Operational Research in Engineering Sciences: Theory and Applications
Vol. 5, Issue 3, 2022, pp. 210-229
ISSN: 2620-1607
eISSN: 2620-1747
DOI: https://doi.org/10.31181/oresta241122181y

A TWO-STAGE INTEGRATED MODEL FOR SUPPLIER SELECTION AND ORDER ALLOCATION: AN APPLICATION IN DAIRY INDUSTRY

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Received: 06 July 2022
Accepted: 16 November 2022
First online: 24 November 2022

Research paper

Abstract: *Selecting the best supplier is a recurrent organizational challenge that occurs in a supply chain (SC) as a result of the presence of complex variables, restrictive criteria, and conflicting priorities. Since an SC network is often developed with ambiguous conditions and information due to the industrialization of society and the intricacy of market competitiveness, fuzzy decision-making models are more effective. This paper proposes a two-stage decision-making model to select suppliers and to estimate cost-effective order numbers per supplier. The initial stage of the proposed model involves identifying fuzzy linguistic variables, interpreting appropriate decision criteria for evaluating suppliers, and modelling fuzzy technique for order preference and similarity to ideal solution (TOPSIS) method. The goal of fuzzy TOPSIS method is to attenuate the ambiguous expert inputs. In the second stage, economic order quantity is determined and assigned to each supplier using TOPSIS scores as inputs for a linear programming (LP) model. Different constraints, including demand, density qualification, acidity qualification, price, and capacity are formulated using the LP model. The mathematical model seeks to optimize total value of purchasing. The model is implemented in a dairy company to show its applicability and effectiveness. It has been found that supplier A1 and supplier A4 need to deliver 8000 kg of dry milk to the company, while supplier A5 needs to supply only 3500 kg. It is expected that the obtained results will assist organizations in developing a methodical strategy for addressing order allocation and supplier selection problems in more a realistic context.*

Key words: *Supplier selection, Order allocation, Integrated model, Fuzzy TOPSIS, Linear programming*

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1. Introduction

Business organizations are increasingly required to use knowledge-based operations due to the very dynamic nature of corporate affairs. Their entire strategy would be geared around improving their competitive position. Supplier selection, one of the key supply chain management (SCM) activities, has contributed to a wide range of researches. This has encouraged businesses to pursue more reliable and competitive goals (Udenio et al. 2015). Two of the most crucial tasks for purchasing decision-makers (DMs) to complete are selecting the best supplier and allocating order quantities because they have an impact on the company's long-term profitability. The key objective is to get the right product in the right quantity from the right supplier at the right time and at a fair price. Purchasing is a strategic action in addition since it lowers costs and raises profits. Decisions about order allocation in supplier selection are crucial in establishing the cost-effectiveness of the business. Because an organization's needs could exceed the capability of a single supplier, this process entails determining various quantities of goods that are purchased from several suppliers. Supplier selection is one of the most prevalent multi-criteria decision-making (MCDM) problems since it is driven by competing considerations like performance, cost, and timely delivery (Wu et al. 2016; Rao et al. 2017). In the SC network, knowledge-based decision models are receiving a lot of attention. Making effective decision support systems to aid managerial decisions has been the subject of a significant amount of original research work. Computerized information systems that support management decision-making processes are referred to as decision support systems. Early in the 1970s, Scott Morton's research gave rise to the idea of decision support systems. In an intricate and poorly organized situation, the approach seeks to examine strategic decisions in order to provide decision makers (DMs) with support. An integrated decision support model offers various benefits in the decision-making process by assisting policymakers with their responsibilities and improving quality of the planning phase (Zarate, 2012). A decision support system is a concept that combines computer information processing with human judgement.

The development of new theories and methods for SCM may lead to more sophisticated and intelligent systems. SC experts may make highly skilled decisions, information exchange, and internal coordination simpler by utilizing these kinds of solutions, which will raise the value of products and services (Chandra and Kumar, 2000). SCM has teamed up with the application of information and decision-making technology to develop competitive advantages with customers and stakeholders by improving coordination and communication across suppliers and partners for organizations (Negi and Anand, 2014). The market has a significant impact on the suppliers chosen in a logistics network. One of the fastest-growing industries with a significant impact on a nation's economic performance is the SC and logistics sector, which aid in activities relating to the flow of goods efficiently (Mešic et al. 2022; Puška et al. 2022). Over the past few decades, the development of decision support systems has undergone a fundamental change. By keeping track of the materials cost, a decision support model has helped DMs select practical strategies for reducing overall manufacturing costs (Wong et al. 2009). A few review studies on intelligent models, decision support systems, and systems have been done in the area of SCM (Seuring, 2013; Taticchi et al. 2013). According to Seuring (2013), a strategic decision-making support model must be used to conduct practical research on the performance of sustainability and SCM. Liu et al. (2012) developed a sustainability evaluation method that combined life cycle assessment with an MCDM framework to aid the ecological, sociological, and financial implications of SCM. Using a fuzzy analytical network process (ANP), Bhattacharya et al. (2014) sought to build a collaborative decision-making model while demonstrating a SC performance measurement perspective. Over time, a number of decision-making strategies have been developed to provide more useful supplier selection possibilities. Numerous methods have been used extensively in the literature, including linear programming (LP), data envelopment analysis (DEA), neural networks, fuzzy approaches, and technique for order preference by similarity to ideal solution (TOPSIS). Chen et al. (2006) used a fuzzy systematic approach to enhance TOPSIS and handle the elements of supplier revenue, interpersonal intimacy, technical proficiency, adherence to quality, and conflict resolution in their solution to the supplier selection problem. In order to choose the best supplier in a situation involving group decision-making, Cao et al. (2015) developed the TOPSIS method in conjunction with intuitionistic fuzzy sets. Overall, integrated models aid researchers in developing their concepts. Uncertainty and fuzziness will surely be prevalent for experts, DMs, and managers. Fuzzy theory was utilized by combining quality function deployment (QFD) and LP, respectively, in Bevilacqua et al. (2006) and Guneri et al. (2009). However, one of the main issues with utilizing such approaches is that they overlook the probable, potential, unpredictable, and unknown elements that might change the features of the problem, such as cost, quality, production volume, etc., which can have a big impact on the result. Thus, it is essential to take into account and incorporate uncertainties that may have an impact on the final decision in order to develop realistic decision-making models to deal with problems of order allocation and supplier evaluation. Fuzzy logic is one of the methods that has a lot of potential for accounting for uncertainty during the decision-making process. By applying fuzzy logic, decision-makers in real-world industries can share their own viewpoints and offer more dependable and accurate choice solutions (Torkayesh et al. 2020; Yazdani et al. 2020a; Yazdani et al. 2020b). Fuzzy logic is being implemented into decision-making procedures to enable appropriate assessment of relative importance of decision criteria for evaluating suppliers. This will result in more accurate decisions for supplier selection that further the sustainability goals.

To overcome these challenges, a two-stage integrated decision making model using fuzzy TOPSIS and LP has been put out in this study. The goal of this study is to develop a mathematical model that can be applied to address the problem of combining supplier choice and order allocation. A case study for the diary sector in real life is taken into consideration to demonstrate the importance and applicability of the model. Trapezoidal fuzzy logic is used in the proposed decision-making model to reduce the adverse effects of the decision-making outputs and hence, weights of the supplier selection criteria are calculated and the suppliers are ranked. Adoption of a single MCDM method or mathematical model to address the supplier selection and order allocation problems is one of the major problems noted in the literature. In this study, two methods are combined to produce a more trustworthy model that can be used to rank suppliers and determine how much of an order should be distributed among them. In order to evaluate suppliers in a fuzzy environment and establish the appropriate order size, this study employs an LP method. The paper is broken down into four sections: an introduction, a literature review, a discussion of fuzzy logic, fuzzy numbers, and the fuzzy TOPSIS method in Section 3, a case study of a dairy company to find the best supplier of dry milk (milk powder) and the best quantity order in

Section 4, and finally, a possible framework for further research along with conclusions are presented in Section 5.

2. Literature review

This section presents a thorough assessment of the literature as well as significant case studies and decision-making methods. The goal of this section is to give a thorough background on the subject and information on the benefits of decision-making models and strategies for coping with uncertainty in real-world circumstances. To do this, studies based on the integration of MCDM and optimization models are explored after studies that have just used only MCDM models to address the supplier selection problems.

MCDM methods (Badi et al. 2022) are one of the widely used decision-making strategies that allow decision- and policy-makers to compare a number of options based on a number of criteria and then choose the one that will best serve their needs. One of the issues in which MCDM methods have frequently been developed is the challenge of supplier selection and order allocation. Due to the significance of suppliers and their features, industries would suffer irreparable consequences from a poor supplier selection. In this regard, MCDM methods are crucial in assisting industries in making the best choice in order to maximise their earnings and lower the chance of unfavourable outcomes from choosing the incorrect suppliers. For supplier selection problems in electronics industry while taking into account green criteria, Kuo et al. (2015) developed an integrated decision making model employing ANP and VlseKriterijuska Optimizacija I Komoromisno Resenje (VIKOR) methods based on D-numbers. Parkash and Barua (2016) employed AHP and VIKOR methods for third-party logistics selection under fuzzy numbers using a similar methodology. In order to choose the best supplier in the manufacturing of pipes and fittings, Rezaeisaray et al. (2016) proposed an integrated decision making framework using the Decision Making Trial and Evaluation Laboratory (DEMATEL), Analytic Network Process), and the Data Envelopment Analysis (DEA) model. For supplier selection problem in the catering industry, Fu et al. (2019) used a multi-choice goal programming model with AHP and additive Ratio Assessment (ARAS) methods. To address the supplier selection issue in a trapezoidal fuzzy environment, Ghorabaee et al. (2016) introduced an extended form of assessment based on distance from average solution (EDAS) method. The proposed decision-making method was used to evaluate suppliers of a detergent manufacturer. In order to take into account the uncertainties in evaluating suppliers, Wan et al. (2017) developed a novel integrated MCDM model employing ANP and elimination and choice translating reality (ELECTRE II) in an interval 2-tuple linguistic environment. In order to handle the supplier selection issue under green factors, Yazdani et al. (2017) developed a novel decision-making model by fusing the DEMATEL approach with the Quality Function Deployment (QFD) and COmplex PRoportional ASsessment (COPRAS) methods. AHP and TOPSIS methods were utilised by Jain et al. (2020) to assess suppliers in the steel industry while taking sustainability concerns into consideration. The weights of the sustainable supplier selection criteria were calculated using the fuzzy AHP, and suppliers were assessed using the fuzzy TOPSIS method. For a problem involving the selection of green suppliers, Đalić et al. (2020) suggested a unique integrated fuzzy-rough MCDM model incorporating the fuzzy pivot pairwise relative criteria importance assessment (PIPRECIA) and interval rough SAW methods. In order to address the supplier selection issue in the healthcare industry, Stevic et al. (2020) suggested a new MCDM model called Measurement of Alternatives and Ranking according to Compromise Solution (MARCOS method). A novel integrated MCDM model was developed by Yazdani et al. (2020) using a weighting system and EDAS method that were coupled. They devised a combined weighting system based on the best worst method (BWM) and DEMATEL approaches in order to compute the ideal weights of decision criteria because weight determination is the most important phase in addressing MCDM problems. They applied the proposed method to a real-world case study in the Spanish healthcare sector to demonstrate its applicability. Yazdani et al. (2020) introduced a QFD-based AHP-VIKOR decision making tool that deals with choosing the appropriate supplier because of the importance of the dairy business. They employed the AHP and QFD methods to calculate the weights of the choice criteria before using the VIKOR method to evaluate the suppliers. To select the best sustainable supplier, Ecer and Pamucar (2020) used the fuzzy BWM and Bonferroni mean functions-based Combined Compromise Solution (CoCoSo) method. Durmić et al. (2021) investigated a combined application of the Full Consistency Approach (FUCOM) and Rough Simple Additive Weighting (SAW) method in order to eliminate uncertainty and imprecision in the supplier evaluation process for a lime production industry. Puška et al. (2021) applied fuzzy MARCOS method to deal with sustainable supplier selection problem in a food industry. Ulutaş et al. (2021) proposed MULTIMOOSRAL, a novel MCDM approach for a textile supplier selection problem. Three widely used techniques, multi-objective optimization on the basis of simple ratio analysis (MOOSRA), multi-objective optimization on the basis of ratio analysis (MOORA), and the complete multiplicative form of MOORA (MULTIMOORA), were combined to develop this method. Hoseini et al. (2022) created a combined model for resilient supplier selection in the construction industries using Interval Type-2 Fuzzy (IT2F) TOPSIS and IT2F BWM. In order to address supplier selection issues, Zakeri et al. (2022) introduced a unique MCDM technique called the alternative ranking process by alternatives' stability scores (ARPASS). The new method computes the stabilities of the options using standard deviations and Shannon's entropy. Nguyen et al. (2022) proposed a combination model employing DEA, the spherical fuzzy AHP (SF-AHP), and the spherical fuzzy weighted aggregated sum product assessment (SF-WASPAS) to find the sustainable supplier for a steel manufacturing industry. Ecer (2022) used an extended AHP in an interval type-2 fuzzy environment to solve a supplier selection problem while taking into account green notions. Afrasiabi et al. (2022) proposed a hybrid fuzzy MCDM method to solve issues with sustainable-resilient supplier selection in manufacturing scenarios. Initial calculations for the weights of the selection criteria were made using fuzzy BWM. Next, a combined grey relational analysis (GRA) and TOPSIS method was used to evaluate the suppliers in a fuzzy environment. Using the FUCOM method and an unique extension of mixed aggregation by comprehensive normalizing technique under fuzzy environment, Ecer and Torkayesh (2022) suggested a Stratified Fuzzy Decision-Making Approach for Sustainable Circular Supplier Selection in the textile industry.

Although MCDM methods can be used as a trustworthy decision-making approach to address the supplier selection problem, real-world situations necessitate decision-making approaches that simultaneously evaluate suppliers and then allocate the best number of orders to maximise economic, environmental, and social goals. A hybrid

MCDM and multi-objective programming approach for the supplier selection and order allocation problem that takes into account green criteria was given by Kannan et al. (2013). In the first step, the AHP and TOPSIS methodologies were employed to determine the relative ranking orders of suppliers. Then, an optimization model was applied to determine order allocation with respect to order constraints and quality constraints. For the supplier selection and order allocation problem, Hamdan and Cheaitou (2017) suggested an MCDM and multi-objective programming model that takes into account environmental aspects. They first evaluated the providers using fuzzy AHP and TOPSIS before allocating orders using an optimization model. In order to maximise the clean environmental goals, Babbar and Amin (2018) proposed a fuzzy QFD-based multi-objective programming model for the supplier selection and order allocation problem in the beverage industry. With regard to SC disruption issues, Cheraghalipour and Farsad (2018) suggested a new decision-making model for the supplier selection and order allocation problem utilising MCDM models and mixed-integer LP. To address the problems of supplier selection and order allocation, Mohammad et al. (2019) employed a hybrid model that combined fuzzy AHP and TOPSIS methods with fuzzy multi-objective programming. To address it, they turned the multi-objective model into a single-level model using the e-constraint technique. The ultimate Pareto solution was then chosen using the TOPSIS method. Rezaei et al. (2020) devised an integrated decision-making model for the supplier selection and order allocation problems in lean manufacturing combining fuzzy AHP and multi-objective optimization models. Khalili Nasr et al. (2021) introduced a novel two-stage fuzzy supplier selection and order allocation model for a case study in the clothing sector. This model worked in a closed-loop SC. Fuzzy BWM was used in stage 1 to select the best suppliers based on economic, environmental, social, and circular factors, and a multi-objective mixed-integer LP model was employed in stage 2 to distribute orders. Li et al. (2021) presented a two stage mathematical model for selecting a group of suppliers and assigning an order quantity to each source. The risk value, which was determined using qualitative and quantitative approaches based on BWM, was used as the basis for the initial selection of alternative suppliers. For the second step, which deals with dynamic supplier selection and order allocation, a multiobjective mathematical model was constructed. Zhao et al. (2021) developed a new integration strategy based on decision-theoretic rough set and the extended VIKOR methods to address the resilient-sustainable supplier selection and order allocation problem. Aouadni and Euchi (2022) developed a hybrid model based on BWM, Meaningful Mixed Data (MMD)-TOPSIS, and LP model to address both the supplier selection and fair order allocation concerns. BWM was considered for determining the criteria's weights. Utilizing the MMD-TOPSIS technique, suppliers were ranked. In a manufacturing setting, a bi-objective LP was used to fairly distribute the order quantity among the providers by accounting for each supplier's meaningful suitability index (MSI). Goodarzi et al. (2022) suggested an integrated Fuzzy-Delphi, Gray Correlation-based TOPSIS (GC-TOPSIS), and an integer mixed bi-objective non-linear planning model to pick the best supplier and determine the optimal values of the order from each selected supplier.

Despite extensive study on the application of supplier selection and order allotment models, as presented in the literature review, it is observed that there is a relatively little research on the dairy supplier selection and order allocation issue simultaneously and additional knowledge is still required regarding model application at the managerial level. Food items, especially dairy products, are greatly impacted by perishability, which causes food quality to degrade over time. An efficient SCM has to deal with infrastructure problems, which increase chain dynamics risks and reduce chain operations dependability. Since SCM activities are closely related to the issue of food safety and security, it is important to give them top priority (Sharma et al. 2021). It is well known that inherent uncertainties like incomplete information, supply capacity restrictions, supply quality, delivery issues, item availability, logistics and transportation bottlenecks, demand unpredictability, and information misinterpretation have a significant impact on the selection process for dairy suppliers and order allocation. Data inaccuracies have a direct impact on system results and can lead DMs to make poor strategic choices when choosing suppliers and allocating orders. Therefore, one of the key goals and incentives for SC practitioners and academics is the development of such models that can assist DMs while confronting ambiguous circumstances to overcome uncertainty. Utilizing the fuzzy set is the underlying idea behind overcoming ambiguities in decision-making processes. Using the aforementioned ideas as a foundation, this research suggests a two-stage integrated model for supplier selection and order allocation problems in dairy industry to maximise the overall value of the purchase. The developed model is built on the use of fuzzy TOPSIS to reduce ambiguous expert inputs in the first stage, while in the second stage, fuzzy TOPSIS scores are used as inputs for an LP model to predict economic order quantity to be assigned to each supplier. Several constraints including demand, density qualification, acidity qualification, price, and capacity are considered to present a realistic model.

3. Fuzzy TOPSIS Method

Given the few experts involved and the need for quick and precise information processing, the TOPSIS method was chosen for this endeavor because of its simplicity and flexibility. A further benefit is that it distinguishes between the cost (the lower the better) and benefit (the higher the better) criteria and chooses the solutions that are both closest to and farthest from the positive and negative ideal solutions. The conventional TOPSIS, despite being commonly used, has certain drawbacks. The primary one has to do with the use of sharp numbers, which are typically ineffective at capturing the subjective character of human thought and may, in actual circumstances, result in the approach failing to effectively reflect DMs' preferences. Since expert evaluations contain unclear or confusing information, standard TOPSIS cannot address it. This work uses the TOPSIS method and fuzzy logic to address this shortcoming. Fuzzy TOPSIS method has been developed and conducted in many applications like renewable energy and Landfill site selection (Sengul et al. 2015; Beskese et al. 2015), reliability and risk evaluation in process industry (Gopal and Panchal, 2021), Modeling performance assessment for managing transportation businesses (Dimitriou and Sartzetaki, 2022), Optimizing investment decision making (Cao and Xu, 2022) to name a few. In this paper, the rating of criteria and corresponding weights are considered as linguistic variables, as shown in Figures 1 and 2 respectively.

Suppose that k DMs have presented trapezoidal fuzzy numbers both for rating and importance weights of criteria. And k = 1, 2…, K. Then the aggregated fuzzy rating can be considered as;

$$R = (a, b, c, d),\ \text{k = 1, 2…, K} \tag{1}$$

Where

$$a = \min_k\{a_k\},\quad b = \frac{1}{k}\sum_{k=1}^{k} b_k,\quad c = \frac{1}{k}\sum_{k=1}^{k} c_k,\quad d = \max_k\{d_k\}$$

By applying Eq. (3) the aggregated fuzzy weights (w_j) for each criterion, C = {C1, C2…Cn}, and also the aggregated fuzzy rating (x_{ij}) of suppliers, A = {A1, A2…Am}, regarding each criterion can be computed. As presented a supplier selection problem is formed by arranging columns of alternatives with rows of criteria as shown below:

$$D = \begin{bmatrix} x_{11} & x_{12} & \cdots\cdots & x_{1n} \\ x_{21} & x_{22} & \cdots\cdots & x_{2n} \\ \cdot & \cdot & \cdots\cdots & \cdot \\ \cdot & \cdot & \cdots\cdots & \cdot \\ x_{m1} & x_{m2} & \cdots\cdots & x_{mn} \end{bmatrix} \tag{2}$$

From the Eq. (4) the normalized fuzzy decision matrix can be calculated as;

$$R = \left[r_{ij} \right]_{m\times n}, \tag{3}$$

In this matrix, transformation formulae for benefit criteria and cost criteria are the following, respectively. B and C are the sets of benefit and cost criteria.

$$r_{ij} = \left(\frac{a_{ij}}{d_j^*},\ \frac{b_{ij}}{d_j^*},\ \frac{c_{ij}}{d_j^*},\ \frac{d_{ij}}{d_j^*} \right), j \in B, \tag{4a}$$

$$r_{ij} = \left(\frac{a_j^-}{d_{ij}},\ \frac{a_j^-}{c_{ij}},\ \frac{a_j^-}{b_{ij}},\ \frac{a_j^-}{a_{ij}} \right), j \in C, \tag{4b}$$

where

$$d_j^* = \max_i d_{ij},\ j \in B$$

$$a_j^- = \max_i a_{ij},\ j \in C$$

Now based on normalized fuzzy matrix the Weighted normalized fuzzy decision matrix can be calculated as;

$$V = \left[v_{ij} \right]_{m\times n}\ i = 1,2,\ldots,m,\ j = 1,2,\ldots,n, \tag{5}$$

Where $v_{ij} = r_{ij}(.)w_j$.

Fuzzy positive and negative ideal solutions can be constructed as;

$$A^* = \{(\max_j v_{ij} | i \in B), (\min_j v_{ij} | i \in C) | i = 1,2,\ldots\ldots, n\} \tag{6}$$

$$A^- = \{(\min_j v_{ij} | i \in B), (\max_j v_{ij} | i \in C) | i = 1,2,\ldots\ldots, m\} \tag{7}$$

The closeness coefficient of all suppliers to positive and negative ideal solution can be described as;

$$CC_i = \frac{d_i^-}{d_i^* + d_i^-},\ i = 1,2,\ldots,m, \tag{8}$$

Where the d_i^- is the distance between each alternative and fuzzy negative ideal solution and d_i^* is distance between alternative and fuzzy positive ideal solution.

4. Case Study, Model Description and Results

The problem of supplier selection in many industries leads to a global decision-making challenge that require considerable attention and control. In this article we proposed to evaluate and optimize the suppliers in a dairy company in Iran. The study is presented in a two-stage evaluation model that evaluates suppliers and provides the best quantity that should be ordered to the suppliers. In the first stage, suppliers are evaluated based on five criteria and then based on TOPSIS scores (which are the inputs to the 2nd stage). Suppliers were reconsidered in the LP model based on different constraints including demand, density qualification, acidity qualification, price, and capacity. The criteria are identified from the literature review as presented earlier. In addition, to purchase the optimized quantity of dry milk as a main material for dairy products, an LP has been developed model to determine the solution. In order to choose the best supplier from the five prospective alternative suppliers, a selection committee made up of three DMs has been constituted. DM1 (D_1) is a 10-year experienced production manager and worked in dairy and food sectors. D_2 is quality manager and technician in milk quality control department. Finally, D_3 is director of logistic and purchase department and has more than 20 years of experience in food logistics. Five criteria are considered as: Quality (C_1), Price (C_2), Performance history (C_3), Management & organizations (C_4) and Production capacity & facilities (C_5). The decision-making problem has a hierarchical structure, as shown in Figure 3, which can be described in more detail using the following stages and steps:

Stage A:

Step 1: Three DMs used the linguistic elements of Table 1 to express their opinions. Table 2 presents the opinions for assessing the weights of the criteria.

Table 1. The linguistic variables used for criteria weights with the associated fuzzy numbers

Linguistic Variable	Fuzzy Number
Very low (VL)	(0, 0, 0.1, 0.2)
Low (L)	(0.1, 0.2, 0.3, 0.4)
Moderately low (ML)	(0.3, 0.4, 0.4, 0.5)
Moderate (M)	(0.4, 0.5, 0.6, 0.7)
Moderately high (MH)	(0.6, 0.7, 0.7, 0.8)
High (H)	(0.7, 0.8, 0.8, 0.9)
Very high (VH)	(0.8, 0.9, 1, 1)

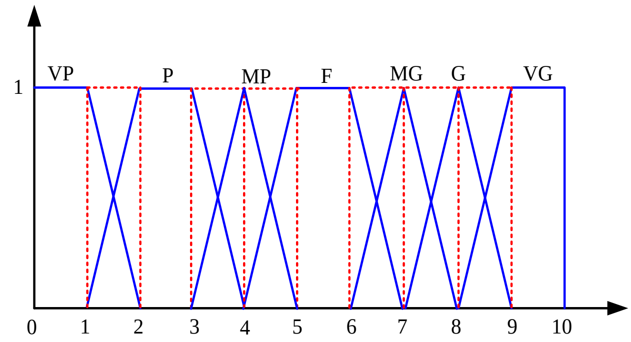


Figure 1. Linguistic variables for rating

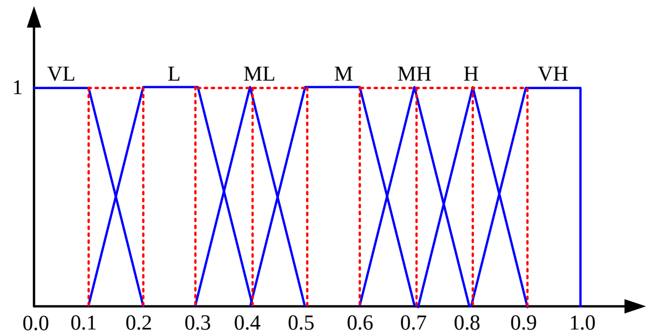


Figure 2. Linguistic variables for weights

Table 2. Criteria weights given by the DMs

	D_1	D_2	D_3
C_1	VH	H	VH
C_2	H	H	VH
C_3	H	H	H
C_4	MH	MH	H
C_5	H	VH	H

Step 2: As illustrated in Table 4, the three DMs also expressed their opinions regarding the suppliers using linguistic variables. Based on Table 3, trapezoidal linguistic variables are converted to associated fuzzy numbers to evaluate the rating of alternative suppliers regarding the considered criteria, as also shown in Table 5. This table also shows the converted fuzzy numbers (as determined using Table 1) for estimating criteria weights.

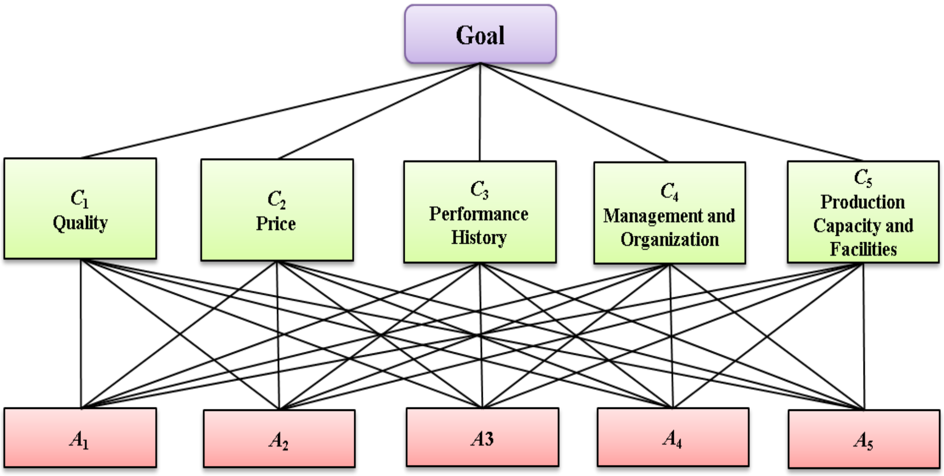


Figure 3. Hierarchical structure of the decision problem

Table 3. Linguistic variables for the performance scores and associated fuzzy numbers

Linguistic Variable	Fuzzy Number
Very poor (VP)	(0, 0, 1, 2)
Poor (P)	(1, 2, 3, 4)
Moderately poor (MP)	(3, 4, 4, 5)
Fair (F)	(4, 5, 6, 7)
Moderately good (MG)	(6, 7, 7, 8)
Good (G)	(7, 8, 8, 9)
Very good (VG)	(8, 9, 10, 10)

Table 4. Rating of five alternative suppliers with respect to five criteria

Criteria	Supplier	DMs		
		D_1	D_2	D_3
C_1	A_1	VG	G	VG
	A_2	G	G	G
	A_3	G	MG	G
	A_4	MG	G	G
	A_5	VG	VG	VG
C_2	A_1	MG	MG	G
	A_2	G	MG	MG
	A_3	G	G	G
	A_4	VG	G	VG
	A_5	G	VG	G
C_3	A_1	MG	MG	G
	A_2	MG	G	MG
	A_3	G	G	G
	A_4	VG	VG	G
	A_5	G	VG	G
C_4	A_1	MG	MG	MG
	A_2	G	G	G
	A_3	G	G	VG

	A_4	VG	VG	G
	A_5	VG	G	G
C_5	A_1	MG	MG	VG
	A_2	MG	MG	G
	A_3	G	G	MG
	A_4	VG	G	G
	A_5	G	VG	MG

Step 3: Normalized fuzzy decision matrix, as shown in Table 6, is formed using the values of fuzzy decision matrix of Table 5. The weighted normalized fuzzy decision matrix is also calculated, as presented in Table 7.

Step 4: FNIS and FPIS are determined as:

$A^* = [(1,1,1,1),(1,1,1,1),(0.9,0.9,0.9,0.9),(0.9,0.9,0.9,0.9),(1,1,1,1)]$
$A^- =[(0.42,0.42,0.42,0.42),(0.42,0.42,0.42,0.42),(0.42,0.42,0.42,0.42),$
$(0.36,0.36,0.36,0.36),(0.42,0.42,0.42,0.42)]$

Table 5. Fuzzy decision matrix and fuzzy weights

	C_1	C_2	C_3	C_4	C_5
A_1	(6,8,8.3,9)	(6,7.3,7.3,9)	(6,7.3,7.3,9)	(6,7,7,8)	(6,7.7,8,10)
A_2	(7,8,8,9)	(6,7.3,7.3,9)	(6,7.3,7.3,9)	(7,8,8,9)	(6,7.3,7.3,9)
A_3	(6,7.7,7.7,9)	(7,8,8,9)	(7,8,8,9)	(7,8.3,8.7,10)	(6,7.7,7.7,9)
A_4	(6,7.7,7.7,9)	(6,8,8.3,9)	(6,8,8.3,9)	(6,8,8.3,9)	(7,8.3,8.7,10)
A_5	(8,9,10,10)	(7,8.3,8.7,10)	(7,8.3,8.7,10)	(7,8.3,8.7,10)	(6,8,8.3,10)
Weight	(0.7,0.6,0.93,1)	(0.7,0.83,0.87,1)	(0.7,0.8,0.8,0.9)	(0.6,0.73,0.73,0.9)	(0.7,0.83,0.87,1)

Table 6. Normalized fuzzy decision matrix

	C_1	C_2	C_3	C_4	C_5
A_1	(0.6,0.8,0.83,0.9)	(0.6,0.73,0.73,0.9)	(0.6,0.73,0.73,0.9)	(0.6,0.7,0.7,0.8)	(0.6,0.77,0.8,1)
A_2	(0.7,0.8,0.8,0.9)	(0.6,0.73,0.73,0.9)	(0.6,0.73,0.73,0.9)	(0.7,0.8,0.8,0.9)	(0.6,0.73,0.73,0.9)
A_3	(0.6,0.77,0.77,0.9)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.7,0.83,0.87,1)	(0.6,0.77,0.77,0.9)
A_4	(0.6,0.77,0.77,0.9)	(0.6,0.8,0.83,0.9)	(0.6,0.8,0.83,0.9)	(0.6,0.8,0.83,0.9)	(0.7,0.83,0.87,1)
A_5	(0.8,0.9,1,1)	(0.7,0.83,0.87,1)	(0.7,0.83,0.87,1)	(0.7,0.83,0.87,1)	(0.6,0.8,0.83,1)

Table 7. Weighted normalized fuzzy decision matrix

	C_1	C_2	C_3	C_4	C_5
A_1	(0.42,0.48,0.77,0.9)	(0.42,0.6,0.63,0.9)	(0.42,0.58,0.58,0.81)	(0.36,0.51,0.51,0.72)	(0.42,0.64,0.7,1)
A_2	(0.49,0.48,0.74,0.9)	(0.42,0.6,0.63,0.9)	(0.42,0.58,0.58,0.81)	(0.42,0.58,0.58,0.81)	(0.42,0.6,0.63,0.9)
A_3	(0.42,0.46,0.72,0.9)	(0.49,0.66,0.7,0.9)	(0.49,0.64,0.64,0.81)	(0.42,0.6,0.63,0.9)	(0.42,0.64,0.67,0.9)
A_4	(0.42,0.46,0.72,0.9)	(0.42,0.66,0.72,0.9)	(0.42,0.64,0.66,0.81)	(0.36,0.58,0.6,0.81)	(0.49,0.69,0.76,1)
A_5	(0.56,0.54,0.93,1)	(0.49,0.69,0.76,1)	(0.49,0.66,0.7,0.9)	(0.42,0.6,0.63,0.9)	(0.42,0.66,0.72,1)

Step 5: Vertex method is used to calculate the distance of suppliers from FPIS and FNIS. Tables 8 and 9 are the results of vertex method calculations.

Step 6: The closeness coefficient of suppliers is computed in Table 10. These scores are used as coefficients for objective function of the mathematical problem:

$CC_1 = 0.414$, $CC_2 = 0.42$, $CC_3 = 0.456$, $CC_4 = 0.457$, $CC_5 = 0.521$

Table 8. Distance between FPIS and supplier rating

	C_1	C_2	C_3	C_4	C_5
$d(A_1,A^*)$	0.408	0.401	0.333	0.396	0.373
$d(A_2,A^*)$	0.39	0.401	0.333	0.333	0.401
$d(A_3,A^*)$	0.423	0.345	0.279	0.314	0.382
$d(A_4,A^*)$	0.423	0.368	0.302	0.351	0.322
$d(A_5,A^*)$	0.32	0.322	0.281	0.314	0.364

Table 9. Distance between FNIS and supplier rating

	C_1	C_2	C_3	C_4	C_5
$d(A_1,A^-)$	0.299	0.277	0.225	0.209	0.34
$d(A_2,A^-)$	0.292	0.277	0.225	0.275	0.277
$d(A_3,A^-)$	0.284	0.305	0.252	0.326	0.292
$d(A_4,A^-)$	0.284	0.307	0.254	0.278	0.364
$d(A_5,A^-)$	0.397	0.364	0.305	0.326	0.348

Table 10. Computation of d_i^*, d_i^- and CC_i

	d^-	d^*	$d^- + d^*$	CC_i
A_1	1.35	1.911	3.261	0.414
A_2	1.346	1.858	3.204	0.420
A_3	1.459	1.743	3.202	0.456
A_4	1.487	1.766	3.253	0.457
A_5	1.74	1.601	3.341	0.521

Table 11. The model parameters

X_i	Order quantity of dry milk for i^{th} supplier	p_i	Unit price of i^{th} supplier
D	Demand (30000 kg in model)	P	Determined unit price respect to budget (7.5 thousand in model)
CC_i	TOPSIS score of ith suppliers	C_i	Capacity of delivery of i^{th} supplier
d_i	Density of dry milk for i^{th} supplier		
a_i	Acidity percentile in dry milk of i^{th} supplier		
A	Company acceptance limit for Acidity of dry milk (15 in model)		
B	Company acceptance limit for density of dry milk (38 in model)		

Stage B:

After having the closeness coefficients of Table 10 and according to the model parameters as shown in Table 11, the best order quantity is attained in Stage B by maximizing the total value of purchasing (Z). An integrated LP model is formed as follows:

Objective function:

$$Max(Z) = \sum_{i=1}^{n} CC_i X_i$$

Subject to:

$\sum_{i=1}^{n} X_i = D$ (Demand constraint)

$\sum_{i=1}^{n} X_i\, d_i \leq BD$ (Density Qualification constraint)

$\sum_{i=1}^{n} X_i\, a_i \leq AD$ (Acidity Qualification constraint)

$\sum_{i=1}^{n} X_i\, p_i \leq PD$ (Price constraint)

$X_i \leq C_i$ (Capacity of suppliers' constraint)

$X_i \geq 0, i = 1,2,\ldots,n$ (Non-negativity of variables)

$Max(Z) = 0.414X_1 + 0.42X_2 + 0.456X_3 + 0.457X_4 + 0.521X_5$

Subject to:

$X_1 + X_2 + X_3 + X_4 + X_5 = 30000$

$36X_1 + 38X_2 + 37.5X_3 + 39X_4 + 41X_5 = 1140000$

$13.1X_1 + 14.4X_2 + 12.5X_3 + 16X_4 + 12.8X_5 = 450000$

$6.9X_1 + 7.2X_2 + 7X_3 + 7.8X_4 + 8X_5 = 225000$

$X_1 \leq 8000$

$X_2 \leq 9000$

$X_3 \leq 5000$

$X_4 \leq 8000$

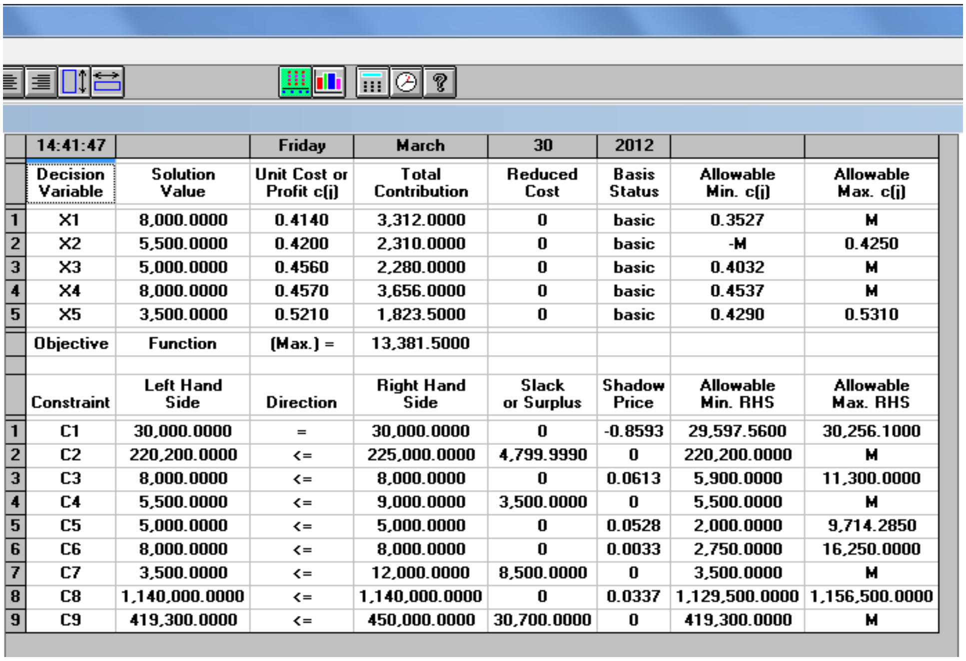
$X_5 \leq 12000$

$X_i \geq 0, i = 1,2,3,4,5$

The model is solved by WIN QSB software for more accurate and precise results, as shown in Fig 4. The optimized amount of order from each supplier are as follows:

$X_1 = 8000,\ X_2 = 5500,\ X_3 = 5000,\ X_4 = 8000,\ X_5 = 3500, Z = 13381.50$

In the similar manner, supplier A1 and supplier A4 needs to deliver to the company the 8000 kg of dry milk, while supplier A5 just provides 3500 kg. The total cost for each period of order will be almost 13381.50 thousand. It is seen a supplier selection problem has been formulated and then the optimal quantity of order divided by each supplier has been assigned to them. The planning department presents this plan to the financial department and one copy to each supplier for further operations.



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Decision Variable	Solution Value	Unit Cost or Profit c(j)	Total Contribution	Reduced Cost	Basis Status	Allowable Min. c(j)	Allowable Max. c(j)
X1	8,000.0000	0.4140	3,312.0000	0	basic	0.3527	M
X2	5,500.0000	0.4200	2,310.0000	0	basic	-M	0.4250
X3	5,000.0000	0.4560	2,280.0000	0	basic	0.4032	M
X4	8,000.0000	0.4570	3,656.0000	0	basic	0.4537	M
X5	3,500.0000	0.5210	1,823.5000	0	basic	0.4290	0.5310
Objective	Function	(Max.) =	13,381.5000				
Constraint	Left Hand Side	Direction	Right Hand Side	Slack or Surplus	Shadow Price	Allowable Min. RHS	Allowable Max. RHS
C1	30,000.0000	=	30,000.0000	0	-0.8593	29,597.5600	30,256.1000
C2	220,200.0000	<=	225,000.0000	4,799.9990	0	220,200.0000	M
C3	8,000.0000	<=	8,000.0000	0	0.0613	5,900.0000	11,300.0000
C4	5,500.0000	<=	9,000.0000	3,500.0000	0	5,500.0000	M
C5	5,000.0000	<=	5,000.0000	0	0.0528	2,000.0000	9,714.2850
C6	8,000.0000	<=	8,000.0000	0	0.0033	2,750.0000	16,250.0000
C7	3,500.0000	<=	12,000.0000	8,500.0000	0	3,500.0000	M
C8	1,140,000.0000	<=	1,140,000.0000	0	0.0337	1,129,500.0000	1,156,500.0000
C9	419,300.0000	<=	450,000.0000	30,700.0000	0	419,300.0000	M

Figure 4. Model solution in WIN QSB

5. Managerial Implications:

Results of this research work has been communicated to the SC manager of the company to put them into practice for further validation. The manager demonstrated keen interest in the outcomes and stated that once the top management decided to apply the outcomes, the efficacy of the suggested framework could be further investigated. The following suggestions were also made to the SCM department:

- To analyze the system dynamics of the entire SCM after implementing the results.
- To take into account the ambiguities and fuzziness related to raw data by utilizing a fuzzy-based models as adopted in this work.

6. Conclusions

Supplier selection problem is a strategic operation in production sector, especially when the products are connected with food, dairy and mineral water areas. This study investigates the problem of supplier evaluation in a dairy production factory and utilizes a two-stage model. In order to deal with uncertainty, Fuzzy method helps organizations to tackle complicated decision problems even when they lack information and decision structure is not well defined. A problem of supplier selection in a dairy company was defined and a fuzzy TOPSIS model identified the most important suppliers with the relevant performance score. Then a linear programming model has been designed to obtain efficient order quantity for each supplier. The model solved the model with software and reported to the manager of purchasing department. It has been realized that fuzzy decision-making techniques are effectively implemented in such kind of problems to help operation and purchasing managers in practice. During the data elaboration, participants and managers with various expertise participated and helped us to have better understanding of supplier performance. The idea this study is to deliver potential supplier and inform managers to construct a visionary scale toward supplier problem and improve SC efficiency. The single objective nature of the proposed model is one of its drawbacks; however, challenges with supplier selection and order allocation can also have multiple objectives, such as minimizing the defect rate and maximizing demand, which can also be incorporated into the model. Additional models can be developed to take environmental and social criteria into account in order to address sustainability standards including situations where it is possible to quantify the pollution or carbon emissions that each product causes. The developed model can be easily implemented with the necessary and few alterations to other food supply sectors as well. This work can also be further extended by considering other MCDM methods like MABAC, CoCoSo including rough set theories and D numbers.

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