailers, $i = 1, 2, \cdots, I$
j	Indicator of warehouses, $j = 1, 2, \cdots, J$
k	Indicator of factory, $k = 1, 2, \cdots, K$
l	Indicator of suppliers, $l = 1, 2, \cdots, L$
Fuzzy Parameters	
$\widetilde{D}_i = (D_i^1, D_i^2, \gamma_{D_i}, \beta_{D_i})$	Yearly request from the i^{th} retailers.
A_k	Possible gage of the k^{th} factory.
$\widetilde{B}_l = (B_l^1, B_l^2, \gamma_{B_l}, \beta_{B_l})$	Supply gage of the l^{th} suppliers.
E_j	Possible gage of the j^{th} warehouses.
$\widetilde{C}_{lk} = (C_{lk}^1, C_{lk}^2, \gamma_{C_{lk}}, \beta_{C_{lk}})$	Cost of shipping one item from supply source l to factory k.
$\widetilde{C}_{kj} = \left(C_{kj}^1, C_{kj}^2, \gamma_{C_{kj}}, \beta_{C_{kj}}\right)$	Cost of manufacturing and shipping one item from factory k to warehouse j.
$\widetilde{C}_{ki} = (C_{ki}^1, C_{ki}^2, \gamma_{C_{ki}}, \beta_{C_{ki}})$	Cost of manufacturing and shipping one item from factory k to retailer i.
$\widetilde{C}_{ji} = \left(C_{ji}^1, C_{ji}^2, \gamma_{C_{ji}}, \beta_{C_{ji}}\right)$	Cost of shipping one item from warehouse j to retailer i.
$\widetilde{D}_{kj} = \left(D_{kj}^1, D_{kj}^2, \gamma_{D_{kj}}, \beta_{D_{kj}}\right)$	Delivery time of shipping one item from factory k to warehouse j.
$\widetilde{D}_{ki} = (D_{ki}^1, D_{ki}^2, \gamma_{D_{ki}}, \beta_{D_{ki}})$	Delivery time of shipping one item from factory k to retailer i.
$\widetilde{D}_{ji} = \left(D_{ji}^1, D_{ji}^2, \gamma_{D_{ji}}, \beta_{D_{ji}}\right)$	Delivery time of shipping one item from warehouse j to retailer i.
Decision variables	
W_{lk}	Quantity shipped from supply source l to factory k.
X_{kj}	Quantity shipped from factory k to warehouse j.
Y_{ki}	Quantity shipped from factory k to retailer i.
Z_{lk}	Quantity shipped from warehouse j to retailer i.

1- The price of the thing may rely on the interest of the DM. Here and there, he may choose to spend for the amount requested.
2- The Cost of transportation of one item from the origin to the factory, from the factory to the retailer, from the factory to the distribution center, and from the stockroom to the retailer isn't investigated exactly to the DM.
3- Equivalently, the submission time of delivery one item from the factory to the retailer, from the factory to the stockroom and, from the distribution center to the retailer might change pending the conveyance time frame.

Considering the previous mentioned potential circumstances in SCM, so the main assumption in the proposed BL-MOSCM is that the coefficients of the objective functions and the constraints are fuzzy parameters. we have deemed the accompanying documentations which are recorded underneath in Table 1, (Gupta et al., 2018; Gupta et al., 2021; NabiL et al., 2021; Torabi and Hassini, 2008; Tirkolaee and Aydin, 2022):

Mathematically the BL-MOSCM with fuzzy demands, in Fig. 3., can be modeled as (El Sayed et al., 2020; Gupta et al., 2018; Gupta et al., 2021; Jolai et al., 2011; NabiL et al., 2021; Tirkolaee and Aydin, 2022):

$[1^{st}\textbf{level}]$

$$\underbrace{\min}_{W_{lk}}\left(f_{11} = \sum_{l=1}^{L}\sum_{k=1}^{K}\widetilde{C}_{lk}W_{lk} + \sum_{k=1}^{K}\sum_{i=1}^{I}\widetilde{C}_{ki}Y_{ki}, f_{12} = \sum_{l=1}^{L}\sum_{k=1}^{K}\widetilde{C}_{lk}W_{lk} + \sum_{k=1}^{K}\sum_{j=1}^{J}\widetilde{C}_{kj}X_{kj}, f_{13} = \sum_{l=1}^{L}\sum_{k=1}^{K}\widetilde{C}_{lk}W_{lk} + \sum_{k=1}^{K}\sum_{j=1}^{J}\widetilde{C}_{kj}X_{kj} + \sum_{j=1}^{J}\sum_{i=1}^{I}\widetilde{C}_{ji}Z_{ji}\right) \quad (8)$$

[2^{nd}**level**]

$$\underbrace{\min\min}_{X_{kj},Y_{ki},Z_{ji}}\left(f_{21}=\sum_{k=1}^{K}\sum_{l=1}^{I}\widetilde{D}_{ki}Y_{ki}+\sum_{k=1}^{K}\sum_{j=1}^{J}\widetilde{D}_{kj}X_{kj},\quad f_{22}=\sum_{k=1}^{K}\sum_{i=1}^{I}\widetilde{D}_{ki}Y_{ki}+\sum_{k=1}^{K}\sum_{j=1}^{J}\widetilde{D}_{kj}X_{kj}+\sum_{j=1}^{J}\sum_{i=1}^{I}\widetilde{D}_{ji}Z_{ji}\right) \tag{9}$$

subjectto

$$\sum_{k=1}^{K}W_{lk}\leq\widetilde{B}_{l}, \tag{10}$$

$$\sum_{i=1}^{I}Y_{ki}+\sum_{j=1}^{J}X_{kj}\leq A_{k}, \tag{11}$$

$$\sum_{i=1}^{I}Z_{ji}\leq E_{j}, \tag{12}$$

$$\sum_{j=1}^{J}Z_{ji}+\sum_{k=1}^{K}Y_{ki}\geq\widetilde{D}_{i}, \tag{13}$$

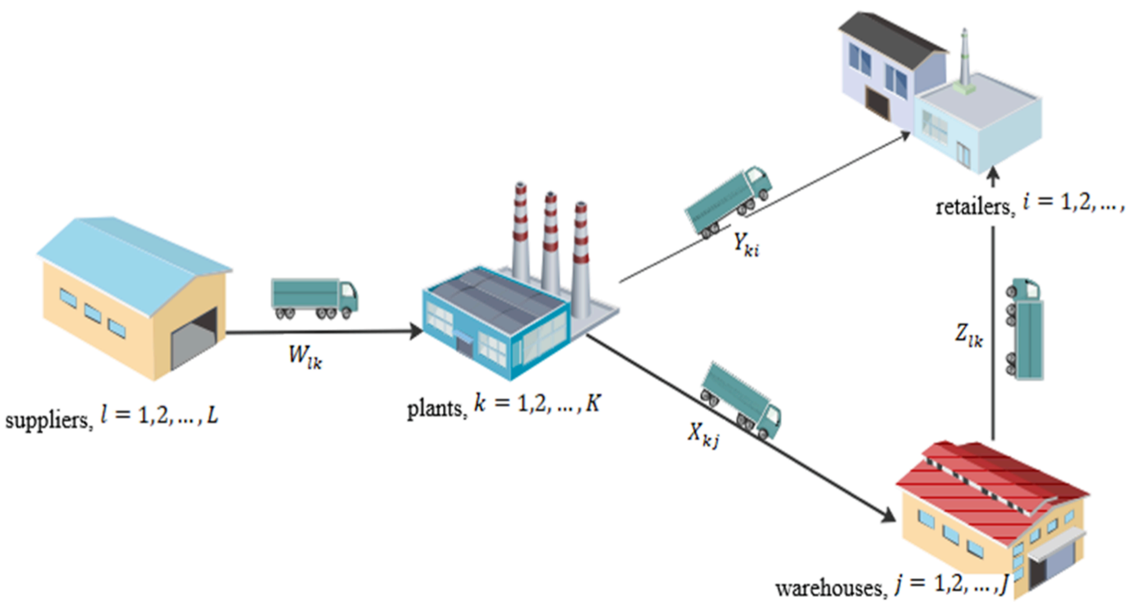

Fig. 3. Supply Chain Network.

$$\sum_{l=1}^{L}W_{lk}\geq\sum_{j=1}^{J}X_{kj}+\sum_{i=1}^{I}Y_{ki}, \tag{14}$$

$$\sum_{k=1}^{K}X_{kj}\geq\sum_{i=1}^{I}Z_{ji}, \tag{15}$$

$$W_{lk}\geq0,X_{kj}\geq0,Y_{ki}\geq0,Z_{ji}\geq0;\forall i,j,l,k \tag{16}$$

where whole the vague demands in model (8)-(16) are assumed to be TFNs of the formation (m,n,α,β) (Baky et al., 2014; Elsisy and El Sayed, 2019; El Sayed et al., 2020; El Sayed and Abo-Sinna, 2021). By applying the α-cut methodology the model (8)-(16) is changed over into the accompanying deterministic form at different values of α (Baky et al., 2014; Elsisy and El Sayed, 2019; El Sayed et al., 2020; El Sayed and Abo-Sinna, 2021):

[1^{st}**level**]

$$\underbrace{\min}_{W_{lk}}\left(\begin{array}{l}(f_{11})_\alpha = \sum_{l=1}^{L}\sum_{k=1}^{K}\left[C^1_{lk} - \gamma_{C_{lk}}(1-\alpha)\right]W_{lk} + \sum_{k=1}^{K}\sum_{i=1}^{I}\left[C^1_{ki} - \gamma_{C_{ki}}(1-\alpha)\right]Y_{ki},\\ (f_{12})_\alpha = \sum_{l=1}^{L}\sum_{k=1}^{K}\left[C^1_{lk} - \gamma_{C_{lk}}(1-\alpha)\right]W_{lk} + \sum_{k=1}^{K}\sum_{j=1}^{J}\left[C^1_{kj} - \gamma_{C_{kj}}(1-\alpha)\right]X_{kj},\\ (f_{13})_\alpha = \left[\begin{array}{l}\sum_{l=1}^{L}\sum_{k=1}^{K}\left[C^1_{lk} - \gamma_{C_{lk}}(1-\alpha)\right]W_{lk} + \sum_{k=1}^{K}\sum_{j=1}^{J}\left[C^1_{kj} - \gamma_{C_{kj}}(1-\alpha)\right]X_{kj}\\ \quad + \sum_{j=1}^{J}\sum_{i=1}^{I}\left[C^1_{ji} - \gamma_{C_{ji}}(1-\alpha)\right]Z_{ji}\end{array}\right]\end{array}\right) \tag{17}$$

[2^{nd}**level**]

$$\underbrace{\min}_{X_{kj},Y_{ki},Z_{ji}}\left(\begin{array}{l}(f_{21})_\alpha = \sum_{k=1}^{K}\sum_{l=1}^{I}\left[D^1_{ki} - \gamma_{D_{ki}}(1-\alpha)\right]Y_{ki} + \sum_{k=1}^{K}\sum_{j=1}^{J}\left[D^1_{kj} - \gamma_{D_{kj}}(1-\alpha)\right]X_{kj},\\ (f_{22})_\alpha = \left[\begin{array}{l}\sum_{k=1}^{K}\sum_{i=1}^{I}\left[D^1_{ki} - \gamma_{D_{ki}}(1-\alpha)\right]Y_{ki} + \sum_{k=1}^{K}\sum_{j=1}^{J}\left[D^1_{kj} - \gamma_{D_{kj}}(1-\alpha)\right]X_{kj}\\ + \sum_{j=1}^{J}\sum_{i=1}^{I}\left[D^1_{ji} - \gamma_{D_{ji}}(1-\alpha)\right]Z_{ji}\end{array}\right]\end{array}\right) \tag{18}$$

subjectto

$$\sum_{k=1}^{K} W_{lk} \le \left[B^2_l + (1-\alpha)\beta_{B_l}\right], \tag{19}$$

$$\sum_{i=1}^{I} Y_{ki} + \sum_{j=1}^{J} X_{kj} \le A_k, \tag{20}$$

$$\sum_{i=1}^{I} Z_{ji} \le E_j, \tag{21}$$

$$\sum_{j=1}^{J} Z_{ji} + \sum_{k=1}^{K} Y_{ki} \ge \left[D^1_i - \gamma_{D_i}(1-\alpha)\right], \tag{22}$$

$$\sum_{l=1}^{L} W_{lk} \ge \sum_{j=1}^{J} X_{kj} + \sum_{i=1}^{I} Y_{ki}, \tag{23}$$

$$\sum_{k=1}^{K} X_{kj} \ge \sum_{i=1}^{I} Z_{ji}, \tag{24}$$

$$W_{lk} \ge 0, X_{kj} \ge 0, Y_{ki} \ge 0, Z_{ji} \ge 0; \forall i, j, l, k \tag{25}$$

Consider $\boldsymbol{G}$ to indicate the set of constraints of the above α-(BL-MOSCM).

5. Interactive approach development for BL-MOSCM with fuzzy demands

To get the α-Pareto optimal solution of the BL-MOSCM with fuzzy demands initially, the α-(BL-MOSCM) is created at an ideal worth of $\alpha \in [0, 1]$ model (17)-(25). In the interactive methodology, after getting the surpassed solutions by the ϵ-constraint strategy and the idea of satisfactoriness, the leader granted the favored solutions that are pleasant in status order alluding to the sufficiency of the favored answers for the follower. Then, the SLDM applies the ϵ-constraint method to obtain the solution which is nearest to the favored solution of the FLDM (Cancinoa et al., 2019; Emam, 2013; Osman et al., 2018). At last, the FLDM decides the favored solution of the α-(BL-MOSCM) as shown by their satisfactoriness. Then, the congruent favored solution to the α-(BL-MOSCM) is acquired (Cancinoa et al., 2019; Emam, 2013; Osman et al., 2018).

5.1. The FLDM problem

The FLDM problem of the α-(BL-MOSCM) follows as (Emam, 2013; Osman et al., 2018):

subjectto

$$\underbrace{\min}_{W_{lk}}\left(\begin{array}{l} f_{11}=\sum_{l=1}^{L}\sum_{k=1}^{K}\left[C_{lk}^{1}-\gamma_{C_{lk}}(1-\alpha)\right]W_{lk}+\sum_{k=1}^{K}\sum_{i=1}^{I}\left[C_{ki}^{1}-\gamma_{C_{ki}}(1-\alpha)\right]Y_{ki},\\ f_{12}=\sum_{l=1}^{L}\sum_{k=1}^{K}\left[C_{lk}^{1}-\gamma_{C_{lk}}(1-\alpha)\right]W_{lk}+\sum_{k=1}^{K}\sum_{j=1}^{J}\left[C_{kj}^{1}-\gamma_{C_{kj}}(1-\alpha)\right]X_{kj},\\ f_{13}=\left[\begin{array}{l}\sum_{l=1}^{L}\sum_{k=1}^{K}\left[C_{lk}^{1}-\gamma_{C_{lk}}(1-\alpha)\right]W_{lk}+\sum_{k=1}^{K}\sum_{j=1}^{J}\left[C_{kj}^{1}-\gamma_{C_{kj}}(1-\alpha)\right]X_{kj}\\ +\sum_{j=1}^{J}\sum_{i=1}^{I}\left[C_{ji}^{1}-\gamma_{C_{ji}}(1-\alpha)\right]Z_{ji}\end{array}\right]\end{array}\right) \tag{26}$$

$$\left(W_{lk},X_{kj},Y_{ki},Z_{ji}\right)\in \boldsymbol{G}. \tag{27}$$

To get the α-Pareto optimal solution of the FLDM; we convert model (26)-(27), by the ϵ-constraint method into the following SO-DM problem (Emam, 2013; Osman et al., 2018):

$$\underbrace{\min}_{W_{lk}} f_{13}=\left[\begin{array}{l}\sum_{l=1}^{L}\sum_{k=1}^{K}\left[C_{lk}^{1}-\gamma_{C_{lk}}(1-\alpha)\right]W_{lk}+\sum_{k=1}^{K}\sum_{j=1}^{J}\left[C_{kj}^{1}-\gamma_{C_{kj}}(1-\alpha)\right]X_{kj}\\ +\sum_{j=1}^{J}\sum_{i=1}^{I}\left[C_{ji}^{1}-\gamma_{C_{ji}}(1-\alpha)\right]Z_{ji}\end{array}\right] \tag{28}$$

subjectto

$$\sum_{l=1}^{L}\sum_{k=1}^{K}\left[C_{lk}^{1}-\gamma_{C_{lk}}(1-\alpha)\right]W_{lk}+\sum_{k=1}^{K}\sum_{i=1}^{I}\left[C_{ki}^{1}-\gamma_{C_{ki}}(1-\alpha)\right]Y_{ki}\leq\delta_{11}, \tag{29}$$

$$\sum_{l=1}^{L}\sum_{k=1}^{K}\left[C_{lk}^{1}-\gamma_{C_{lk}}(1-\alpha)\right]W_{lk}+\sum_{k=1}^{K}\sum_{j=1}^{J}\left[C_{kj}^{1}-\gamma_{C_{kj}}(1-\alpha)\right]X_{kj}\leq\delta_{12}, \tag{30}$$

$$\left(W_{lk},X_{kj},Y_{ki},Z_{ji}\right)\in \boldsymbol{G}. \tag{31}$$

So, the solution of the FLDM issue is gotten by doing algorithm **I**, as

$$\left(W_{lk}^{*},X_{kj}^{*},Y_{ki}^{*},Z_{ji}^{*}\right)=\left(W_{lk}^{F},X_{kj}^{F},Y_{ki}^{F},Z_{ji}^{F}\right).$$

5.2. The SLDM problem

Based on the idea of BLPP, the first level choice W_{lk}^{F} ought to be remembered for the SLDM model; subsequently, the issue of SLDM can be planned as (Emam, 2013; Osman et al., 2018):

$$\underbrace{\min}_{X_{kj},Y_{ki},Z_{ji}}\left(\begin{array}{l}(f_{21})_{\alpha}=\sum_{k=1}^{K}\sum_{l=1}^{I}\left[D_{ki}^{1}-\gamma_{D_{ki}}(1-\alpha)\right]Y_{ki}+\sum_{k=1}^{K}\sum_{j=1}^{J}\left[D_{kj}^{1}-\gamma_{D_{kj}}(1-\alpha)\right]X_{kj},\\ (f_{22})_{\alpha}=\left[\begin{array}{l}\sum_{k=1}^{K}\sum_{i=1}^{I}\left[D_{ki}^{1}-\gamma_{D_{ki}}(1-\alpha)\right]Y_{ki}+\sum_{k=1}^{K}\sum_{j=1}^{J}\left[D_{kj}^{1}-\gamma_{D_{kj}}(1-\alpha)\right]X_{kj}\\ +\sum_{j=1}^{J}\sum_{i=1}^{I}\left[D_{ji}^{1}-\gamma_{D_{ji}}(1-\alpha)\right]Z_{ji}\end{array}\right]\end{array}\right) \tag{32}$$

subjectto

$$\left(W_{lk}^{F},X_{kj},Y_{ki},Z_{ji}\right)\in \boldsymbol{G} \tag{33}$$

The ϵ-constraint procedure is employed to develop the SO-DM issue of the SLDM as:

subjectto

$$minf_{22}=\left[\begin{array}{c}\sum_{k=1}^{K}\sum_{i=1}^{I}\left[D_{ki}^{1}-\gamma_{D_{ki}}(1-\alpha)\right]Y_{ki}+\sum_{k=1}^{K}\sum_{j=1}^{J}\left[D_{kj}^{1}-\gamma_{D_{kj}}(1-\alpha)\right]X_{kj}\\+\sum_{j=1}^{J}\sum_{i=1}^{I}\left[D_{ji}^{1}-\gamma_{D_{ji}}(1-\alpha)\right]Z_{ji}\end{array}\right] \tag{34}$$

$$\sum_{k=1}^{K}\sum_{I=1}^{I}\left[D_{ki}^{1}-\gamma_{D_{ki}}(1-\alpha)\right]Y_{ki}+\sum_{k=1}^{K}\sum_{j=1}^{J}\left[D_{kj}^{1}-\gamma_{D_{kj}}(1-\alpha)\right]X_{kj}\geq\delta_{21}, \tag{35}$$

$$\left(W_{lk}^{F},X_{kj},Y_{ki},Z_{ji}\right)\in\boldsymbol{G} \tag{36}$$

Our essential idea on treating model (34)-(36) is to acquire the latter level non-inferior solution $\left(W_{lk}^{F},X_{kj}^{S},Y_{ki}^{S},Z_{ji}^{S}\right)$ that is nearest to the FLDM solution $\left(W_{lk}^{F},X_{kj}^{F},Y_{ki}^{F},Z_{ji}^{F}\right)$ utilizing algorithm **I**. Therefore, we will check whether $\left(W_{lk}^{F},X_{kj}^{S},Y_{ki}^{S},Z_{ji}^{S}\right)$ is a preferred values to the FLDM or it could be modified based on the test (Emam, 2013; Osman et al., 2018): If.

$$\frac{\|F_1\left(W_{lk}^{F},X_{kj}^{F},Y_{ki}^{F},Z_{ji}^{F}\right)-F_1\left(W_{lk}^{F},X_{kj}^{S},Y_{ki}^{S},Z_{ji}^{S}\right)\|_2}{\|F_1\left(W_{lk}^{F},X_{kj}^{S},Y_{ki}^{S},Z_{ji}^{S}\right)\|_2}<\sigma^{F} \tag{37}$$

Then, $\left(W_{lk}^{F},X_{kj}^{S},Y_{ki}^{S},Z_{ji}^{S}\right)$ is a favored answer for the α-(BL-MOSCM), where σ^F is a small plus fixed assumed by the FLDM. where δ_{rs}, b_{rs}anda_{rs} are defined as (Emam, 2013; NabiL et al., 2021; Osman et al., 2018):

$$\delta_{rt}=(b_{rt}-a_{rt})s_r+a_{rt}, \qquad (r=1,2), \quad (t=1,2,\cdots,v_r), \tag{38}$$

$$b_{rt}=\underbrace{\max}_{\left(W_{lk},X_{kj},Y_{ki},Z_{ji}\right)\in G} f_{rt}\left(W_{lk},X_{kj},Y_{ki},Z_{ji}\right),(r=1,2),(t=1,2,\ldots,v_r), \tag{39}$$

$$a_{rt}=\underbrace{\min}_{\left(W_{lk},X_{kj},Y_{ki},Z_{ji}\right)\in G} f_{rt}\left(W_{lk},X_{kj},Y_{ki},Z_{ji}\right),(r=1,2),(t=1,2,\ldots,v_r), \tag{40}$$

where s_r is the satisfactoriness given by the r^{th} level DM for the t^{th} objective function. The preferred solution of the r^{th} LDM issue is gotten by utilizing algorithm I:

Algorithm I.

Step 1.	*Set the satisfactoriness* $s_{rq},(r=1,2),q=1,2,\cdots$. *Let* $s_r=s_{r0}$ *at the beginning and let* $s_r=s_{r1},s_{r2},s_{r3},\cdots,(r=1,2)$ *respectively.*
Step 2.	*Set up the* ϵ*-constraint issue* $P\left(\epsilon_r(s_{rq})\right)$*, if* $P\left(\epsilon_r(s_{rq})\right)$ *has no solution or an optimal solution, then go to Step 1, to adjust* $s=s_{r(q+1)}<s_{rq}$*. Otherwise, go to Step 3.*
Step 3.	*If the DM contented with* $\left(W_{lk}^{*},X_{kj}^{*},Y_{ki}^{*},Z_{ji}^{*}\right)$*, then it is the preferred solution of the* r^{th} *LDM, go to Step 5. Otherwise, go to Step 4.*
Step 4.	*Adjust satisfactoriness, let* $s_{r(q+1)}>s_{iv}$ *and go to Step 2.*
Step 5.	*Stop.*

6. Interactive Algorithm for BL-MOSCM under Fuzziness

Dependent on the study in the past segments, the proposed interactive algorithm will be developed for addressing the BL-MOSCM with fuzzy demands as:

Step 1.	Set the worth of α, worthy for all DMs.
Step 2.	Formulate the α-(BL-MOSCM), equ. (17)-(25).
Step 3.	calculate the individual most extreme and least qualities of each objective functions.
Step 4.	Set $r=0$.
Step 5.	Execute Algorithm I to get a group of preferred solutions for the FLDM model (28)-(31). The FLDM puts these solutions in order as: Preferred solution $\left(W_{lk}^{r},X_{kj}^{r},Y_{ki}^{r},Z_{ji}^{r}\right),\cdots,\left(W_{lk}^{r+n},X_{kj}^{r+n},Y_{ki}^{r+n},Z_{ji}^{r+n}\right)$. Preferred ranking $\left(W_{lk}^{r},X_{kj}^{r},Y_{ki}^{r},Z_{ji}^{r}\right)\succ\left(W_{lk}^{r+1},X_{kj}^{r+1},Y_{ki}^{r+1},Z_{ji}^{r+1}\right)\succ\cdots\succ\left(W_{lk}^{r+n},X_{kj}^{r+n},Y_{ki}^{r+n},Z_{ji}^{r+n}\right)$.
Step 6.	Given $W_{lk}^{F}=W_{lk}$, to the SLDM problem. Solve the SLDM model (34)-(36), using Algorithm I and get $\left(X_{kj}^{S},Y_{ki}^{S},Z_{ji}^{S}\right)=\left(X_{kj}^{*},Y_{ki}^{*},Z_{ji}^{*}\right)$.
Step 7.	If $\frac{\|F_1\left(W_{lk}^{F},X_{kj}^{F},Y_{ki}^{F},Z_{ji}^{F}\right)-F_1\left(W_{lk}^{F},X_{kj}^{S},Y_{ki}^{S},Z_{ji}^{S}\right)\|_2}{\|F_1\left(W_{lk}^{F},X_{kj}^{S},Y_{ki}^{S},Z_{ji}^{S}\right)\|_2}<\sigma^{F}$, then go to Step 8. Otherwise go to Step 9.
Step 8.	If the FLDM is contented with $\left(W_{lk}^{F},X_{kj}^{S},Y_{ki}^{S},Z_{ji}^{S}\right)$ and $F_1\left(W_{lk}^{F},X_{kj}^{S},Y_{ki}^{S},Z_{ji}^{S}\right)$, then $\left(W_{lk}^{F},X_{kj}^{S},Y_{ki}^{S},Z_{ji}^{S}\right)$ is the preferred solution of the α-(BL-MOSCM), go to Step 10. Otherwise go to Step 9.
Step 9.	Let $r=r+1$, and go to Step 4.
Step 10.	Stop.

7. Numerical example

The following case study presented by Gupta et al. (Gupta et al., 2018) is considered to illustrate the suggested interactive process. The SCM comprising of assembling firm having various factories, warehouses, retailers and clients in various geological districts or areas. It is expected that the five suppliers supply is crude material to four assembling factories. The allocation framework comprises of six warehouses where the item is briefly positioned and put to away prior market out eight retailers from which items are sold out too many clients. The fuzzy information has been summed up in Tables from Tables 2-9:

Based on the above datasets of transportation cost and delivery time of the SCM, utilizing the α-cut methodology, then the α-(BL-MOSCM) can be formulated as:

[1^{st}**level**]

$$\underbrace{\min}_{W_{lk}}\left(\begin{array}{l}(f_{11})_\alpha=\left(\begin{array}{l}(175+20\alpha)W_{11}+(280+15\alpha)W_{21}+\ldots+(257+13\alpha)W_{44}+(325+15\alpha)W_{54}\\+(280+15\alpha)Y_{11}+(417+13\alpha)Y_{12}+\ldots+(405+15\alpha)Y_{47}+(417+13\alpha)Y_{48}\end{array}\right)\\(f_{12})_\alpha=\left(\begin{array}{l}(175+20\alpha)W_{11}+(280+15\alpha)W_{21}+\ldots+(257+13\alpha)W_{44}+(325+15\alpha)W_{54}\\+(280+15\alpha)X_{11}+(133+12\alpha)X_{12}+\ldots+(280+15\alpha)X_{45}+(287+13\alpha)X_{46}\end{array}\right)\\(f_{13})_\alpha=\left(\begin{array}{l}(175+20\alpha)W_{11}+(280+15\alpha)W_{21}+\ldots+(257+13\alpha)W_{44}+(325+15\alpha)W_{54}\\+(280+15\alpha)X_{11}+(133+12\alpha)X_{12}+\ldots+(280+15\alpha)X_{45}+(287+13\alpha)X_{46}\\+(133+12\alpha)Z_{11}+(165+15\alpha)Z_{12}+\ldots+(175+15\alpha)Z_{67}+(150+15\alpha)Z_{68}\end{array}\right)\end{array}\right)$$

[2^{nd}**level**]

$$\underbrace{\min}_{X_{kj},Y_{ki},Z_{ji}}\left(\begin{array}{l}(f_{21})_\alpha=\left(\begin{array}{l}(43+2\alpha)Y_{11}+(63+2\alpha)Y_{12}+\ldots+(74+\alpha)Y_{47}+(63+2\alpha)Y_{48}\\(22+3\alpha)X_{11}+(13+2\alpha)X_{12}+\ldots+(63+2\alpha)X_{45}+(65+5\alpha)X_{46}\end{array}\right)\\(f_{22})_\alpha=\left(\begin{array}{l}(43+2\alpha)Y_{11}+(63+2\alpha)Y_{12}+\ldots+(74+\alpha)Y_{47}+(63+2\alpha)Y_{48}\\(22+3\alpha)X_{11}+(13+2\alpha)X_{12}+\ldots+(63+2\alpha)X_{45}+(65+5\alpha)X_{46}\\(12+3\alpha)Z_{11}+(13+2\alpha)Z_{12}+\ldots+(38+2\alpha)Z_{67}+(66+2\alpha)Z_{68}\end{array}\right)\end{array}\right)$$

subjectto

$$W_{11}+W_{12}+W_{13}+W_{14}\le(196-6\alpha),$$

$$W_{21}+W_{22}+W_{23}+W_{24}\le(502-12\alpha)$$

$$W_{31}+W_{32}+W_{33}+W_{34}\le(220-10\alpha)$$

$$W_{41}+W_{42}+W_{43}+W_{44}\le(214-9\alpha)$$

$$W_{51}+W_{52}+W_{53}+W_{54}\le(314-14\alpha)$$

$$Y_{11}+Y_{12}+Y_{13}+Y_{14}+Y_{15}+Y_{16}+Y_{17}+Y_{18}+X_{11}+X_{12}+X_{13}+X_{14}+X_{15}+X_{16}\le 471,$$

$$Y_{21}+Y_{22}+Y_{23}+Y_{24}+Y_{25}+Y_{26}+Y_{27}+Y_{28}+X_{21}+X_{22}+X_{23}+X_{24}+X_{25}+X_{26}\le 296,$$

$$Y_{31}+Y_{32}+Y_{33}+Y_{34}+Y_{35}+Y_{36}+Y_{37}+Y_{38}+X_{31}+X_{32}+X_{33}+X_{34}+X_{35}+X_{36}\le 327,$$

$$Y_{41}+Y_{42}+Y_{43}+Y_{44}+Y_{45}+Y_{46}+Y_{47}+Y_{48}+X_{41}+X_{42}+X_{43}+X_{44}+X_{45}+X_{46}\le 318,$$

$$Z_{11}+Z_{12}+Z_{13}+Z_{14}+Z_{15}+Z_{16}+Z_{17}+Z_{18}\le 154,$$

$$Z_{21}+Z_{22}+Z_{23}+Z_{24}+Z_{25}+Z_{26}+Z_{27}+Z_{28}\le 177,$$

$$Z_{31}+Z_{32}+Z_{33}+Z_{34}+Z_{35}+Z_{36}+Z_{37}+Z_{38}\le 160,$$

$$Z_{41}+Z_{42}+Z_{43}+Z_{44}+Z_{45}+Z_{46}+Z_{47}+Z_{48}\le 202,$$

$$Z_{51}+Z_{52}+Z_{53}+Z_{54}+Z_{55}+Z_{56}+Z_{57}+Z_{58}\le 178,$$

$$Z_{61}+Z_{62}+Z_{63}+Z_{64}+Z_{65}+Z_{66}+Z_{67}+Z_{68}\le 218,$$

$$Z_{11}+Z_{21}+Z_{31}+Z_{41}+Z_{51}+Z_{61}+Y_{11}+Y_{21}+Y_{31}+Y_{41}\ge(85+5\alpha)$$

$$Z_{12}+Z_{22}+Z_{32}+Z_{42}+Z_{52}+Z_{62}+Y_{12}+Y_{22}+Y_{32}+Y_{42}\ge(46+4\alpha)$$

$$Z_{13}+Z_{23}+Z_{33}+Z_{43}+Z_{53}+Z_{63}+Y_{13}+Y_{23}+Y_{33}+Y_{43}\ge(82+3\alpha)$$

$$Z_{14}+Z_{24}+Z_{34}+Z_{44}+Z_{54}+Z_{64}+Y_{14}+Y_{24}+Y_{34}+Y_{44}\ge(59+6\alpha)$$

$$Z_{15}+Z_{25}+Z_{35}+Z_{45}+Z_{55}+Z_{65}+Y_{15}+Y_{25}+Y_{35}+Y_{45}\ge(58+2\alpha)$$

$$Z_{16}+Z_{26}+Z_{36}+Z_{46}+Z_{56}+Z_{66}+Y_{16}+Y_{26}+Y_{36}+Y_{46}\ge(101+4\alpha)$$

$$Z_{17}+Z_{27}+Z_{37}+Z_{47}+Z_{57}+Z_{67}+Y_{17}+Y_{27}+Y_{37}+Y_{47}\ge(105+5\alpha)$$

Table 2
Fuzzy transportation cost from supplier to plant.

Suppliers	Plant			
	G_1	G_2	G_3	G_4
A	(195, 200, 20, 15)	(90, 100, 12, 15)	(145, 155, 12, 13)	(120, 130, 13, 16)
B	(295, 305, 15, 17)	(145, 155, 12, 13)	(195, 200, 20, 15)	(195, 200, 20, 15)
C	(490, 500, 18, 12)	(120, 130, 13, 16)	(203, 230, 14, 15)	(203, 230, 14, 15)
D	(390, 405, 16, 17)	(295, 305, 15, 17)	(240, 260, 12, 13)	(270, 280, 13, 15)
E	(590, 600, 15, 14)	(690, 705, 18, 16)	(295, 305, 15, 17)	(340, 350, 15, 17)

Table 3
Fuzzy transportation and production cost of plant to retailer.

Plant	Retailers							
	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8
G_1	(295, 305, 15, 17)	(430, 450, 13, 17)	(340, 350, 15, 17)	(430, 450, 13, 17)	(240, 260, 12, 13)	(340, 350, 15, 17)	(390, 405, 16, 17)	(470, 480, 14, 16)
G_2	(340, 350, 15, 17)	(490, 500, 18, 12)	(295, 305, 15, 17)	(370, 380, 12, 15)	(270, 280, 13, 15)	(370, 380, 12, 15)	(470, 480, 14, 16)	(430, 450, 13, 17)
G_3	(430, 450, 13, 17)	(470, 480, 14, 16)	(340, 350, 15, 17)	(340, 350, 15, 17)	(295, 305, 15, 17)	(370, 385, 15, 17)	(430, 450, 13, 17)	(470, 480, 14, 16)
G_4	(490, 500, 18, 12)	(430, 450, 13, 17)	(320, 330, 17, 18)	(390, 405, 16, 17)	(320, 330, 17, 18)	(385, 395, 14, 16)	(420, 430, 15, 16)	(430, 450, 13, 17)

Table 4
Fuzzy transportation and production cost of plant to warehouse.

Plant	Warehouses					
	N_1	N_2	N_3	N_4	N_5	N_6
G_1	(295, 305, 15, 17)	(145, 155, 12, 13)	(195, 200, 20, 15)	(195, 200, 20, 15)	(120, 130, 13, 16)	(295, 305, 15, 17)
G_2	(390, 405, 16, 17)	(120, 130, 13, 16)	(220, 230, 14, 15)	(240, 260, 12, 13)	(270, 280, 13, 15)	(310, 320, 19, 16)
G_3	(540, 550, 10, 11)	(145, 155, 12, 13)	(195, 200, 20, 15)	(295, 305, 15, 17)	(240, 260, 12, 13)	(295, 305, 15, 17)
G_4	(640, 650, 9, 13)	(340, 350, 15, 17)	(295, 305, 15, 17)	(170, 180, 14, 16)	(295, 305, 15, 17)	(300, 310, 13, 16)

$$Z_{18}+Z_{28}+Z_{38}+Z_{48}+Z_{58}+Z_{68}+Y_{18}+Y_{28}+Y_{38}+Y_{48}\geq(78+2\alpha)$$

$$W_{11}+W_{21}+W_{31}+W_{41}+W_{51}\geq X_{11}+X_{12}+X_{13}+X_{14}+X_{15}+X_{16}+Y_{11}+Y_{12}+Y_{13}$$

$$+Y_{14}+Y_{15}+Y_{16}+Y_{17}+Y_{18},$$

$$W_{12}+W_{22}+W_{32}+W_{42}+W_{52}\geq X_{21}+X_{22}+X_{23}+X_{24}+X_{25}+X_{26}+Y_{21}+Y_{22}+Y_{23}$$

$$+Y_{24}+Y_{25}+Y_{26}+Y_{27}+Y_{28},$$

$$W_{13}+W_{23}+W_{33}+W_{43}+W_{53}\geq X_{31}+X_{32}+X_{33}+X_{34}+X_{35}+X_{36}+Y_{31}+Y_{32}+Y_{33}$$

$$+Y_{34}+Y_{35}+Y_{36}+Y_{37}+Y_{38},$$

$$W_{14}+W_{24}+W_{34}+W_{44}+W_{54}\geq X_{41}+X_{42}+X_{43}+X_{44}+X_{45}+X_{46}+Y_{41}+Y_{42}+Y_{43}$$

$$+Y_{44}+Y_{45}+Y_{46}+Y_{47}+Y_{48},$$

$$X_{11}+X_{21}+X_{31}+X_{41}\geq Z_{11}+Z_{12}+Z_{13}+Z_{14}+Z_{15}+Z_{16}+Z_{17}+Z_{18},$$

$$X_{12}+X_{22}+X_{32}+X_{42}\geq Z_{21}+Z_{22}+Z_{23}+Z_{24}+Z_{25}+Z_{26}+Z_{27}+Z_{28},$$

$$X_{13}+X_{23}+X_{33}+X_{43}\geq Z_{31}+Z_{32}+Z_{33}+Z_{34}+Z_{35}+Z_{36}+Z_{37}+Z_{38},$$

$$X_{14}+X_{24}+X_{34}+X_{44}\geq Z_{41}+Z_{42}+Z_{43}+Z_{44}+Z_{45}+Z_{46}+Z_{47}+Z_{48},$$

$$X_{15}+X_{25}+X_{35}+X_{45}\geq Z_{51}+Z_{52}+Z_{53}+Z_{54}+Z_{55}+Z_{56}+Z_{57}+Z_{58},$$

$$X_{16}+X_{26}+X_{36}+X_{46}\geq Z_{61}+Z_{62}+Z_{63}+Z_{64}+Z_{65}+Z_{66}+Z_{67}+Z_{68},$$

$$W_{lk}\geq0,X_{kj}\geq0,Y_{ki}\geq0,Z_{ji}\geq0;\forall i,j,l,k$$

Firstly, we obtain the individual maximum and minimum values for the objective functions at the different values of α as indicated in Table 10 and Table 11, respectively:

The first case at $\alpha=0$, Let $(\boldsymbol{G})_{\boldsymbol{\alpha}}$ denote the set of constrains of the above model. Then we formulate and solve the FLDM problem using the ∊-constraint method as:

$$\underbrace{\min}_{W_{lk}}\ f_{13}=\begin{pmatrix}175W_{11}+280W_{21}+472W_{31}+\ldots+189W_{34}+257W_{44}+325W_{54}\\+280X_{11}+133X_{12}+175X_{13}+\ldots+156X_{44}+280X_{45}+287X_{46}\\+133Z_{11}+165Z_{12}+142Z_{13}+\ldots+162Z_{66}+175Z_{67}+150Z_{68}\end{pmatrix}$$

subjectto

$$\begin{pmatrix}175W_{11}+280W_{21}+472W_{31}+\cdots+189W_{34}+257W_{44}+325W_{54}\\+280Y_{11}+417Y_{12}+325Y_{13}+\cdots+371Y_{46}+405Y_{47}+417Y_{48}\end{pmatrix}$$
$$\leq 1133337,$$

$$\begin{pmatrix}175W_{11}+280W_{21}+472W_{31}+\cdots+189W_{34}+257W_{44}+325W_{54}\\+280X_{11}+133X_{12}+175X_{13}+\cdots+156X_{44}+280X_{45}+287X_{46}\end{pmatrix}$$
$$\leq 1105509,$$

$$\left(W_{lk},X_{kj},Y_{ki},Z_{ji}\right)\in(\boldsymbol{G})_{\boldsymbol{\alpha}=0}.$$

Table 5
Fuzzy transportation cost from warehouse to retailer.

Warehouses	Retailers							
	M₁	**M₂**	**M₃**	**M₄**	**M₅**	**M₆**	**M₇**	**M₈**
N_1	(145, 155, 12, 13)	(180, 190, 15, 17)	(160, 164, 18, 19)	(170, 180, 14, 16)	(165, 175, 13, 15)	(198, 200, 16, 17)	(183, 185, 12, 15)	(165, 175, 15, 16)
N_2	(110, 120, 10, 13)	(190, 210, 17, 16)	(165, 167, 13, 12)	(165, 175, 13, 15)	(180, 190, 18, 16)	(180, 190, 18, 16)	(184, 186, 13, 14)	(171, 173, 17, 19)
N_3	(120, 130, 13, 16)	(90, 100, 12, 15)	(130, 132, 13, 14)	(178, 179, 10, 12)	(180, 190, 15, 17)	(180, 190, 15, 17)	(183, 185, 13, 15)	(170, 172, 15, 11)
N_4	(128, 130, 14, 13)	(160, 170, 16, 18)	(135, 137, 12, 15)	(180, 190, 18, 16)	(190, 210, 17, 16)	(170, 180, 14, 16)	(180, 190, 15, 17)	(170, 173, 14, 15)
N_5	(135, 140, 10, 12)	(165, 175, 13, 15)	(145, 147, 14, 13)	(180, 190, 15, 17)	(190, 2000, 15, 13)	(160, 170, 16, 18)	(190, 210, 17, 16)	(170, 180, 14, 16)
N_6	(170, 180, 14, 16)	(150, 160, 13, 16)	(145, 155, 12, 13)	(90, 100, 12, 15)	(195, 200, 16, 17)	(180, 190, 18, 16)	(190, 200, 15, 13)	(165, 175, 15, 16)

The above model is solved by using LINGO 18 software, where.$\delta_{11} = (b_{11} - a_{11})s_1 + a_{11} = 1133337 and \delta_{12} = (b_{12} - a_{12})s_1 + a_{12} = 1105509$, so, the solution of the FLDM is.

$$\begin{pmatrix} W^F_{22}; W^F_{32}; W^F_{23}; W^F_{14}; W^F_{24}; \\ X^F_{kj} \\ Y^F_{22}; Y^F_{23}; Y^F_{25}; Y^F_{27}; Y^F_{28}; Y^F_{36}; Y^F_{41}; Y^F_{44}; Y^F_{48}; \\ Z^F_{ji} \end{pmatrix} = \begin{pmatrix} 76; 220; 101; 196; 21 \\ 0 \\ 46; 82; 58; 105; 5; 101; 85; 59; 73 \\ 0 \end{pmatrix}$$

and $s_1 = 1$, $\sigma^F = 0.9$ are given by the FLDM. Secondly, the SLDM formulated as:

$$\min f_{22} = \begin{pmatrix} 43Y_{11} + 63Y_{12} + 47Y_{13} + \cdots + 63Y_{46} + 74Y_{47} + 63Y_{48} \\ 22X_{11} + 13X_{12} + 13X_{13} + \cdots + 35X_{44} + 63X_{45} + 65X_{46} \\ 12Z_{11} + 13Z_{12} + 17Z_{13} + \cdots + 25Z_{66} + 38Z_{67} + 66Z_{68} \end{pmatrix}$$

subjectto

$$\begin{pmatrix} 43Y_{11} + 63Y_{12} + 47Y_{13} + \cdots + 63Y_{46} + 74Y_{47} + 63Y_{48} \\ 22X_{11} + 13X_{12} + 13X_{13} + \cdots + 35X_{44} + 63X_{45} + 65X_{46} \end{pmatrix} \le 106332,$$

$$W^F_{22} = 76; W^F_{32} = 220; W^F_{23} = 101; W^F_{14} = 196; W^F_{24} = 21,$$

$$(X_{kj}, Y_{ki}, Z_{ji}) \in (\boldsymbol{G})_{\alpha=0}.$$

where $\delta_{21} = (b_{21} - a_{21})s_2 + a_{21} = 106332$, so the SLDM solution is

$$\begin{pmatrix} W^F_{22}; W^F_{32}; W^F_{23}; W^F_{14}; W^F_{24}; \\ X^S_{22}; X^S_{36}; X^S_{43}; X^S_{44}; \\ Y^S_{21}; Y^S_{25}; \\ Z^S_{23}; Z^S_{26}; Z^S_{32}; Z^S_{46}; Z^S_{47}; Z^S_{48}; Z^S_{61}; Z^S_{62}; Z^S_{64} \end{pmatrix} = \begin{pmatrix} 76; 220; 101; 196; 21 \\ 164; 101; 15; 202 \\ 74; 58 \\ 82; 82; 15; 19; 105; 78; 11; 31; 59 \end{pmatrix}$$

and $s_2 = 1$, is given by the SLDM. Now, the FLDM test function, equ. (37), will be used to choose whether the solution

$$\begin{pmatrix} W^F_{22}; W^F_{32}; W^F_{23}; W^F_{14}; W^F_{24}; \\ X^S_{22}; X^S_{36}; X^S_{43}; X^S_{44}; \\ Y^S_{21}; Y^S_{25}; \\ Z^S_{23}; Z^S_{26}; Z^S_{32}; Z^S_{46}; Z^S_{47}; Z^S_{48}; Z^S_{61}; Z^S_{62}; Z^S_{64} \end{pmatrix} = \begin{pmatrix} 76; 220; 101; 196; 21 \\ 164; 101; 15; 202 \\ 74; 58 \\ 82; 82; 15; 19; 105; 78; 11; 31; 59 \end{pmatrix}$$

is acceptable or not:

$$\frac{\left\| F_1\begin{pmatrix} 76, 220, 101, 196, 21 \\ 0 \\ 46, 82, 58, 105, 5, 101, 85, 59, 73 \\ 0 \end{pmatrix} - F_1\begin{pmatrix} 76, 220, 101, 196, 21 \\ 164, 101, 15, 202 \\ 74, 58 \\ 82, 82, 15, 19, 105, 78, 11, 31, 59 \end{pmatrix} \right\|_2}{\left\| F_1\begin{pmatrix} 76, 220, 101, 196, 21 \\ 164, 101, 15, 202 \\ 74, 58 \\ 82, 82, 15, 19, 105, 78, 11, 31, 59 \end{pmatrix} \right\|_2} =$$

$$\frac{\sqrt{(313995 - 114926)^2 + (75970 - 157510)^2 + (75970 - 222848)^2}}{\sqrt{(114926)^2 + (157510)^2 + (222848)^2}} = 0.8796$$

$$< 0.9$$

So

$$\begin{pmatrix} W^F_{22}; W^F_{32}; W^F_{23}; W^F_{14}; W^F_{24}; \\ X^S_{22}; X^S_{36}; X^S_{43}; X^S_{44}; \\ Y^S_{21}; Y^S_{25}; \\ Z^S_{23}; Z^S_{26}; Z^S_{32}; Z^S_{46}; Z^S_{47}; Z^S_{48}; Z^S_{61}; Z^S_{62}; Z^S_{64} \end{pmatrix} = \begin{pmatrix} 76; 220; 101; 196; 21 \\ 164; 101; 15; 202 \\ 74; 58 \\ 82; 82; 15; 19; 105; 78; 11; 31; 59 \end{pmatrix}$$

is the preferred solution to the BL-MOSCM problem.

The second case at $\alpha = 0.5$, we can formulate and solve SO-DM problem of the FLDM as:

Table 6
Fuzzy delivery time of item from plant to retailer.

Plant	Retailers							
	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8
G_1	(45, 50, 2, 1)	(65, 75, 2, 4)	(50, 60, 3, 2)	(60, 70, 3, 4)	(35, 45, 2, 1)	(48, 50, 1, 2)	(70, 80, 5, 3)	(75, 85, 3, 4)
G_2	(30, 40, 2, 1)	(55, 65, 3, 2)	(40, 50, 5, 8)	(35, 45, 2, 1)	(20, 30, 2, 1)	(48, 50, 1, 2)	(65, 75, 2, 4)	(75, 85, 3, 4)
G_3	(70, 80, 5, 3)	(65, 75, 2, 4)	(70, 75, 5, 3)	(75, 85, 3, 4)	(55, 65, 3, 2)	(65, 75, 2, 4)	(70, 80, 2, 3)	(90, 95, 3, 4)
G_4	(90, 95, 3, 4)	(90, 100, 3, 7)	(75, 85, 3, 4)	(80, 90, 4, 6)	(55, 65, 3, 2)	(65, 75, 2, 4)	(75, 80, 1, 2)	(65, 70, 2, 4)

Table 7
Fuzzy delivery time of item from plant to warehouse.

Plant	Warehouses					
	N_1	N_2	N_3	N_4	N_5	N_6
G_1	(25, 35, 3, 2)	(15, 25, 2, 1)	(15, 25, 2, 1)	(10, 15, 1, 2)	(25, 30, 2, 3)	(25, 28, 2, 4)
G_2	(35, 45, 2, 1)	(15, 25, 2, 1)	(20, 30, 2, 1)	(25, 30, 2, 3)	(25, 28, 2, 4)	(35, 40, 3, 2)
G_3	(50, 60, 2, 3)	(55, 65, 3, 2)	(50, 60, 5, 3)	(55, 60, 5, 3)	(55, 65, 3, 2)	(35, 45, 2, 1)
G_4	(80, 90, 4, 6)	(55, 65, 3, 2)	(40, 50, 5, 8)	(40, 50, 5, 8)	(65, 75, 2, 4)	(70, 80, 5, 3)

Table 8
Fuzzy delivery time of item from warehouse to retailer.

Ware houses	Retailers							
	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8
N_1	(15, 25, 3, 1)	(15, 19, 2, 1)	(20, 30, 3, 5)	(25, 35, 3, 2)	(20, 30, 1, 2)	(20, 30, 3, 2)	(30, 40, 2, 1)	(30, 32, 5, 3)
N_2	(20, 21, 3, 2)	(15, 25, 1, 2)	(20, 30, 4, 5)	(20, 25, 1, 3)	(27, 29, 2, 4)	(27, 29, 2, 4)	(30, 40, 2, 1)	(25, 28, 2, 4)
N_3	(20, 30, 2, 1)	(15, 25, 2, 1)	(20, 21, 3, 2)	(30, 40, 2, 1)	(30, 33, 2, 1)	(35, 45, 2, 1)	(40, 42, 2, 4)	(35, 40, 3, 2)
N_4	(15, 25, 2, 1)	(20, 22, 1, 3)	(20, 22, 2, 3)	(25, 28, 2, 4)	(27, 29, 2, 4)	(26, 28, 4, 3)	(22, 24, 5, 3)	(20, 22, 2, 3)
N_5	(15, 25, 2, 1)	(16, 18, 2, 1)	(15, 17, 2, 1)	(14, 16, 3, 2)	(35, 40, 3, 2)	(34, 36, 2, 4)	(36, 38, 5, 6)	(40, 42, 2, 4)
N_6	(14, 16, 3, 2)	(10, 15, 1, 2)	(15, 17, 2, 1)	(16, 18, 2, 1)	(30, 32, 5, 3)	(29, 31, 4, 5)	(40, 42, 2, 4)	(68, 72, 2, 4)

$$\underbrace{\min}_{W_{lk}} f_{13} = \begin{pmatrix} 185W_{11} + 287.5W_{21} + 481W_{31} + \ldots + 196W_{34} + 263.5W_{44} + 332.5W_{54} \\ +287.5X_{11} + 139X_{12} + 185X_{13} + \ldots + 163X_{44} + 287.5X_{45} + 293.5X_{46} \\ +139Z_{11} + 172.5Z_{12} + 151Z_{13} + \ldots + 171Z_{66} + 182.5Z_{67} + 157.5Z_{68} \end{pmatrix}$$

subjectto

$$\begin{pmatrix} 185W_{11} + 287.5W_{21} + 481W_{31} + \cdots + 196W_{34} + 263.5W_{44} + 332.5W_{54} \\ 287.5Y_{11} + 423.5Y_{12} + 332.5Y_{13} + \cdots + 371Y_{46} + 405Y_{47} + 417Y_{48} \end{pmatrix} \leq 1144537,$$

$$\begin{pmatrix} 185W_{11} + 287.5W_{21} + 481W_{31} + \cdots + 196W_{34} + 263.5W_{44} + 332.5W_{54} \\ +287.5X_{11} + 139X_{12} + 185X_{13} + \cdots + 163X_{44} + 287.5X_{45} + 293.5X_{46} \end{pmatrix} \leq 1114414,$$

$$\left(W_{lk}, X_{kj}, Y_{ki}, Z_{ji}\right) \in \boldsymbol{G}.$$

The above model is solved by using LINGO 18 software, where $\delta_{11} = (b_{11} - a_{11})s_1 + a_{11} = 1144537$ and $\delta_{12} = (b_{12} - a_{12})s_1 + a_{12} = 1114414$, so the solution of the FLDM is.

$$\begin{pmatrix} W^F_{22}; W^F_{32}; W^F_{23}; W^F_{14}; W^F_{24}; \\ X^F_{kj} \\ Y^F_{22}; Y^F_{23}; Y^F_{25}; Y^F_{27}; Y^F_{36}; Y^F_{41}; Y^F_{43}; Y^F_{44}; Y^F_{48}; \\ Z^F_{ji} \end{pmatrix} = \begin{pmatrix} 81; 215; 103; 193; 37.5 \\ 0 \\ 48; 81.5; 59; 107.5; 103; 87.5; 2; 62; 79 \\ 0 \end{pmatrix}$$

and $s_1 = 1$, $\sigma^F = 0.9$ are given by the FLDM.

Secondly, the SLDM formulate it's SO-DM problem as:

$$\boldsymbol{min} f_{22} = \begin{pmatrix} 43Y_{11} + 63Y_{12} + 47Y_{13} + \cdots + 63Y_{46} + 74Y_{47} + 63Y_{48} \\ 22X_{11} + 13X_{12} + 13X_{13} + \cdots + 35X_{44} + 63X_{45} + 65X_{46} \\ 12Z_{11} + 13Z_{12} + 17Z_{13} + \cdots + 25Z_{66} + 38Z_{67} + 66Z_{68} \end{pmatrix}$$

subjectto

$$\begin{pmatrix} 43Y_{11} + 63Y_{12} + 47Y_{13} + \cdots + 63Y_{46} + 74Y_{47} + 63Y_{48} \\ 22X_{11} + 13X_{12} + 13X_{13} + \cdots + 35X_{44} + 63X_{45} + 65X_{46} \end{pmatrix} \leq 108486.5,$$

$$W^F_{22} = 81; W^F_{32} = 215; W^F_{23} = 103; W^F_{14} = 193; W^F_{24} = 37.5,$$

$$\left(X_{kj}, Y_{ki}, Z_{ji}\right) \in \boldsymbol{G}.$$

where $\delta_{21} = (b_{21} - a_{21})s_2 + a_{21} = 108486.5$, so the SLDM solution is

$$\begin{pmatrix} W^F_{22}; W^F_{32}; W^F_{23}; W^F_{14}; W^F_{24}; \\ X^S_{22}; X^S_{36}; X^S_{43}; X^S_{44} \\ Y^S_{21}; Y^S_{25}; Y^S_{46}; \\ Z^S_{23}; Z^S_{26}; Z^S_{32}; Z^S_{46}; Z^S_{47}; Z^S_{48}; Z^S_{62}; Z^S_{64} \end{pmatrix} = \begin{pmatrix} 81; 215; 103; 193; 37.5 \\ 149.5; 103; 7; 202 \\ 87.5; 59; 21.5 \\ 83.5; 66; 7; 15.5; 107.5; 79; 41; 62 \end{pmatrix}$$

and $s_2 = 1$, is given by the SLDM.

Table 9
Right Hand Side Parameters.

Fuzzy supply	Fuzzy Demand	Fixed capacity of plant	Fixed capacity of warehouse
$(180, 190, 5, 6)$	$(90, 95, 5, 6)$	471	154
$(480, 490, 10, 12)$	$(50, 55, 4, 5)$	296	177
$(200, 210, 8, 10)$	$(85, 90, 3, 2)$	327	160
$(201, 205, 7, 9)$	$(65, 70, 6, 7)$	318	202
$(290, 300, 12, 14)$	$(60, 65, 2, 3)$		178
	$(105, 110, 4, 5)$		218
	$(110, 115, 5, 7)$		
	$(80, 85, 2, 3)$		

Table 10
The individual maximum of the objective functions.

	$(f_{11})_\alpha$	$(f_{12})_\alpha$	$(f_{13})_\alpha$	$(f_{21})_\alpha$	$(f_{22})_\alpha$
$\alpha = 0$	1,133,337	1,105,509	1,220,263	106,332	118,589
$\alpha = 0.5$	1,144,537	1,114,414	1,237,190	108486.5	121668.2
$\alpha = 1$	1,149,130	1,117,480	1,247,548	109,380	123,477

Table 11
The individual minimum of the objective functions.

	$(f_{11})_\alpha$	$(f_{12})_\alpha$	$(f_{13})_\alpha$	$(f_{21})_\alpha$	$(f_{22})_\alpha$
$\alpha = 0$	75,970	75,970	75,970	76,170	17,473
$\alpha = 0.5$	83559.5	83559.5	83559.5	8498.25	19167.75
$\alpha = 1$	91,475	91,475	91,475	9425	20,908

Now, the FLDM test function, equ. (37), will be used to choose whether the solution.

$$\begin{pmatrix} W^F_{22}; W^F_{32}; W^F_{23}; W^F_{14}; W^F_{24}; \\ X^S_{22}; X^S_{36}; X^S_{43}; X^S_{44} \\ Y^S_{21}; Y^S_{25}; Y^S_{46}; \\ Z^S_{23}; Z^S_{26}; Z^S_{32}; Z^S_{46}; Z^S_{47}; Z^S_{48}; Z^S_{62}; Z^S_{64} \end{pmatrix} = \begin{pmatrix} 81; 215; 103; 193; 37.5 \\ 149.5; 103; 7; 202 \\ 87.5; 59; 21.5 \\ 83.5; 66; 7; 15.5; 107.5; 79; 41; 62 \end{pmatrix}$$ is acceptable or not:

$$\frac{\left\| F_1\begin{pmatrix} 81; 215; 103; 193; 37.5 \\ 0 \\ 48; 81.5; 59; 107.5; 103; 87.5; 2; 62; 79 \\ 0 \end{pmatrix} - F_1\begin{pmatrix} 81; 215; 103; 193; 37.5 \\ 149.5; 103; 7; 202 \\ 87.5; 59; 21.5 \\ 83.5; 66; 7; 15.5; 107.5; 79; 41; 62 \end{pmatrix}\right\|_2}{\left\| F_1\begin{pmatrix} 81; 215; 103; 193; 37.5 \\ 149.5; 103; 7; 202 \\ 87.5; 59; 21.5 \\ 83.5; 66; 7; 15.5; 107.5; 79; 41; 62 \end{pmatrix}\right\|_2} =$$

$$\frac{\sqrt{(332586.25 - 136326.75)^2 + (83559.5 - 148110.5)^2 + (83559.5 - 218258)^2}}{\sqrt{(136326.75)^2 + (148110.5)^2 + (218258)^2}}$$

$= 0.83 < 0.9$

So

$$\begin{pmatrix} W^F_{22}; W^F_{32}; W^F_{23}; W^F_{14}; W^F_{24}; \\ X^S_{22}; X^S_{36}; X^S_{43}; X^S_{44} \\ Y^S_{21}; Y^S_{25}; Y^S_{46}; \\ Z^S_{23}; Z^S_{26}; Z^S_{32}; Z^S_{46}; Z^S_{47}; Z^S_{48}; Z^S_{62}; Z^S_{64} \end{pmatrix} = \begin{pmatrix} 81; 215; 103; 193; 37.5 \\ 149.5; 103; 7; 202 \\ 87.5; 59; 21.5 \\ 83.5; 66; 7; 15.5; 107.5; 79; 41; 62 \end{pmatrix}$$ is the preferred solution to the BL-MOSCM problem.

The third case at $\alpha = 1$, the crisp BL-MOSCM can be formulate as:

$$\underbrace{\min}_{W_{lk}} f_{13} = \begin{pmatrix} 195W_{11} + 295W_{21} + 490W_{31} + \ldots + 203W_{34} + 270W_{44} + 340W_{54} \\ +295X_{11} + 145X_{12} + 195X_{13} + \ldots + 170X_{44} + 295X_{45} + 300X_{46} \\ +145Z_{11} + 180Z_{12} + 160Z_{13} + \ldots + 180Z_{66} + 190Z_{67} + 165Z_{68} \end{pmatrix}$$

subjectto

$$\begin{pmatrix} 195W_{11} + 295W_{21} + 490W_{31} + \cdots + 203W_{34} + 270W_{44} + 340W_{54} \\ 295Y_{11} + 430Y_{12} + 340Y_{13} + \cdots + 385Y_{46} + 420Y_{47} + 430Y_{48} \end{pmatrix} \le 1149130,$$

$$\begin{pmatrix} 195W_{11} + 295W_{21} + 490W_{31} + \cdots + 203W_{34} + 270W_{44} + 340W_{54} \\ +295X_{11} + 145X_{12} + 195X_{13} + \cdots + 170X_{44} + 295X_{45} + 300X_{46} \end{pmatrix} \le 1117480,$$

$(W_{lk}, X_{kj}, Y_{ki}, Z_{ji}) \in \boldsymbol{G}.$

The above model is solved by using LINGO 18 software, where

Table 12
Allocated Optimal Quantity.

Optimum Quantity Shipped				
α	Source to plant W_{lk}	Plant to retailer (Y_{ki})	Plant to warehouse (X_{kj})	Warehouse to retailer (Z_{ji})
0	(0,0,0,0,00,76,220,0,00,101, 0,0,0,196;21,0,0,0)	(0,0,0,0,0,0,0,0,74,0,0,0,58,0,0,00,0, 0,0,0,0,0,00,0,0,0,0,0,0,0,0)	(0,0,0,0,0,0,0,164,0,0,0,0,0,00, 0,0,101,0,015,202,0,0)	(0,0,0,0,0,0,0,0,0,0,82,0,0,82,0,00,15,0,0,0,0,0,00,0,0,0, 0,19,105,78,0,0,0,0,0,0,0,011,31,0,59,0,0,0,0)
0.5	(0,0,0,0,00,81,215,0,00,103, 0,0,0,193;37.5,0,0,0)	(0,0,0,0,0,0,0,0,87.5,0,0,0,59,0,0,00, 0,0,0,0,0,0,00,0,0,0,0,21.5,0,0)	(0,0,0,0,0,0,0,149.5,0,0,0,0,0, 00,0,0,103,0,07,202,0,0)	(0,0,0,0,0,0,0,0,0,0,83.5,0,0,66,0,00,7,0,0,0,0,0,00,0,0,0, 0,15.5,107.8,79,0,0,0,0,0,0,0,00,41,0,62,0,0,0,0)
1	(0,0,0,0,00,86,210,0,00,105, 0,0,0,190,54,0,0,0)	(0,0,0,0,0,0,0,0,90,0,0,0,60,0,0,00,0, 0,0,0,0,0,00,0,0,0,54,0,0,0)	(0,0,0,0,0,0,0,146,0,0,0,0,0,00, 0,0,105,0,00,190,0,0)	(0,0,0,0,0,0,0,0,0,0,30,65,0,51,0,00,0,0,0,0,0,0,0,00,0,0,0, 0,110,80,0,0,0,0,0,0,0,0,00,50,55,0,0,0,0,0,0)

Table 13
Rapprochement between the interactive approach and the existing methods.

	Interactive approach	Gupta et al. (Gupta et al., 2018)	Ideal objective values
$\alpha = 0$	$f_{11} = 114926 f_{12} = 157510 f_{13} = 222848 f_{21} = 16176 f_{22} = 24566$	$f_{11} = 313342 f_{12} = 199200 f_{13} = 236367 f_{21} = 25421 f_{22} = 31328$	$f_{11} = 75970 f_{12} = 75970 f_{13} = 75970 f_{21} = 76170 f_{22} = 17473$
$\alpha = 0.5$	$f_{11} = 136326.75 f_{12} = 148110.5 f_{13} = 218258 f_{21} = 18467 f_{22} = 27072.75$	$f_{11} = 295698.5\ f_{12} = 218163 f_{13} = 269486.5 f_{21} = 27143 f_{22} = 33868$	$f_{11} = 83559.5 f_{12} = 83559.5 f_{13} = 83559.5 f_{21} = 8498.25 f_{22} = 19167.75$
$\alpha = 1$	$f_{11} = 159065 f_{12} = 172270 f_{13} = 246000 f_{21} = 20875 f_{22} = 29497$	$f_{11} = 271607 f_{12} = 243227 f_{13} = 289991 f_{21} = 28932 f_{22} = 35932$	$f_{11} = 91475 f_{12} = 91475 f_{13} = 91475 f_{21} = 9425 f_{22} = 20908$

$\delta_{11} = (b_{11} - a_{11})s_1 + a_{11} = 1149130 and \delta_{12} = (b_{12} - a_{12})s_1 + a_{12} =$ 1117480, so the solution of the FLDM is.

$$\begin{pmatrix} W^F_{22}; W^F_{23}; W^F_{32}; W^F_{14}; W^F_{24}; \\ X^F_{kj} \\ Y^F_{22}; Y^F_{23}; Y^F_{25}; Y^F_{27}; Y^F_{36}; Y^F_{41}; Y^F_{43}; Y^F_{44}; Y^F_{48}; \\ Z^F_{ji} \end{pmatrix} = \begin{pmatrix} 86; 105; 210; 190; 54 \\ 0 \\ 50; 76; 60; 110; 105; 90; 9; 65; 80 \\ 0 \end{pmatrix}$$

and $s_1 = 1$, $\sigma^F = 0.9$ are given by the FLDM. Secondly, the SLDM problem formulated as:

$$\boldsymbol{minf_{22}} = \begin{pmatrix} 45Y_{11} + 65Y_{12} + 50Y_{13} + \cdots + 65Y_{46} + 75Y_{47} + 65Y_{48} \\ 25X_{11} + 15X_{12} + 15X_{13} + \cdots + 40X_{44} + 65X_{45} + 70X_{46} \\ 15Z_{11} + 15Z_{12} + 20Z_{13} + \cdots + 29Z_{66} + 40Z_{67} + 68Z_{68} \end{pmatrix}$$

subjectto

$$\begin{pmatrix} 45Y_{11} + 65Y_{12} + 50Y_{13} + \cdots + 65Y_{46} + 75Y_{47} + 65Y_{48} \\ 25X_{11} + 15X_{12} + 15X_{13} + \cdots + 40X_{44} + 65X_{45} + 70X_{46} \end{pmatrix} \leq 109380,$$

$$W^F_{22} = 86; W^F_{32} = 210; W^F_{23} = 105; W^F_{14} = 190; W^F_{24} = 54,$$

$$(X_{kj}, Y_{ki}, Z_{ji}) \in \boldsymbol{G}.$$

where $\delta_{21} = (b_{21} - a_{21})s_2 + a_{21} = 109380$, so the SLDM solution is

$$\begin{pmatrix} W^F_{22}; W^F_{23}; W^F_{32}; W^F_{14}; W^F_{24}; \\ X^S_{22}; X^S_{36}; X^S_{44}; \\ Y^S_{21}; Y^S_{25}; Y^S_{46} \\ Z^S_{23}; Z^S_{24}; Z^S_{26}; Z^S_{47}; Z^S_{48}; Z^S_{62}; Z^S_{63} \end{pmatrix} = \begin{pmatrix} 86; 105; 210; 190; 54 \\ 146; 105; 190 \\ 90; 60; 54 \\ 30; 65; 51; 110; 105; 80; 50; 55 \end{pmatrix}$$

and $s_2 = 1$, is given by the SLDM. Now, the FLDM test function, equ. (37), will be used to choose whether the solution

$$\begin{pmatrix} W^F_{22}; W^F_{23}; W^F_{32}; W^F_{14}; W^F_{24}; \\ X^S_{22}; X^S_{36}; X^S_{44}; \\ Y^S_{21}; Y^S_{25}; Y^S_{46} \\ Z^S_{23}; Z^S_{24}; Z^S_{26}; Z^S_{47}; Z^S_{48}; Z^S_{62}; Z^S_{63} \end{pmatrix} = \begin{pmatrix} 86; 105; 210; 190; 54 \\ 146; 105; 190 \\ 90; 60; 54 \\ 30; 65; 51; 110; 105; 80; 50; 55 \end{pmatrix}$$

is acceptable or not:

$$\frac{\left\| F_1 \begin{pmatrix} 86; 105; 210; 190; 54 \\ 0 \\ 50; 76; 60; 110; 105; 90; 9; 65; 80 \\ 0 \end{pmatrix} - F_1 \begin{pmatrix} 86; 105; 210; 190; 54 \\ 146; 105; 190 \\ 90; 60; 54 \\ 30; 65; 51; 110; 80; 50; 55 \end{pmatrix} \right\|_2}{\left\| F_1 \begin{pmatrix} 86; 105; 210; 190; 54 \\ 146; 105; 190 \\ 90; 60; 54 \\ 30; 65; 51; 110; 105; 80; 50; 55 \end{pmatrix} \right\|_2}$$

$$= \frac{\sqrt{(351875 - 159065)^2 + (91475 - 172270)^2 + (91475 - 246000)^2}}{\sqrt{(159065)^2 + (172270)^2 + (246000)^2}} = 0.7649$$

$$< 0.9$$

So $\begin{pmatrix} W^F_{22}; W^F_{23}; W^F_{32}; W^F_{14}; W^F_{24}; \\ X^S_{22}; X^S_{36}; X^S_{44}; \\ Y^S_{21}; Y^S_{25}; Y^S_{46} \\ Z^S_{23}; Z^S_{24}; Z^S_{26}; Z^S_{47}; Z^S_{48}; Z^S_{62}; Z^S_{63} \end{pmatrix} = \begin{pmatrix} 86;105;210;190;54 \\ 146;105;190 \\ 90;60;54 \\ 30;65;51;110;80;50;55 \end{pmatrix}$ is the preferred solution to the BL-MOSCM problem.

The rapprochement between the suggested interactive methodology and the method exhibited by Gupta et al. (Gupta et al., 2018) is specified in Table 13. The outcomes displayed that the compromise solution of the suggested interactive approach is greatly preferred to the FGP approach proposed by Gupta et al. (Gupta et al., 2018). Also, the interactive approach gives the DM the merit of indicate inclinations during the solution operation, not at all like the FGP approach. The upside of articulating inclinations by DM during the solution operation is promising in actual applications as it allows the DM the opportunity of associating with the analyst.

Discussion: The Tables 12 and 13 gives the optimal values of the objective functions at different values of $\alpha \in [0,1]$ alongside optimal order allocation from source to factory, factory to the retailer, plant to stockroom and distribution center to retailer respectively. Particularly, $\alpha = 0$ specify the broadest least chance, showing that the target function won't at any point fall outside of this reach while at the opposite finish of $\alpha = 1$, it offers the most likely benefit of the goal. It is seen that transportation sum may change at a few upsides of α.

A SCN comprises of an expansive organization for the equip of material from the source to plant, and afterward plant to the retailer, while the remainder of the material moved from plant to stockroom, and afterward shipped from distribution center to retailer as indicated by the interest of the market. The issue considered in this paper is a genuine multi-objective issue looked by the operational supervisor in an assembling unit, where they need to limit the transportation cost and conveyance time respectively. The proposed BL-MOSCN for request distribution considers yearly demand from retailers and likely limit of provider and stockroom with various expense capacities and conveyance time. This study assists the DM to dissect the situations of uncertain judgment in SCN when client's requests and supplies of the item are under ambiguity. In the presented BL-MOSCN model a specific α-level is adopted to represent the confidence level on DMs' subjective uncertainty to specify parameter values in the α-(BL-MOSCM). For simplification, the α-level for all parameters in the solution process are consider the same. However, these may be limitations in practical applications. The determination of α-levels for various DMs' subjective uncertainties could be different in the real world, due to DMs' different consideration of the corresponding objective functions. Thus, we solve the α-(BL-MOSCM) for different values of level sets.

8. Conclusion

The issue considered in this paper is a genuine MOPP looked by the functional administrator in an assembling unit, where they need to minimize the transportation cost and delivery time, respectively. The proposed BL-MOSCM with fuzzy parameters for request distribution considers yearly interest from retailers and potential limits of provider and stockroom with various expense functions and delivery time. The primary goal of this paper is to foster an interactive approach that minimizes the whole transportation cost and delivery time, respectively. The uniqueness of the model lies in its capacity to think about dubiousness sought after and supply parameters. The idea of the α-level is utilized to deal with the vagueness by considering of all TFNs. An illustrative case study is presented to show the suggested interactive methodology for tackling BL-MOSCM with fuzzy parameters. The competence and applicability of the suggested interactive approach is verified via comparison with the existing methods. It is expected that, this research will further accelerate the benefit in treating BLPP more in this field of SCN.

Novel findings and recommendations in the present study is that the interactive approach gives the DM the merit to indicate inclinations during the solution operation, which is totally different from the FGP approach. The upside of articulating inclinations by DM during the solution operation is promising in actual applications as it allows the DM the opportunity of associating with the analyst. Moreover, the uncertain BL-MOSCM is more genuine than the conventional deterministic one. Coming up next are a few findings and recommendations drawn from the proposed study which is supportive for any managers in assembling unit:

- The proposed model assists the DM in minimizing transportation expenses and conveyance time of large SCN.
- This study assists the DM to dissect the situations of vulnerability judgment in SCN when client's requests and supplies of the item are under ambiguity.
- The model also, assists the DM in concocting a decent appropriation methodology.
- It likewise helps DMs in the investigation of the outcomes acquired under a certain also questionable climate in the SCN and gives the thoughts how to function with such sort of surprising circumstances.

The major limitation, which is computational complexity, of the proposed BL-MOSCM with fuzzy parameters is that a specific α-level is adopted in the proposed methods to represent the confidence level on DMs' subjective uncertainty to specify parameter values in the BL-MOSCM. For simplicity, the α-level for all parameters of the BL-MOSCM are assumed to be the same. However, there may be limitations in real-world models. The determination of α-levels for various DMs' subjective uncertainties could be different in the real world due to DMs' different consideration of the real SCN data. Also, the current mathematical examination, a theoretically built SCN have been considered. The proposed model restricted to dubiousness just, yet in true issues, the DM needs to confront probabilistic and multi-choices circumstances.

Several open points for future research in BL-MOSCM, from our point of view, to be studied in the future are:

1. The study of BL-MOSCM in rough environment is an active point to be considered.
2. Real-world case studies of BL-MOSCM are a vital field in the future research, and.
3. BL-MOSCM with multi-choice parameters is an interesting topic to be investigated.

CRediT authorship contribution statement

M.A. El Sayed: Conceptualization, Methodology, Software, Supervision. **F.A. Farahat:** Visualization, Investigation, Writing – review & editing. **M.A. Elsisy:** Visualization, Investigation, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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