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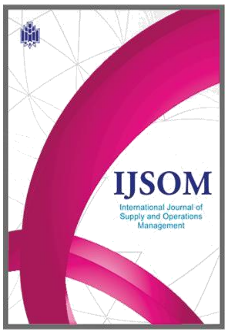

Fuzzy TOPSIS and Grey Relation Analysis Integration for Supplier Selection in Fiber Industry

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Abstract

In the present work, selection of right corrugated box supplier for fibre industry is studied. Decision makers independently evaluate the supplier's strength for both qualitative (quality, reliability, flexibility, stability, capability, and availability) and quantitative (order volume, price, delivery, credit period and location) criteria's with conflict in nature. Inappropriate choice of supplier by traditional approach could result in financial losses. Hybrid approach (Fuzzy TOPSIS and Grey relational analysis *GRA*) is proposed to select the right corrugated box supplier from the pool of suppliers for Fiber industry located in Goa, India. Fuzzy TOPSIS method is applied to evaluate the qualitative criteria, whereas, GRA for quantitative criteria's for selecting the best supplier. Considering the ranks obtained from both the qualitative and quantitative criteria's evaluated by Fuzzy TOPSIS and GRA, the best supplier is selected. In addition, sensitivity analysis is performed to know the changes in rank of suppliers with variation in preferential weights assigned to qualitative and quantitative criterion.

Keywords: Supplier selection; Multi Criteria Decision Making; Fuzzy TOPSIS; Grey Relation Analysis; Sensitivity Analysis.

1. Introduction

Survival of organization is merely dependent on adaptability to change with respect to technological advances, fierce competition in markets and business environments across globe [Markabi et al (2014)]. Thereby, effective handling of complex operations and associated management in an uncertain environment is a tedious task for any business organization, not only to survive, but being competitive in world market [Kogan et al. (2007)]. Supply chain plays major role to make organization capable to adapt changes with regard to uncertain future. Supply chain encompasses series of activities right from supplier process to the end customer product (i.e. information flow starting from raw material to final finished product) application [Sandeep et al. (2011)]. The cost of raw materials in many manufacturing firms accounts as high as 70% of total product cost [Setak et al. (2012)]. Therefore, raw material supplier selection has competitive edge over product cost, quality and customer satisfaction. Note that, supplier who supply best quality raw material at reduced cost offers competitive edge over other firms, which help the organization to remain competitive in global market [Patil (2014), Ghodsypour et al. (2001)]. Traditional methods such as try-error-method, and experts' judgement are often found inefficient for selecting suppliers, where there is increased complexity of operations and strategic importance.

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Growing era in supply chain also bought increased complexity in operations and strategic decisions to evaluate suppliers with multiple criteria's [Liao et al. (2011)]. Selection of right supplier from various alternatives and multiple criteria (qualitative and quantitative) are treated as MCDM problem. In 1966, Dickson reported that there are about 23 different criteria (cost, quality, service, delivery, geographical location, financial position and credit rating, production capacity, business history, technical capability, future purchases, communication system, operational controls, position in the industry, attitude, labor relations, desire, warranties and claim policy, packaging requirements, relationships, training aids, management and organization, compliance and performance history) essential for supplier selection [Dickson (1966)]. Analysis of criteria's with preference to evaluate the supplier performance and acceptable solutions play a vital role in decision making against the supplier selection problem. There are different methodologies applied to solve the supplier selection problem such as, multi attribute decision making (analytic hierarchy approach *AHP*, VIKOR, Technique for order preference by similarity to ideal solution *TOPSIS*, Preference ranking organization method for enrichment evaluation *PROMETHEE*, decision making trial and evolution laboratory *DEMATEL*, etc.), mathematical programming (goal, stochastic, linear, non-linear and multi-objective programming, data envelopment analysis etc.), probabilistic approach, artificial intelligent approach (soft computing algorithms, neural networks, decision theory and so on), hybrid approach and others [Chai et al. (2013)].

MCDM methods are widely applied to determine acceptable solutions by evaluating different criteria's. Multicriteria optimization and compromise solution approaches such as AHP and VIKHOR are applied to evaluate the effectiveness of selection of sustainable suppliers in supply chains [Luthra et al. (2017a)]. Analytical hierarchy method has been used to for green supplier selection in automotive manufacturing firms [Yu et al. (2016)]. PROMETHEE approach rank the green suppliers for the problems associated to food supply chain [Govindan et al. (2017)]. Fuzzy TOPSIS method applied to examine and select the best supplier for detergent powder production industry [Roshandel et al. (2013)]. DEMATEL methodology was successfully applied for risk analysis in shipbuilding industry and sustainable consumption and production in supply chain management [Luthra et al. (2017b), Seker et al. (2017)]. AHP (to determine the preference for criteria) and TOPSIS (to rank suppliers) methods are used to select the potential and sustainable suppliers to Iran steel industries [Azimifard et al. (2018)]. The optimization model based on data envelopment analysis was applied to evaluate the efficacy and productivity of potential suppliers under uncertain conditions [Azadi et al. (2015)]. Three methods such as DEMATEL, AHP and TOPSIS are applied to improve the efficiency of food supply chain management [Ortiz-Barrios et al. (2020)]. Recently DEA model was proposed to estimate the optimistic, pessimistic and efficacy of supply chain management in presence of big data (datasets which are complex and huge) [Badiezadeh et al. (2018)]. Mathematical programming method was proposed to select the green supplier and disassembly of products to solve the logistic network problem [Ghayebloo et al. (2015)]. The multi-objective mathematical programming method is applied to estimate the material flow under dynamic consecutive time segments in a closed loop supply chain network considering suppliers and remanufacturer subcontractors [Ghassemi et al. (2018)]. Neural network tools were tested to evaluate the cost parameters that assist supply chain manager related to decision on inventory [Borade et al. (2011)]. The dynamic tabu search metaheuristic algorithm was developed to optimize the inventory management policies in supply chain management [Argilaguet Montarelo et al. (2017)]. Soft computation tools (fuzzy logic, neural networks and genetic algorithms) are successfully applied to improve the effectiveness and efficiency of key aspects (i.e. customer service levels and reduction of operational cost) in supply chain management [Ko et al. (2010)]. Soft computing approach are applied to evaluate the suppliers considering the cost management, quality implementation and company size [Carrera et al. (2020)]. The above literature on different decision-making methodologies proved their potential in evaluating suppliers to solve various problems associated to supply chain management in industries.

Rapid growth in supply chain with increased complexity of operations, data sets and strategic importance led decision making analysis become more complex and unpredictable. Supplier selection in decision process requires evaluation of the following stages [Chai et al. (2020)], collecting information of suppliers, selecting or shortlisting the suppliers, developing attributes, form group composed of qualified decision makers, determining the preferences for each criterion, identify optimal solutions from alternatives. For many complex problems the decision on supplier selection process are breakdown to aforementioned stages and evaluated as separate task in each stage to find the optimal solution. Therefore, decision making techniques must be adopted at each stage to attain best solutions as input to the next, or final stage [Chai et al. (2016)]. Hybridization with the combination of different decision-making techniques to solve each stage, that rank suppliers to arrive potential solution. The solutions at each processing steps rely mainly on the relative importance (i.e. preference or weights) assigned by the experts. Hybrid decision making approaches are successfully applied to solve supplier selection process in inventory management [Argilaguet Montarelo et al. (2017)], shipbuilding industry [Seker et al. (2017)], Iron steel industry [Azimifard et al. (2018)], sustainable consumption and production in supply chain management [Luthra et al. (2017b)], food supply chain management [Ortiz-Barrios et al. (2020)] and detergent powder production industry [Roshandel et al. (2013)]. It is confirmed from the above literature that, successful hybridization methods ensure determining the quality suppliers for solving various industry problems related to supply chain management.

This paper proposes the case study conducted for the corrugated box supplier selection for fiber industry located in Goa, India for evaluation. To evaluate the supplier selection the qualitative (quality, reliability, flexibility, stability, capability, and availability) and quantitative (order volume, price, delivery, credit period and location) criteria's are taken. Considering qualitative and quantitative criteria's finest approach suits for corrugated box supplier selection problem in fiber industry is the hybrid approach (Fuzzy TOPSIS and *GRA*). To solve the supplier selection problems in evaluating 11 criteria's with hybrid approach, Fuzzy TOPSIS method evaluates the qualitative criteria and GRA for quantitative criteria's. The Fuzzy TOPSIS and GRA determined composite scores obtained after evaluating the qualitative and quantitative criteria by assigning equal importance helps to rank the supplier for fiber industry. The structure of paper is as follows. **Section II** briefs methodology employed for supplier selection, **Section III** demonstrates the methodology of fuzzy TOPSIS and Grey Relation Analysis, **Section IV** discuss the results of Fuzzy TOPSIS and GRA for corrugated box supplier selection and **Section V** concludes the research study.

2. Supplier Selection Methodology

Supply chain management is the effective management consisting of series of activities, that are indeed essential to apprehend highest quality of product. Selecting the best raw material supplier for fiber industry play vital role in supply chain management. For selection, suppliers are evaluated based according to the decision makers defined criteria's. The proposed method considers decision makers group to select the best supplier among pool of suppliers. Decision maker group includes Unit Head, Purchase Manager, Production Head and Quality Inspector. Based on the year of experience, position headed and authority level, each decision maker is given weightage. Approach takes qualitative and quantitative criteria in consideration for making decision of best supplier. Qualitative criteria take account of criteria's which are non-measurable in nature, whereas quantitative comprises the measurable criteria's. Description on how the experts defined the qualitative and quantitative criteria's for supplier selection are presented in **Table 1** and **Table 2.**

Table 1. Description on experts defined qualitative criteria

Criteria	**Description**
Quality	Accountability of supplier for supplying product as per the required specification
Reliability	Reliability of supplier to maintain confidentiality related to product information
Flexibility	Flexibility of supplier meet change in quantity and delivery time with change in customer requirement
Stability	Financial stability of supplier and credit worthy
Capability	Capability to manage risks and orders according to the requirements
Availability	Availability to offer service and support as and when required

Table 2. Description on experts defined quantitative criteria

Criteria	**Description**
Price	Price defines in terms of profitability of an organization
Order quantity	Order quantity helps indirectly towards profit for an organization, as inventory reduces both storage space and handling cost. Just-in time approach can be employed where the supplier is close to organization.
Credit and delivery time	Credit and delivery time facilitate towards better financial planning.

The hybrid method integrates the fuzzy TOPSIS and GRA for corrugated box supplier selection process in Fiber industry. Fuzzy TOPSIS ranks supplier by evaluating qualitative criteria's, whereas GRA ranks supplier by evaluating quantitative criteria's. Score of supplier's are calculated using Fuzzy TOPSIS, and GRA is combined together after assigning appropriate weightage to qualitative and quantitative criteria's. Final composite score of supplier ranks assist the decision maker in selection of best supplier. Methodology adopted for supplier selection is summarized as follows;

Step 1: To purchase raw materials, form the decision makers group consisting of four members whose role is to evaluate suppliers against different criteria's. Note that, group of four members are chosen which are directly and indirectly accountable for best supplier selection.

Step 2: The weights are assigned to each decision makers based on their knowledge level, experience, job responsibility and authority level. Note that all the four members are assigned with different weights.

Step 3: Group meeting and brainstorming sessions are carried out to determine the criteria's essential for the evaluation of supplier. Once all the identified criteria's were agreed upon by decision makers, they were classified into two categories such as qualitative and quantitative.

Step 4: Later the importance or preference weights for each qualitative criteria's are decided based on decision makers input.

Step 5: Supplier quality audit was carried out to collect or gather information related to process, quality checks, infrastructure and machinery set-up. With the collected information each decision maker was allowed to evaluate the supplier.

Step 6: Fuzzy TOPSIS method was used to evaluate the supplier by determining the supplier score. The rank was decided for qualitative criteria based on each supplier score.

Step 7: Supplier quotations are evaluated based on the data related to price, order quantity, location, credit period and delivery time. GRA was applied to evaluate the quantitative criteria. The collected data sets are processed to determine the score and then rank, through the following steps such as normalization, determining deviation sequence, grey relational coefficient and grey relational grading.

Step 8: The scores achieved through qualitative and quantitative criteria was fused together to decide the final score and rank each supplier. Based on score the best supplier was selected from pool of supplier's.

3. Case Study

Fiber industry located at Goa, India, is considered as a case study which requires strategic decision to select the best supplier for corrugated box. The medium scale operating industry with the annual business of ten crore was selected to demonstrate the application. The primary business of an industry is to supply the pool filter enclosure for domestic and international clients. Rapid progress in global market, industry is continuously striving to give competitive edge by improving quality and reducing price. Packing was the major concern area where the improvement was needed at the cost of price. Therefore, Industry decided to select the best supplier with respect to corrugated boxes that meet the quality and price requirement. The best three suppliers are selected among the ten suppliers in Goa, to demonstrate the effectiveness of the case study.

Total eleven criteria's (quality, reliability, flexibility, stability, capability, availability, price, order quantity, location credit period and delivery time) are selected to evaluate the suppliers based on the stakeholder opinion and recent literature [Govindan et al. (2017), Chai et al. (2013), Chai et al. (2020), Yu et al. (2016), Azimifard et al. (2018)]. Four decision makers (DM 1, DM 2, DM 3, and DM 4) opinion is taken into account to select the best supplier among the potential three suppliers. Decision makers are stakeholder of supply chain management. Decision maker group includes Unit Head, Purchase Manager, Production Head and Quality Inspector. Fuzzy TOPIS method rank the supplier for qualitative criteria's (quality, reliability, flexibility, stability, capability and availability). GRA rank the supplier by evaluating quantitative criteria (price, order quantity, location, credit period and delivery time). The composite score of the supplier is determined by pooling both qualitative and quantitative criteria together to establish final ranking. The hierarchy of supplier selection problem is shown in Figure 1.

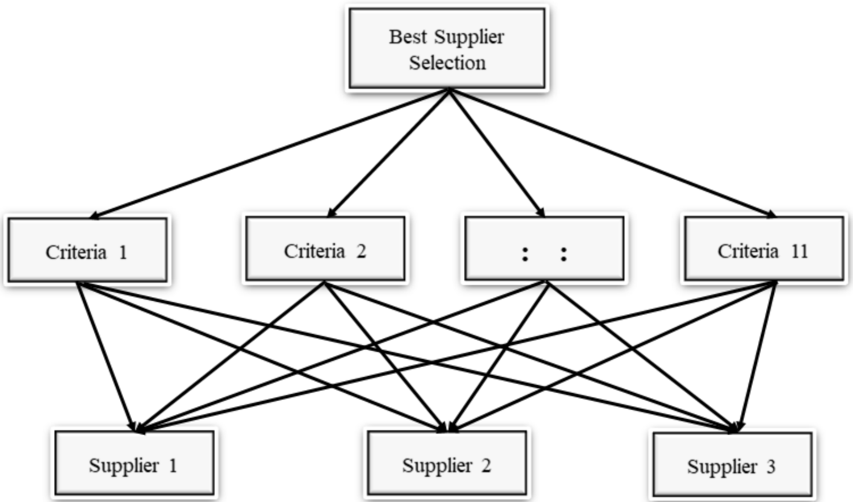

Figure 1. Hierarchy structure for Supplier Selection.

3.1. Ranking Suppliers for Qualitative Criteria by Fuzzy TOPSIS

Chen et al. 1992, proposed the MCDM methods to determine solutions from the set of many alternatives [Chen & Hwang, 1992]. TOPSIS method is developed with the well-defined logic in determining positive and negative ideal solutions. The alternatives supposed to be evaluated are compared with those of ideal positive and negative solutions to determine the distances, and in turn score. Note that, the optimal solution lies nearest to positive ideal and farthest to negative ideal solution. Fuzzy concepts are integrated in to TOPSIS, wherein the fuzzy concepts transform the linguistic terms to quantifiable numbers. These numbers with decision makers preferences are the basic inputs for evaluating suppliers.

The computational steps in Fuzzy TOPSIS method applied to solve supplier selection problem is discussed below,

Step 1: Table 3 presents the linguistic variable with different scale of importance used by decision makers (DM 1, DM 2, DM 3, DM 4) to evaluate the qualitative criteria for supplier selection. The decision makers (DM 1, DM 2, DM 3 and DM 4) judgement are based on the assigned importance with reference to their experience, decision making authority and designation. DM 1 is designated as unit head of the organization, having higher authority and experience and hence given highest weightage (7, 9, 9). DM 2 is the purchase manger having considerable authority, but possess less experience compared to DM 3 (i.e. production manager) and hence they were assigned with the weightage of (5, 7, 9) and (3, 5, 7), respectively. DM4 is quality checker and assigned with less weightage of (1, 1, 3). Weights of decision makers are shown in Table 4. Decision maker's linguistic expression is converted into weights as shown in Table 2. Conversion gives aggregated weight to each criterion

Table 3. Linguistic term for decision maker and criteria

Linguistic Scale	Fuzzy Number	Triangular fuzzy number
Equally Important/Very Low	EI	(1, 1, 3)
Weakly Important/Low	WI	(1, 3, 5)
Strong Important/Medium	SI	(3, 5, 7)
Very Strong Important/High	VI	(5, 7, 9)
Immense Important/Very High	II	(7, 9, 9)

Table 4. Weighted aggregate of qualitative criteria

Criteria	DM 1	DM 2	DM 3	DM 4	Aggregated Weight of each criteria
	Weightage of each decision maker				
	(7, 9, 9)	**(5, 7, 9)**	**(3, 5, 7)**	**(1, 1, 3)**	
Quality	(7, 9, 9)	(7, 9, 9)	(5, 7, 9)	(7, 9, 9)	**(26.5, 47, 63)***
Reliability	(5, 7, 9)	(7, 9, 9)	(1, 3, 5)	(5, 7, 9)	(15, 29, 45)
Flexibility	(3, 5, 7)	(3, 5, 7)	(3, 5, 7)	(3, 5, 7)	(4, 16.5, 35)
Stability	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(18, 35.5, 58)
Capability	(3, 5, 7)	(3, 5, 7)	(3, 5, 7)	(3, 5, 7)	(4, 16.5, 35)
Availability	(1, 3, 5)	(1, 3, 5)	(1, 3, 5)	(1, 3, 5)	(4, 8, 24.5)
(26.5, 47, 63)*= (7 x 7 + 5 x 7 + 3 x 5 + 1 x 7)/4, (9 x 9 + 7 x 9 + 5 x 7 + 1 x 9)/4, (9 x 9 + 9 x 9 + 7 x 9 + 3 x 9)/4					

Step 2: Next step was to evaluate each supplier considering all qualitative criteria based on facilities, infrastructure, innovation practices, system, manpower etc. Decision makers audited supplier site independently, conducted meetings with supplier representative and based on their observation assigned weights to all criteria's of each supplier. Supplier evaluation considering all subjective parameters transferred to linguistic variables to rate suppliers for each criterion by decision makers is noted in Table 5.

Table 5. Supplier Evaluation based on Qualitative Criteria's

Criteria	Supplier	Decision Makers (DM)			
		DM 1 (7, 9, 9)	DM 2 (5, 7, 9)	DM 3 (3, 5, 7)	DM 4 (1, 1, 3)
Quality	S1	(1, 3, 5)	(1, 3, 5)	(3, 5, 7)	(3, 5, 7)
	S2	(3, 5, 7)	(1, 3, 5)	(3, 5, 7)	(3, 5, 7)
	S3	(3, 5, 7)	(3, 5, 7)	(5, 7, 9)	(3, 5, 7)
Reliability	S1	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)
	S2	(3, 5, 7)	(5, 7, 9)	(3, 5, 7)	(3, 5, 7)
	S3	(5, 7, 9)	(3, 5, 9)	(3, 5, 9)	(5, 7, 9)
Flexibility	S1	(1, 3, 5)	(1, 3, 5)	(1, 3, 5)	(3, 5, 7)
	S2	(3, 5, 7)	(3, 5, 7)	(1, 3, 5)	(3, 5, 7)
	S3	(1, 1, 3)	(1, 3, 5)	(1, 1, 3)	(1, 1, 3)
Stability	S1	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)
	S2	(3, 7, 9)	(5, 7, 9)	(5, 7, 9)	(3, 7, 9)
	S3	(3, 7, 9)	(3, 7, 9)	(3, 7, 9)	(3, 7, 9)
Capability	S1	(1, 1, 3)	(1, 3, 5)	(1, 3, 5)	(3, 5, 7)
	S2	(3, 5, 7)	(3, 5, 7)	(3, 5, 7)	(5, 7, 9)
	S3	(3, 5, 7)	(5, 7, 9)	(5, 7, 9)	(3, 5, 9)
Availability	S1	(3, 5, 7)	(3, 5, 7)	(1, 3, 5)	(3, 5, 7)
	S2	(1, 1, 3)	(1, 3, 5)	(1, 1, 3)	(1, 1, 3)
	S3	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)

Step 3: The linguistic variables presented in Table 4 and 5, are transformed to triangular fuzzy numbers to estimate the fuzzy weights for each criterion. These weights are assigned to each decision makers based on their knowledge level, experience, job responsibility and authority level. Note that all the four members are assigned with different

weights. Table 6 shows weightage of three suppliers based on decision maker evaluation. Weightage for each criterion is obtained considering decision makers weightage towards supplier selection process. Table 7 represents the criterion weightage taking into account importance of each criterion as decided by decision maker.

Table 6. Criterion Weightage

Criteria	Supplier S1	Supplier S2	Supplier S3
Quality	**(6, 19.5, 35)***	(9.5, 24, 37.5)	(13.5, 30, 45.5)
Reliability	(20, 38.5, 54)	(14.5, 31, 46.5)	(16, 32.5, 54)
Flexibility	(4.5, 17, 31.5)	(10.5, 25, 38.5)	(4, 9, 22.5)
Stability	(20, 38.5, 54)	(16, 38.5, 54)	(12, 38.5, 54)
Capability	(4.5, 12.5, 29)	(12.5, 28, 43.5)	(16, 33.5, 51.5)
Availability	(10.5, 25, 38.5)	(4, 9, 22.5)	(20, 38.5, 54)

(6, 19.5, 35)*= (7 x 1 + 5 x 1 + 3 x 3 + 1 x 3)/4, (9 x 3 + 7 x 3 + 5 x 5 + 1 x 5)/4, (9 x 5 + 9 x 5 + 7 x 7 + 3 x 7)/4. Table 6 values are computed based on the decision matrix of Table 5.

Table 7. Criterion Weightage based on importance

Criteria	Supplier S1	Supplier S2	Supplier S3
Quality	**(159, 916.5, 2205)***	(251.75, 1128, 2362.5)	(357.75, 1410, 2866.5)
Reliability	(300, 1116.5, 2430)	(217.5, 899, 2092.5)	(240, 942.5, 2430)
Flexibility	(18, 280.5, 1102.5)	(42, 412.5, 1347.5)	(16, 148.5, 787.5)
Stability	(360, 1366.75, 3132)	(288, 1366.75, 3132)	(216, 1366.75, 3132)
Capability	(18, 206.25, 1015)	(50, 462, 1522.5)	(64, 552.75, 1802.5)
Availability	(42, 200, 943.25)	(16, 72, 551.25)	(80, 308, 1323)

(159, 916.5, 2205)*= (6 x 26.5, 19.5 x 47, 35 x 63), Table 7 values are computed based on Table 6 and Table 4. X_{max} and X_{min} = 3132 and 16.

Step 4: Table 7 data sets of fuzzy decision matrix are used to construct the normalized fuzzy-decision matrix. The normalized values lie within the ranges between zero and one using Eq. 1 (refer Table 8). X_i be the value to be normalized, X_{max} and X_{min} corresponds to maximum and minimum value in the decision matrix

$$Normalization\ [0,1] = \left(\frac{(X_i - X_{min})}{(X_{max} - X_{min})}\right) \quad (1)$$

Table 8. Normalized Criteria Weightage

Criteria	Supplier S1	Supplier S2	Supplier S3
Quality	**(0.05, 0.29, 0.7)***	(0.08, 0.36, 0.75)	(0.11, 0.45, 0.91)
Reliability	(0.09, 0.35, 0.77)	(0.06, 0.28, 0.66)	(0.07, 0.3, 0.77)
Flexibility	(0, 0.08, 0.35)	(0.01, 0.13, 0.43)	(0, 0.04, 0.25)
Stability	(0.11, 0.43, 1)	(0.09, 0.43, 1)	(0.06, 0.43, 1)
Capability	(0, 0.06, 0.32)	(0.01, 0.14, 0.48)	(0.02, 0.17, 0.57)
Availability	(0.01, 0.06, 0.3)	(0, 0.02, 0.17)	(0.02, 0.09, 0.42)

(0.05, 0.29, 0.7)* = ((159-16)/(3132-16)), ((916.5-16)/(3132-16)), ((2205-16)/(3132-16))
Table 7 data sets are used to construct the Table 8.

Step 5: The distance from the fuzzy positive ideal solution (D_i^+) and fuzzy negative ideal solution (D_i^-) is determined. The fuzzy closeness coefficient (C_i) is determined using the Eq. 2 and their values are presented in Table 7.

$$C_i = \left(\frac{D_i^-}{D_i^- + D_i^+}\right) \quad (2)$$

Table 9. Closeness index and supplier score

Criteria	Supplier 1	Supplier 2	Supplier 3
D_i^+	**0.872***	0.866	0.853
D_i^-	0.393	0.404	0.450
C_i	**0.310***	0.318	0.345
Normalized C_i	**0.318***	0.327	0.355
Rank	3	2	1

Using Table 8: {((0.05 + 0.09 + 0 + 0.11 + 0 + 0.01)/6 = **0.043**)}, {((0.29 + 0.35 + 0.08 + 0.43 + 0.06 + 0.06)/6 = **0.211**)}, {((0.7 + 0.77 + 0.35 + 1.0 + 0.32 + 0.3)/6 = **0.573**)} = 1 – 0.043, 1-0.211, 1-0.573 = **0.96, 0.79, 0.43**
D_i^+= (0.96 + 0.79)/2 = 0.872
D_i^-= (0.21 + 0.57)/2 = 0.393
Using Eq. 2, **0.31* = (0.393/(0.393+0.872)), 0.318*** = (0.310 + 0.318 + 0.345)/0.310

Fuzzy TOPSIS based on normalize C_i value help to rank the suppliers for qualitative criteria. The highest value corresponds to normalized C_i of the supplier is designated with highest rank. Therefore, Fuzzy TOPSIS evaluated the qualitative criteria's rank the supplier in sequence as, Supplier 3: Rank 1, Supplier 2: Rank 2, and Supplier 3: Rank 3, respectively. After ranking suppliers based on qualitative criteria, the next step was to evaluate each supplier based on quantitative criteria.

3.2. Ranking Suppliers for Quantitative Criteria by Grey Relational Analysis (GRA)

In 1982, Deng propose the grey relational analysis defined based on combining the theories of system, space and control [Deng, 1982]. Grey relation analysis capture the correlations between reference factors and other factors in a system. GRA is applied to evaluate the supplier on quantitative criteria. The data gathered from the fiber industry is presented in Table 10. Criteria selected for quantitative analysis includes order volume, price, delivery time, credit period and location. All these criteria have direct or indirect impact on the cost of final product. Supplier Quotation facilitated the data collection.

Table 10. Quantitative Assessment of Suppliers

Supplier	Order Volume (Nos.)	Price (Rs.)	Delivery Time (Days)	Credit Period (Days)	Location (Kms)
S1	500	390	2	30	45
S2	1200	250	5	30	35
S3	200	450	3	15	45

Step 1: Normalize the collected data sets in Table 10. The data series are normalized using smaller-the-better (STB) response for order volume, price, delivery time and location, whereas, credit period was normalized using larger-the-better (LTB) response. Credit period offered by supplier gives financial flexibility and help for better planning. Longer credit period offers more advantage over shorter period. Normalized values are tabulated in Table 11. The formulae used for data normalization $Y_i^*(j)$ correspond to LTB is given below,

$$Y_i^*(j) = \left(\frac{Y_i(j) - Y_i(j)_{min}}{Y_i(j)_{max} - Y_i(j)_{min}}\right) \quad (3)$$

Data normalization correspond to STB quality characteristics is given in Eq. 4.

$$Y_i^*(j) = \left(\frac{Y_i(j)_{max} - Y_i(j)}{Y_i(j)_{max} - Y_i(j)_{min}}\right) \quad (4)$$

Terms, $Y_i(j)$be the value to be normalized, $Y_i(j)_{max}$ refers to maximum value of entity *J*, and $Y_i(j)_{min}$ be the minimum value of entity *J*.

Table 11. Normalized Value of Quantitative Assessment of Suppliers

Supplier	Order Volume	Price	Delivery	Credit Period	Location
S1	0.7	0.3	1	1	0
S2	0	1	0	1	1
S3	1	0	0.67	0	0

Step 2: Calculate the deviation value $\Delta_{o\,i}(j)$. The deviation value is the absolute value of difference between reference value (i.e. 1) and comparable values (i.e. Table values of 11) and computed values are presented in Table 12.

Table 12. Deviation Value of Quantitative Assessment of Suppliers

Supplier	Order Volume	Price	Delivery	Credit Period	Location
S1	0.3	0.7	0	0	1
S2	1	0	1	0	0
S3	0	1	0.33	1	1

Step 3: Calculate the grey relation coefficient $\gamma_{oi}(j)$ value using Eq. 5. Term ε refers to distinguished coefficient whose value vary in the ranges between 0 and 1. For the present work, ε = 0.5.

$$\gamma_{oi}(j) = \frac{\Delta min + \varepsilon \Delta max}{\Delta_{o\,i}(j) + \varepsilon \Delta max} \quad (5)$$

Sample calculation of grey relation coefficient γ values presented in Table 13 is shown below,

$\gamma_{o1}(1)$ = (0 + 0.5 x 1)/(0.3 + 0.5 x 1) = 0.625;

$\gamma_{o1}(2)$ = (0 + 0.5 x 1)/(1.0 + 0.5 x 1) = 0.333;

$\gamma_{o1}(3)$ = (0 + 0.5 x 1)/(0.0 + 0.5 x 1) = 1.000;

The computation of grey relational grading $\tau(j)$ value is done using Eq. 6. Term $W_i(j)$ be the weight correspond to each quantitative criterion. Equal weights (W = 0.2) are assigned to each criterion for calculating the grey relational grading.

$$\tau(j) = \sum_{j=1}^{n} (\gamma_{0i}(j) \times W_i(j)) \tag{6}$$

The calculation corresponds to grey relational grade τ, is shown below.

$\tau(1)$ = 0.625 x 0.2 + 0.417 x 0.2 + 1.0 x 0.2 + 1.0 x 0.2 + 0.333 x 0.2 = 0.675;

$\tau(2)$ = 0.333 x 0.2 + 1.0 x 0.2 + 0.333 x 0.2 + 1.0 x 0.2 + 1.000 x 0.2 = 0.733;

$\tau(3)$ = 1.0 x 0.2 + 0.333 x 0.2 + 0.602 x 0.2 + 0.333 x 0.2 + 0.333 x 0.2 = 0.386;

The normalized grey relational grading values are calculated using values of grey relational grading τ shown below,

0.376 = 0.675 / (0.675 + 0.733 + 0.386);

0.408 = 0.733 / (0.675 + 0.733 + 0.386);

0.215 = 0.386 / (0.675 + 0.733 + 0.386);

Table 13. Grey Relation coefficient, grey grade and normalization

Supplier	Order Volume γ_{o1}	Price γ_{o2}	Delivery γ_{o3}	Credit Period γ_{o4}	Location γ_{o5}	Grade τ	Normalization
S1	0.625	0.417	1	1	0.333	0.675	**0.376**
S2	0.333	1	0.333	1	1	0.733	**0.408**
S3	1	0.333	0.602	0.333	0.333	0.386	**0.215**

Table 13 data sets based on normalized values of grey relational grade score is used to rank the supplier. Note that, higher values of normalized grade score correspond to best supplier for quantitative criteria's. GRA evaluated quantitative criteria's rank the supplier in sequence as, Supplier 2: Rank 1, Supplier 1: Rank 2, and Supplier 3: Rank 3, respectively.

The primary goal of supplier chain management is to locate the optimal solutions by evaluating all criteria's which are of both qualitative and quantitative in nature. Fuzzy TOPSIS determine rank the supplier for qualitative criteria, whereas GRA rank the supplier for quantitative criterion. The hybrid approach combines the rank obtained to qualitative criteria and GRA determined rank for quantitative criteria to rank the suppliers considering 11 criteria's. The average values of Fuzzy TOPSIS and GRA ranking is computed for each supplier and are presented in Table 14. Note that, Supplier 2 resulted with highest value compared to Supplier 1 and Supplier 3 (Table 14). Therefore, Supplier 2 is recommended for fiber industry.

Table 14. Supplier ranking with equal importance to qualitative and quantitative criteria

Supplier	Fuzzy TOPIS Ranking	GRA Ranking	Total	Final Rank
S1	0.318	0.376	0.347	2
S2	0.327	0.408	0.367	1
S3	0.355	0.215	0.285	3

Sensitivity analysis is carried out by varying the preferential weights assigned to qualitative and quantitative criteria. Rank of the supplier remains unaltered, with the small change variation in importance of qualitative and quantitative criteria. Supplier rank changes only when the preferential weights to qualitative criteria is maintained above 0.9 (refer Table 15). This indicates the qualitative criteria is less sensitive (i.e. very reasonable variation), compared to quantitative criteria's. So, it is very important to evaluate supplier based on both criteria's and also to define importance to each criteria group for supplier selection.

Table 15. Sensitivity analysis for supplier ranking with different preferential weights to qualitative and quantitative criteria

Supplier	**Fuzzy TOPIS Rank**	**GRA Rank**	**Sensitivity analysis with different weight fractions (qualitative, quantitative)**								
			0.9, 0.1	**0.8, 0.2**	**0.7, 0.3**	**0.6, 0.4**	**0.5, 0.5**	**0.4, 0.6**	**0.3, 0.7**	**0.2, 0.8**	**0.1, 0.9**
S1	0.318	0.376	0.324	0.330	0.335	0.341	0.347	0.353	0.359	0.364	0.370
S2	0.327	**0.408**	0.335	**0.343**	**0.351**	**0.359**	**0.368**	**0.376**	**0.384**	**0.392**	**0.400**
S3	**0.355**	0.215	**0.341**	0.327	0.313	0.299	0.285	0.271	0.257	0.243	0.229
Rank	S3	S2	S3	S2	S2	S2	S2	S2	S2	S2	S2

4. Conclusion

Organization faces major challenge in the selection process of right supplier for raw materials. Right supplier selection process is considered as the critical decision-making activity, as it involves complex operations with various criteria's and requires strategic decision. The criteria's are qualitative (quality, reliability, flexibility, stability, capability, and availability) and quantitative (order volume, price, delivery, credit period and location) with conflict in nature. Evaluation of total 11 criteria's with conflict to one another for supplier selection is considered as tedious task for any organization. Hybridization with the combination of different decision-making techniques (Fuzzy TOPSIS, GRA) to solve each stage, that rank suppliers to arrive potential solution. Fuzzy TOPIS method enables decision maker to propose right supplier for qualitative criteria, whereas, GRA method evaluates quantitative criteria's to aid decision maker.

The hybrid (fuzzy TOPIS and GRA) method is used to select right corrugated box supplier for fiber industry in Goa. Decision maker involvement is considered as prime importance to select the best supplier. Prior to evaluation process, group of four decision makers (DM 1: Unit head, DM 2: Purchase Manager, DM 3: Production Head and DM 4: Quality Inspector) are formed based on year of experience, position headed and authority level. Decision makers are allowed to select the best supplier among the potential three suppliers selected from ten suppliers. Detailed quality audit was conducted by quality personal to get the right information of suppliers related to qualitative criteria. Triangular fuzzy number was used to find importance of qualitative criteria and also compare three suppliers' facilities. Supplier 3 is recommended by the Fuzzy TOPSIS method after evaluating all the qualitative criteria's. GRA method normalizes quantitative data based on smaller the better or larger the better response. Supplier Quotation assisted the data collection which are relevant to quantitative criteria. Supplier 2 is recommended for quantitative criteria evaluated by the GRA method. The hybrid approach (Fuzzy TOPSIS and GRA) score obtained by the fusion of qualitative and quantitative criteria considering equal importance could rank supplier in the order of S2, S1 and S3, respectively. Through sensitivity analysis, it was observed that rank of the supplier remains unaltered with the small change variation in importance (weights) of qualitative and quantitative criteria. Supplier rank changes only when the preferential weights to qualitative criteria is maintained above 0.9. Note that rank of supplier changes in the order of S2, S3 and S1, respectively. The integration of Fuzzy TOPIS and GRA methods solved effectively the corrugated box supplier selection problem raised in Fiber industries. The method will aid decision maker to select right supplier, considering all criteria's and available alternatives with simple mathematical steps. Thus, avoiding selection of wrong supplier that ultimately results in financial losses.

Conflict of Interest: The authors declare that there is no conflict of interest.

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