Fuzzy-AHP-TOPSIS: An integrated multi-criteria decision support system for supplier selection in Pakistan's textile industry

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Abstract
One of the most important tasks within supply chain procurement process is supplier selection. Supplier selection being a complex task usually identified as a multiple criteria decision making problem to develop the decision support system for supplier selection while dealing with supply chain management. This research paper aims to propose and apply a subjective approach using fuzzy logic to develop a new Fuzzy-AHP-TOPSIS based decision support system for supplier selection in a Pakistani textile industry. This research deals with the selection of cotton supplier by fuzzy soft computing approach integrated in to analytical hierarchy process (AHP). Then to get the optimal solution, we used Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). We first reviewed the literature to identify various criteria for supplier selection. All the criteria are discussed with the supply chain expert in the textile industry to shortlist the relevant criteria. The shortlisted criteria are then compared pair-wise for calculating the weights of each criterion by the textile company's procurement manager. The calculated weights are then further used to rank suppliers using TOPSIS. Consistency ratio is being calculated to nullify the bias within decision makers' mind. This new method improved the supply chain performance of the case company which may be employed by other textile companies for their supplier selection needs.

1. Introduction

Supplier selection (SS) plays an important part in enabling efficient production and timely delivery of products within any organizations' supply chain. Procurement represents approximately 80 percent of the overall cost of products in high tech industries [1]. According to [2], procurement is one of the major standalone cost in manufacturing for any company and is being reflected in the end product price which has a direct impact on customers. It has been identified that more than 60 % of an organizations' revenue generated through sales is being used for procurement [3]. Therefore, selecting an appropriate supplier is imperative for any manufacturing or even service industry if they need to achieve reduced cost of production, increased customer satisfaction and to have a competitive advantage [4]. The ever increasing demands of customers needs to be met by the organizations in today's competitive business environment and this makes them more than dependant on their suppliers as it directly impacts end product cost, timely delivery of product and demand management within supply chain management (SCM).

SS is a multi-criteria decision making problem (MCDM) involving both qualitative and quantitative criteria [5]. A number of researchers have used various standalone as well as hybrid MCDM techniques for supplier evaluation and selection [6]–[10]. These techniques are from a number of different fields from soft computing, operations research and decision theory [11]. But none of the studies have used the integrated model comprising involving TOPSIS, AHP and Fuzzy logic for supplier selection problem from Pakistan's perspective. This research gap inspired us to work on and propose a new integrated model based on fuzzy, AHP and TOPSIS approach to evaluate and select the best supplier in a Pakistani textile company. The next section will present theoretical background and will discuss about fuzzy AHP and TOPSIS. Section 3 will provide numerical illustration of the proposed hybrid technique being applied to a textile manufacturing company in Pakistan for supplier selection. And the last part will conclude this research study and discuss future research directions.

2. Literature Review

A number of researchers have employed various techniques to target the problem of supplier selection. Some are related to computer science and soft computing, others related to operations research and some related to mathematical techniques. In this research study, we will be using AHP and TOPSIS. Therefore, we are going to review the application of Fuzzy, AHP and TOPSIS being applied for various MCDM problems. Table 1 summarizes and presents the use of AHP and TOPSIS for multi-criteria selection problems.

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Table 1: Use of AHP / TOPSIS for Multi-criteria Selection Problems

S. No.	Reference	Use of AHP / TOPSIS	Selection Problem
1	[12]	AHP / TOPSIS	Weapon Selection
2	[13]	AHP / FUZZY LP	Vendor
3	[14]	FUZZY / TOPSIS	Supplier
4	[15]	AHP / TOPSIS	Supplier
5	[16]	AHP	Job Candidate
6	[17]	AHP /FUZZY / TOPSIS	Spillway for Dam
7	[18]	AHP/TOPSIS	Machine
8	[19]	FUZZY AHP	Supplier
9	[20]	AHP/TOPSIS	Supplier
10	[21]	FUZZY AHP	Supplier
11	[22]	AHP	Supplier
12	[23]	FUZZY / TOPSIS	Supplier
13	[24]	AHP/ FUZZY / TOPSIS	Supplier
14	[25]	Fuzzy TOPSIS	Supplier

In [12], researchers have integrated fuzzy TOPSIS and AHP for best weapon selection. Another research used the combination of AHP and Linear Programming for vendor selection problem of a flour mill [13]. Researchers in [14] used fuzzy TOPSIS to rank the best suppliers by integrating Shannon Entropy. Jain et-al used the combination of TOPSIS and AHP for selecting the best supplier for an Indian automotive company [15]. Reference [16] introduced a novel model for selecting a suitable job candidate by integrating Complex proportional assessment of alternatives with grey relations (COPRAS-G) and AHP. Another research applied AHP and F-TOPSIS technique for selecting the appropriate dam spillway [17]. Reference [18] applied AHP and TOPSIS in an hybrid form to select the best machine. In [19], researchers used F-AHP for in a washing machine company in Turkey for supplier selection problem. Freeman and Chen in [20] used AHP along with ENTROPY and TOPSIS for sustainable supplier selection. Researchers in [21] selected the suitable supplier for gear motor industry by using Fuzzy AHP. In [22], researchers selected the suitable supplier for an automotive company in Pakistan using AHP. Researchers in [23] used a customized F-TOPSIS technique for the problem of supplier selection. Another research applied hybrid Fuzzy-AHP-TOPSIS method for suitable project selection for an Iranian Oil Company [24]. Researchers in [25] used Fuzzy AHP for selecting the appropriate for detergent manufacturing company in Iran.

It is pretty evident from the literature review that fuzzy logic, TOPSIS as well as AHP have been widely used for MCDM problems and especially for supplier selection. But only a few papers have been found who have used F-AHP for selecting the suitable supplier in a Pakistani context which highlights the research gap in this area. Therefore, this research aims at using for the first time hybrid F-AHP-TOPSIS technique in a textile manufacturing company in Pakistan for the problem of supplier selection.

3. Theoretical Background

3.1 Fuzzy AHP

Lotfi Zadeh is the inventor of fuzzy logic [26], [27]. The idea was to derive conclusions and results when there is uncertain situation or imprecise and vague information [28]–[31]. AHP was developed by Saaty while the idea to integrate fuzzy logic with AHP in order to develop more robust decision support system (DSS) was proposed later by Buckley [32] in order to cater to real world imprecision and uncertainty [33]–[35]. Various studies have been found to utilize AHP for a number of MCDM problems [36]. It assigns priorities to various decision criteria by performing pair wise comparison between alternatives [37]. In a generic AHP model as shown in figure 1, first level denotes the goal; the criteria and sub-criteria (if any) are in the third and fourth levels respectively and the last level contains the alternatives [5], [38].

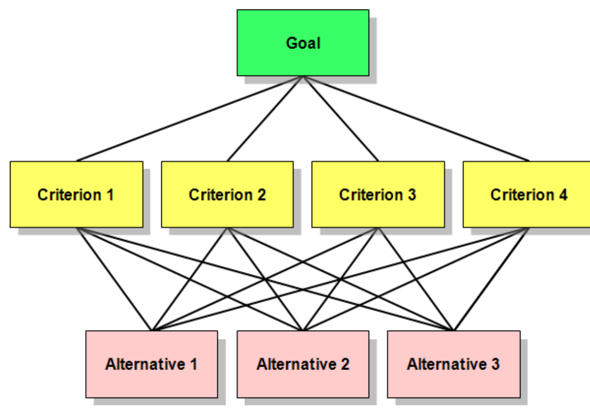

Fig. 1 Generalized structure of AHP [39]

AHP as originally proposed do not cater to the uncertainty and ambiguity that is part of human nature. This can be achieved by integrating fuzzy soft computing technique as proposed by Zadeh [40]. In Fuzzy-AHP, human linguistic variables are being represented by fuzzy numbers in our case we will be using fuzzy triangular fuzzy numbers which are then used for performing pair-wise comparison among the criteria and alternatives [3], [8], [38]. This is being performed by first developing a fuzzy decision matrix [41]. One of the first research to incorporate fuzzy logic into AHP were of Laarhoven and Pedcrycz [42]. They introduced the triangular membership function to be used in F-AHP [3]. Another researcher came up with the method to calculate fuzzy priorities of pair-wise comparison having fuzzy triangular numbers. Some other researchers such as chang [43] and Samvedi et-al [41] also came up with new methods to incorporate triangular fuzzy membership functions for AHP pair-wise comparisons. This study utilizes the method described by Buckley and uses triangular fuzzy membership function to calculate relative weights of criteria as well as alternatives. Reason for using triangular membership function is that while interviewing the case company which is discussed in the next section, all the approximate values for each criterion as described by the procurement department's staff was around a single value instead of any standard or a range of values. Following are the steps to be performed:

Step 1: Fuzzy linguistic numbers to compare criteria and alternative is shown in table 2.

Table 2: Linguistic variables mapped to triangular fuzzy values.

Linguistic Variables	Saaty Value	Fuzzy Triangular Values
Equally Important	1	(1, 1, 1)
Slightly Important	3	(2, 3, 4)
Strongly Important	5	(4, 5, 6)
Very Strongly Important	7	(6, 7, 8)
Extremely Important	9	(9, 9, 9)

The sample pair-wise comparison matrix "A" is shown is equation 1. Here d_{ij} indicates the comparison of i^{th} criterion with j^{th} criterion using fuzzy triangular values as mentioned in table 2. For the above example of Cr1 is strongly important than Cr2, d_{12} value represent this comparison and will have be equal to; d_{12} = (4, 5, 6).

$$A = \begin{bmatrix} d_{11} & d_{12} & \dots & d_{1k} \\ d_{21} & \dots & \dots & d_{2k} \\ \dots & \dots & \dots & \dots \\ d_{n1} & d_{n2} & \dots & d_{nk} \end{bmatrix} \quad (1)$$

Step 2: The geometric mean (GM) of fuzzy comparison values are calculated for each criterion which is shown in equation 2.

$$r_i = \left(\prod_{j=1}^{n} d_{ij}\right)^{1/n} ; i = 1, 2..., n \quad (2)$$

Step 3: Find the vector summation of each r_i. Later the summation vector's reciprocal is being looked upon and is being replaced by the fuzzy triangular value to make it in an increasing order. Then find the fuzzy weight of each criterion i (w_i) by multiplying each r_i with this reverse vector.

$$w_i = r_i \text{ x } (r_1 + r_2 + \cdots + r_n)^{-1} = (lw_i , mw_i , uw_i) \quad (3)$$

Step 4: In this step, defuzzification of fuzzy weights by utilizing centroid method is being carried out via applying equation 4.

$$M_i = \frac{lw_i + mw_i + uw_i}{3} \quad (4)$$

Step 5: M_i is a non fuzzy member which needs to be normalized using equation 5.

$$M_i = \frac{lw_i + mw_i + uw_i}{\sum_{i=1}^{n} M_i} \quad (5)$$

Step 6: Calculate the consistency ratio CR by using equation 5.

CR = CI/RI = Consistency Index / Random Consistency Index of A (6)

Where,

$$CI = \frac{\lambda max - n}{n-1} \quad (7)$$

RI = 1.98 (n-2) / n

If CR<= 0.10, the inconsistency level is considered acceptable. Otherwise, the decision maker needs to revise his judgment in order to get the better accurate decision.

Step 6: If CR is acceptable, then rank of alternatives based on the relative weights calculated using equation 4 and select the best alternative.

After all the criteria and alternative's normalized weights are being calculated, weight of alternative is multiplied to the weight of the criteria it is related. Ranking is based on the score achieved by each alternative and the one with highest score is ranked first which may be selected by the deciding organization.

3.2 TOPSIS

TOPSIS is mainly developed with thought that the best among various options has the longest geometric distance (GD) from the negative ideal solution (NEIS) and the shortest geometric distance from the positive ideal solution (POIS) [44]. TOPSIS comprises following steps:

Step 1: Formation of decision matrix using the following equation 8.

$$A = \begin{bmatrix} d_{11} & \dots & d_{1n} \\ d_{21} & \dots & d_{2n} \\ \dots & \dots & \dots \\ d_{m1} & \dots & d_{mn} \end{bmatrix} \quad (8)$$

Step 2: Normalize the decision matrix using equation 9.

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x^2{}_{ij})}} \quad (9)$$

Step 3: Formation of weighted normalized decision matrix is being done using equation 10.

$$V = v_{ij} = w_j . r_{ij} \quad (10)$$

Step 4: Determine POIS and NEIS for criteria using equation 11 and 12 respectively

$$POIS = V_j^+ = MAX_i(V_{ij}) \quad (11)$$

$$NEIS = V_j^- = MIN_i(V_{ij}) \quad (12)$$

Step 5: Calculate the GD of the alternatives from the POIS and NEIS using equation 13 and 14 respectively

$$S_i^+ = \sqrt{\sum_{j=1}^{n} (V_j^+ - V_{ij})^2} \quad (13)$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} (V_j^- - V_{ij})^2} \quad (14)$$

Step 6: Calculate the relative closeness to the ideal solutions using equation 15.

$$C_i = \frac{S_i^-}{S_i^- + S_i^+} \quad (15)$$

The alternative with highest relative closeness value is supposed to be ranked as the best alternative.

4. Methodological Steps

This research has proposed and later applied the following Fuzzy-AHP-TOPSIS integrated DSS for supplier selection in a textile manufacturing company in Pakistan which is shown in figure 2.

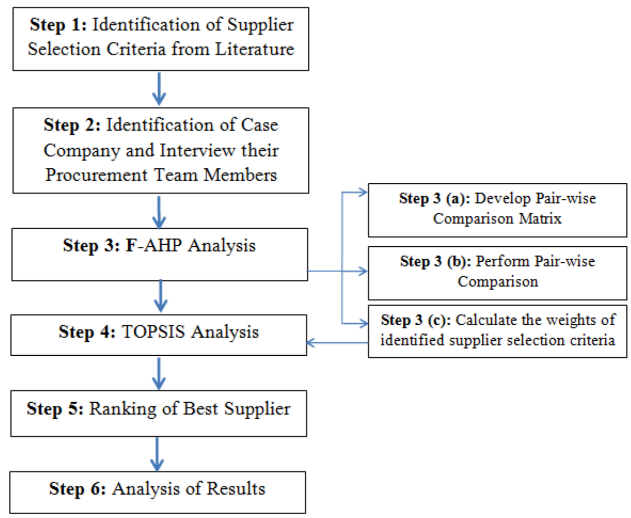

Fig. 2 Fuzzy-AHP-TOPSIS Integrated DSS

The research first started with comprehensive literature review about various criteria being used for SS. Then the case company was being selected from which the data needs to be collected. After identification of the case company, the researcher then identified the relevant supply chain procurement staff that can identify the criteria they use for SS.

Later those identified criteria from the literature were being discussed with the procurement staff of the company to shortlist the specific criteria they feel most appropriate for their SS needs. Then the same expert(s) is being used to perform pair-wise comparison by first developing pair-wise comparison matrix and then performing pair-wise comparison of criteria and alternatives. Then the weights of identified criteria are then being utilized into TOPSIS for calculating GD from POIS and NEIS. Then results are being analyzed and finally alternative suppliers are being ranked.

5. Numerical Illustration

This paper deals with the case company for selection of paper cone in a leading textile manufacturing company in Pakistan. The company's name has been kept confidential. The list of possible criteria was identified from the available literature and specific criteria were shortlisted with respect to the case company after interviewing the company's supply chain department personal. Then the pair-wise comparison was being done by the expert and the pair-wise comparison matrix for criteria only has been shown in table 3. The step 3 of the methodology presented in section 4 is being applied to calculate weights of criteria and alternatives which is shown in table 4. The criteria and alternative hierarchy has been shown in figure 3.

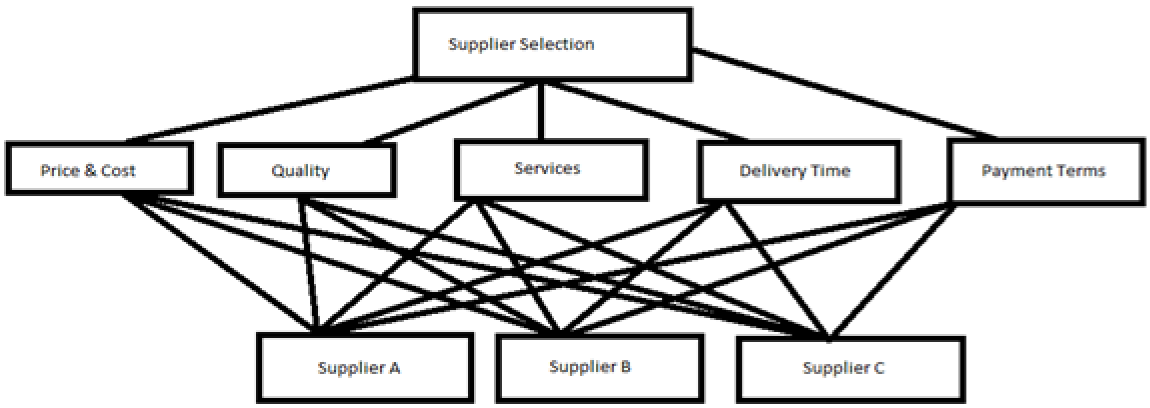

Fig. 3 Decision Goal, Criteria and Alternatives Hierarchy for XYZ Textile Company

Table 3: Comparison Matrix for Criteria

Criteria	Price & Cost	Quality	Serv ices	Deliver y time	Payment Terms
Price & Cost	(1, 1, 1)	(1/6, 1/5, 1/4)	(1, 1, 1)	(1/6, 1/5, 1/4)	(1/8, 1/7, 1/6)
Quality	(4, 5, 6)	(1, 1, 1)	(4, 5, 6)	(2, 3, 4)	(1/4, 1/3, 1/2)
Services	(1, 1, 1)	(1/6, 1/5, 1/4)	(1, 1, 1)	(1/4, 1/3, 1/2)	(1/6, 1/5, 1/4)
Delivery time	(4, 5, 6)	(1/4, 1/3, 1/2)	(2, 3, 4)	(1, 1, 1)	(1/4, 1/3, 1/2)
Payment Terms	(6, 7, 8)	(2, 3, 4)	(4, 5, 6)	(2, 3, 4)	(1, 1, 1)

After the pair-wise matrix is being developed, each criterion fuzzy linguistic number's GM is being calculated using equation 2. For example, r_1 GM of fuzzy linguistic numbers of "price & cost" criterion is being calculated which is shown below:

$$r_i = \left(\prod_{j=1}^{n} d_{ij}\right)^{1/n}$$

$$= [(1 * 1/6 * 1 * 1/6 * 1/8)^{1/5}\ ;\ (1 * 1/5 * 1 * 1/5 * 1/7)^{1/5}\ ;\ (1 * 1/4 * 1 * 1/4 * 1/6)^{1/5}]$$

= [0.32; 0.36; 0.40]

Table 4 shows all the GM of fuzzy comparison values for each criterion. Additionally it shows the total as well as reverse values. The last row of table 4 has been modified as fuzzy triangular number needs to be in ascending order.

Table 4: GM of Fuzzy Comparison Values

Criteria	**Ri**		
Price & Cost	0.32	0.36	0.40
Quality	1.52	1.90	2.35
Services	0.37	0.42	0.50
Delivery time	0.87	1.11	1.43
Payment Terms	2.49	3.16	3.78
Total	5.57	6.95	8.46
Reverse (Power of -1)	0.18	0.14	0.12
Increasing Order	0.12	0.14	0.18

In the next step, the fuzzy weight 'Price & Cost' (w_1) criterion is calculated using equation 3 as follows:

w_i = [(0.32*0.12); (0.36*0.14); (0.40*0.18)]

= [0.039; 0.050; 0.072]

Similarly the fuzzy weights for all criteria are calculated and are shown in table 5.

Table 5: Relative Fuzzy Weights for each Criterion

Criteria		**Wi**	
Price & Cost	0.039	0.050	0.072
Quality	0.182	0.267	0.423
Services	0.044	0.059	0.090
Delivery time	0.104	0.155	0.258
Payment Terms	0.299	0.442	0.680

After calculating the fuzzy weights of each criterion, the relative non-fuzzy weight needs to be calculated by averaging the fuzzy numbers for each individual criterion which is then used to calculate the normalized weights for each criterion and is shown in table 6.

Table 6: Average and normalized non-fuzzy weights for each criterion

Criteria	**Mi**	**Ni**
Price & Cost	0.054	0.051
Quality	0.291	0.276
Services	0.064	0.061
Delivery time	0.172	0.163
Payment Terms	0.474	0.449

Then the weights obtained through fuzzy AHP analysis is being used in TOPSIS to calculate POIS and NEIS using equations 11 and 12 respectively which are shown in table 7. Then the GD from the POIS and NEIS are being calculated using equation 13 and 14 respectively and are shown in table 8.

Table 7: POIS and NEIS Calculation

			SUPPLIER SELECTION CRITERIA		
AHP Weights	0.05080	0.27552	0.06114	0.16342	0.44912
Alternatives	**Price & Cost**	**Quality**	**Services**	**Delivery time**	**Payment Terms**
Supplier A	0.01259	0.01736	0.04137	0.04650	0.34618
Supplier B	0.03365	0.07494	0.01346	0.01180	0.02467
Supplier C	0.00456	0.18322	0.00632	0.10513	0.07828
POIS= V_i^+	0.0336	0.1832	0.0414	0.1051	0.3462
NEIS= V_i^-	0.0046	0.0174	0.0063	0.0118	0.0247

Table 8: GD from Positive Ideal and Negative Ideal Solutions

Alternatives	**Si+**	**Si-**
Supplier A	0.177	0.325
Supplier B	0.353	0.065
Supplier C	0.272	0.198

The relative closeness is then calculated using equation 15 using its value to rank the alternatives which is which is demonstrated in table 9.

Table 9: Relative Closeness / Performance Scores

Alternatives	**Ci**	**Rank**
Supplier A	0.647444745	1
Supplier B	0.155337157	3
Supplier C	0.421161056	2

In order to be sure that the ranking of alternative suppliers that we have achieved is not biased and have acceptable inconsistency, we are going to calculate the consistency ratio of our criteria decision matrix before it was being fuzzified using the triangular fuzzy numbers. This will be calculated by first calculating Eigen Value referred to as (λmax) and is calculated by

$\lambda max = \sum AW$

Where,

$$AW = \begin{pmatrix} 1 & 1/5 & 1 & 1/5 & 1/7 \\ 5 & 1 & 5 & 3 & 1/3 \\ 1 & 1/5 & 1 & 1/3 & 1/5 \\ 5 & 1/3 & 3 & 1 & 1/3 \\ 7 & 3 & 5 & 3 & 1 \end{pmatrix} \times \begin{pmatrix} 0.50 \\ 0.27 \\ 0.06 \\ 0.16 \\ 0.44 \end{pmatrix}$$

$$= \begin{pmatrix} 0.26 \\ 1.44 \\ 0.31 \\ 0.82 \\ 2.4 \end{pmatrix}$$

$$\lambda max = 0.26+1.44+0.31+0.82+2.4$$

$$= 5.240$$

$$\text{Consistency Index (CI)} = \frac{(\lambda max - n)}{n-1}$$

$$CI = \frac{(5.240 - 5)}{5-1}$$

$$= \frac{0.240}{4}$$

$$= 0.06$$

$$\text{Random Inconsistency (RI)} = \frac{1.98(n-2)}{n}$$

$$= \frac{1.98(5-2)}{5} = 1.18$$

$$CR = \frac{CI}{RI} = \frac{0.06}{1.18}$$

$$= 0.05$$

As CR <0.10, consistency ratio of our decision matrix is acceptable.

6. Results and Discussion

SS plays an important role for any organizational supply chain performance. This single process is critical for the organizations in order to meet customer demands in timely and cost effectively. This research study proposed fuzzy soft computing techniques in hybrid form along with AHP and TOPSIS to rank the suppliers for textile industry in from Pakistan's perspective. The criteria that were identified for the case textile manufacturing company were price & cost, quality, services, delivery time and payment terms. The criteria were compared pair-wise through the company's supply chain and procurement experts using AHP approach. Fuzzy linguistic variables were been integrated in the AHP so as to cater to linguistic chaos and human language ambiguity while performing pair-wise comparisons. The priority ranking being calculated by AHP for each of the criteria is price & cost (5%), quality (27.6 %), services (5.9%), delivery time (15.8%) and payment terms (45.8%) with inconsistency of 0.053. It can be observed from table 9 that the best supplier for the case company has been supplier A followed by supplier C.

7. Conclusion

Selecting the best supplier is one of the critical tasks within supply chain management. This one single decision could have a strong impact on any organization's performance. This allows them to narrow down the gap between supply and demand as well as optimization of their final manufactured product cost which eventually results in more profit margins and increased revenue. This paper proposed a new decision support system using integrating soft computing technique with operations research techniques to act as a general supplier selection model for textile industries in Pakistan.

Following are the major contributions of this research study: A novel method integrating Fuzzy, AHP and TOPSIS has been applied for supplier selection in textile industry. Secondly no previous studies have been found to use F-AHP-TOPSIS in a Pakistan's textile industry for supplier selection problem. Thirdly by incorporating fuzzy soft computing technique in AHP analysis enabled the decision maker to deal with vagueness, imprecision and linguistic chaos while performing pair-wise comparison. Last but not the least, this research study could become a standard decision support tool for supplier selection and procurement team for other textile companies in Pakistan.

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