Fuzzy Multi-Criteria Based Decision Support System for Supplier Selection in Textile Industry

S.M. Aqil Burney, Syed Mubashir Ali

College of Computer Science & Information Systems, Institute of Business Management (IoBM)

Abstract
It has been recognized that supplier selection is one of the fundamental operations in supply chain. Over the past few decades, industries as well as academia has focused on optimization of product cost and providing improved services to the clients by optimizing supply chain management. There needs to be an efficient supplier selection method in order to achieve this goal. The supplier selection is a multiple criteria decision making problem which involves numerous factors including both quantitative and qualitative data. This study applies fuzzy analytic hierarchy process (F-AHP) approach for supplier selection in a textile industry in Pakistan. Criteria for supplier selection were identified by having informal interview with the purchase manager of a textile manufacturing company for paper cone supplier selection. Criteria identified and considered for supplier selection were price & cost, quality, services, delivery time & payment terms. Later, ranking of suppliers have been done to select the best supplier and discussed research implications.

Key words:
Soft computing, supply chain management, multiple criteria decision making, Pakistan textile industry.

1. Introduction

Supplier selection has received a lot of attention both by academic researchers as well as practitioners because of its significance in achieving successful supply chain management [1], [2]. In order to achieve sustainability and efficient performance for any organization, evaluation and selection of a suitable supplier is one of the most vital components of supply chain management [3]–[5]. Particularly for manufacturing industry, one of the critical success factor for achieving reduced purchasing / manufacturing cost, improved customer satisfaction and increased competitive advantage is selecting the right supplier [6]. According to [7], procurement of goods constitutes the major standalone cost for any organization. It has been recognized that more than 60% of organization’s sales revenue is being spent on purchased items [8], [9].

Supplier selection is a complex decision making process [10], consisting of multiple objectives and conflicting criteria that needs to be taken into consideration and evaluated accordingly [11], [12]. It is a strategic decision taken by organizations as a result of the identification and evaluation of potential suppliers with the intention to have contract with them for organizational needs [13]. There has been a variety of approaches being utilized to evaluate and select potential suppliers using multiple criteria decision making (MCDM) techniques [14]–[17]. These techniques belong to diverse fields including but not limited to operations research, soft computing and decision theory [18].

The next section will review the existing literature for supplier selection techniques. Section 3 briefly explains the fuzzy-AHP approach. Section 4 will apply fuzzy-AHP for supplier selection in a textile manufacturing company in Pakistan. Section 5 will discuss limitations of this research. The last section will highlight future research directions and will conclude this paper.

2. Literature Review

According to [18], the process of identification, evaluation and contracting with the suppliers by the purchaser is referred to as supplier selection. Another study [19] looked for and discussed various criteria that can be used to evaluate suppliers and how important it is in selecting and retaining good suppliers. The criteria identified in this study were generalized and not according to any specific organization type or industry. Another research proposed multiple criteria decision analysis method for the problem of supplier selection [20]. The research focused on the various factors that affect supplier selection decision process and the relation between each factor.

A researcher from turkey divided the criteria for supplier selection under 4 main categories namely supplier, product performance, service performance and cost which were also further divided into sub criteria. However their research was based on the interview of the manager purchase in a white good manufacturing company in Turkey [21]. In [22], researchers proposed voting analytic hierarchy process method for evaluating and selection supplier. The proposed approach utilized ranking of votes instead of paired comparison to determine the weights for ranking of potential suppliers.

Jain et.al utilized fuzzy AHP and TOPSIS method for supplier evaluation and selection in an automotive industry in India [10]. Another study from the same

Manuscript received January 5, 2019
Manuscript revised January 20, 2019

researcher reviewed various issues related to selection of a suitable supplier as well as the relationship between supplier and buyer. supplier related issues in a dynamic supply chain [23]. Another research [24] also viewed the supplier selection issue as a MCDM problem. They implemented a hybrid fuzzy AHP and fuzzy TOPSIS methods for selecting appropriate supplier for customized equipment. They also discussed about the other possible and applicable MCDM techniques that can be used in for supplier selection.

From the above literature review, it is evident that supplier selection is clearly a multi-criteria decision making problem. The next section will discuss about the methodology of the research study.

3. Materials & Methods

Fuzzy logic is used to make conclusions that are based on uncertain, imprecise, vague, ambiguous and missing value information [25]–[28]. Fuzzy logic was first proposed by Zadeh [29], [30]. AHP was developed by Saaty and fuzzy AHP or F-AHP integrates the fuzzy logic with AHP in order to make the decision support system tolerant to imprecise and uncertain [31]–[33]. AHP has been widely used to solve multiple criteria decision making (MCDM) problems [34]. It assigns priorities to various decision criteria by performing pair wise comparison between alternatives [35]. In a generic AHP model, first level denotes the goal; the criteria and sub-criteria (if any) are in the third and fourth levels respectively and the fourth level contains the alternatives [36], [37].

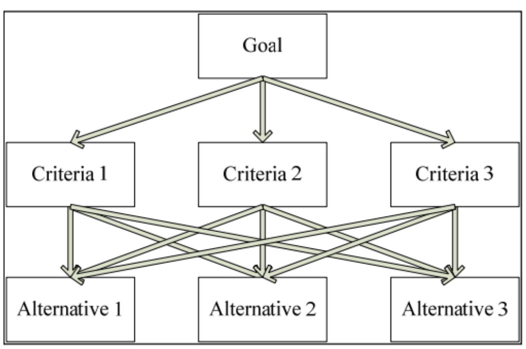

Fig. 1 Generalized structure of AHP [38]

In F-AHP, linguistic variables represented by triangular fuzzy numbers are being utilized to perform pair-wise comparison among the criteria and alternatives themselves [8], [36], [39]. This is achieved by constructing a fuzzy judgment matrix [40]. Laarhoven and Pedcrycz [41] were one of the first researchers to integrate fuzzy logic into AHP. They introduced the triangular membership function to be used in F-AHP for pair-wise comparison [8]. Buckley introduced a new method to compute fuzzy weights and specifically utilized triangular membership functions [42]. Other researchers such as chang [43] and Samvedi et-al [40] also introduced new methods to use triangular membership functions in 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 purchasing staff was around a single value instead of any standard or a range of values. Following are the steps to be performed:

<u>Step 1:</u> Comparing criteria and alternatives using linguistic variables shown in table 1.

Table 1: 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)

As we can see from table 1; the linguistic terms are mapped to triangular fuzzy numbers. Suppose if the expert suggests that "Criterion 1 (Cr1) is strongly important than criterion 2 (Cr2)", then it will take (4, 5, 6) fuzzy triangular value. On the other hand, while constructing pair-wise matrix, comparison of Cr2 to Cr1 will have fuzzy triangular value (1/6, 1/5, 1/4).

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 1. 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).

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

<u>Step 2:</u> The geometric mean of fuzzy comparison values are calculated for each criterion which is shown in equation 2.

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

<u>Step 3:</u> Find the vector summation of each r_i. Then find the reciprocal of summation vector and replace 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.

$w_i = r_i \times (r_1 + r_2 + \cdots + r_n)^{-1} = (lw_i, mw_i, uw_i)$ (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.

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

After finding the normalized weights of all the criteria and the alternatives, the score or rank of each alternative is calculated by multiplying each alternative weight with the related criteria. The alternative with the highest score is ranked 1st and can be selected by the decision maker. This methodology has been applied for supplier selection is a textile industry using a real case study which is discussed in the next section.

4. Application of F-Ahp in Textile Industry

This research applied F-AHP methodology in a XYZ textile manufacturing company in Pakistan which produces denim fabric and cotton yarn. The company is the largest manufacturer of denim in Asia. The company's name and the alternative suppliers' names are kept confidential on the request of the company. Paper cone, one of the most frequently used raw materials used in yarn manufacturing industry was taken into account for its supplier selection with respect to 5 criteria and 3 alternative suppliers. The overall goal and hierarchy of the supplier selection criteria and alternatives with respect to the case company is shown in Figure 2. The weight needs to be calculated for both the criteria and alternatives; therefore both the parts will be analyzed one by one.

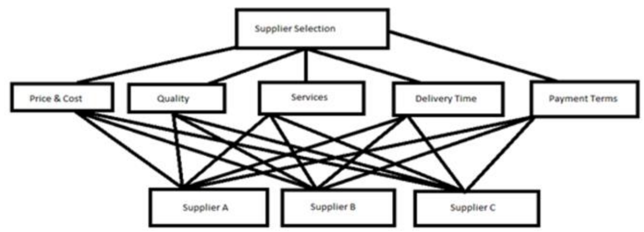

Fig. 2 AHP hierarchy for XYZ Textile Company

To identify and finalize the criteria, and then to evaluate the alternative suppliers, an interview was being conducted with the purchasing manager of the XYZ textile company. According to the company's preferences, pair-wise comparison matrix was formed shown in table 2.

Table 2: Comparison Matrix for Criteria

Criteria	Price & Cost	Quality	Services	Delivery time	Payment Terms
Price & Cost	(1, 1, 1)	(1/6, 1/5, 1/4)	(1, 1, 1)	(1/8, 1/7, 1/6)	(1/8, 1/7, 1/6)
Quality	(4, 5, 6)	(1, 1, 1)	(4, 5, 6)	(4, 5, 6)	(4, 5, 6)
Services	(1, 1, 1)	(1/6, 1/5, 1/4)	(1, 1, 1)	(2, 3, 4)	(9, 9, 9)
Delivery time	(6, 7, 8)	(1/6, 1/5, 1/4)	(1/4, 1/3, 1/2)	(1, 1, 1)	(6, 7, 8)
Payment Terms	(6, 7, 8)	(1/6, 1/5, 1/4)	(1/9, 1/9, 1/9)	(1/8, 1/7, 1/6)	(1, 1, 1)

After creating pair-wise matrix, the geometric mean of fuzzy comparison values of each criterion is being calculated using equation 2. For example, r_1 geometric mean of fuzzy comparison value of "price & cost" criterion is calculated as shown below:

$$r_i = \left(\prod_{j=1}^{n} d_{ij}\right)^{1/n}$$
$$= [\ (1*1/6*1*1/8*1/8)^{1/5}\ ;\ (1*1/5*1*1/7*1/7)^{1/5}\ ;\ (1*1/4*1*1/6*1/6)^{1/5}]$$
= [0.30; 0.33; 0.37]

Table 3 shows all the geometric means of fuzzy comparison values for each criterion. Additionally it shows the total as well as reverse values. The last row of table 3 has been modified as fuzzy triangular number needs to be in ascending order.

Table 3: Geometric means of fuzzy comparison values

Criteria	r_i		
Price & Cost	0.30	0.33	0.37
Quality	3.03	3.62	4.19
Services	1.25	1.40	1.55
Delivery time	1.08	1.27	1.52
Payment Terms	0.43	0.47	0.52
Total	6.09	7.09	8.15
Reverse (Power of -1)	0.16	0.14	0.12
Increasing Order	0.12	0.14	0.16

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

w_i = [(0.30*0.12); (0.33*0.14); (0.37*0.16)] = [0.037; 0.047; 0.059]

Similarly the fuzzy weights for all criteria are calculated and are shown in table 4.

Table 4: Relative fuzzy weights for each criterion

Criteria	w_i		
Price & Cost	0.037	0.047	0.059
Quality	0.364	0.507	0.671
Services	0.149	0.196	0.248
Delivery time	0.130	0.177	0.243
Payment Terms	0.051	0.065	0.083

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 5.

Table 5: Average and normalized non-fuzzy weights for each criterion

Criteria	**Mi**	**Ni**
Price & Cost	0.047	0.047
Quality	0.514	0.509
Services	0.198	0.196
Delivery time	0.183	0.182
Payment Terms	0.066	0.066

After calculating the normalized non-fuzzy relative weights for each criterion, the alternatives are to be compared pair-wise with respect to each individual criterion using the same above mentioned methodology. Table 6 shows the pair wise comparison matrix with respect to 'Price & Cost' criterion.

Table 6: Comparison matrix for alternatives with respect to 'Price & Cost' Criterion

	Price & Cost		
Alternatives	Supplier A	Supplier B	Supplier C
Supplier A	(1, 1, 1)	(1/4, 1/3, 1/2)	(2, 3, 4)
Supplier B	(2, 3, 4)	(1, 1, 1)	(6, 7, 8)
Supplier C	(1/4, 1/3, 1/2)	(1/8, 1/7, 1/6)	(1, 1, 1)

Using the same previous methodology used for individual criterion, the fuzzy geometric mean (r_i) and relative fuzzy weights of alternatives with respect to each criteria (w_i) is shown in table 7 and 8 respectively.

Table 7: Geometric means for alternatives with respect to 'Price & Cost' Criterion

Alternatives	r_i		
Supplier A	0.79	1.00	1.26
Supplier B	2.29	2.76	3.17
Supplier C	0.31	0.36	0.44
Total	3.40	4.12	4.87
Reverse (Power of -1)	0.29	0.24	0.21
Increasing Order	0.21	0.24	0.29

Table 8: Fuzzy weights for alternatives with respect to 'Price & Cost' Criterion

Alternatives	w_i		
Supplier A	0.167	0.240	0.365
Supplier B	0.481	0.662	0.921
Supplier C	0.066	0.087	0.127

Later, the average and normalized non-fuzzy weights are being calculated using centroid method which is shown in table 9.

Table 9: Average and normalized non fuzzy weights for each alternative with respect to 'Price & Cost' Criterion

Alternatives	**Mi**	**Ni**
Supplier A	0.257	0.248
Supplier B	0.688	0.662
Supplier C	0.093	0.090

The similar methodology is being employed to calculate the non-fuzzy normalized weights of each alternative with respect to all criterions and is being shown in table 10.

Table 10: Average and normalized weights for each alternative with respect to each criterion

Alternatives	**Criteria**				
	Price & Cost	Quality	Service	Delivery time	Payment Terms
Supplier A	0.248	0.063	0.677	0.285	0.771
Supplier B	0.662	0.272	0.220	0.072	0.055
Supplier C	0.090	0.665	0.103	0.643	0.174

By using the data in table 5 and table 10, ranking of alternative suppliers is presented in table 11. It can be observed that for the case company, the best supplier who ranked first is Supplier B.

Table 11: Individual score for each alternative with respect to each criterion

Criteria		**Score of Alternatives with respect to each criterion**		
	Weights	**Supplier A**	**Supplier B**	**Supplier C**
Price & Cost	0.047	0.248	0.662	0.090
Quality	0.509	0.063	0.272	0.665
Services	0.196	0.677	0.220	0.103
Delivery Time	0.182	0.285	0.072	0.643
Payment Terms	0.066	0.771	0.055	0.174
Total		2.043	1.282	1.676
Normalized Score		**0.296**	**0.372**	**0.332**

Table 12: Ranking of Alternative Suppliers

Supplier	**Weight**	**Rank**
Supplier A	0.296	3
Supplier B	0.372	1
Supplier C	0.332	2

5. Research Limitations

There are a number of limitations in this research study. Firstly, the data for conducting this study was gathered from one organization belonging to a textile industry. Secondly, the researchers have used fuzzy triangular numbers instead of other fuzzy membership functions. There is a possibility that using trapezoidal or some other membership function to fuzzify the Saaty scale of AHP might have ranked the suppliers differently. Lastly, the case company used only five basic criteria and no sub-criteria which if used may have differently ranked the suppliers.

6. Conclusion

Supplier selection is a critical task in supply chain management. It can greatly impact an organizational business performance by minimizing demand and supply gap as well as optimizing cost thus resulting in increased customer satisfaction. This research proposed a method for selecting the best supplier for any textile industry in Pakistan using a real case study as an example.

This research has done three novel contributions. First, AHP has been applied in textile industry in Pakistan for supplier selection which will gives confidence to the decision makers and procurement managers within this industry to perform decision making with confidence. Second, 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. Lastly, this research can become a simple decision making tool and a starting point for other textile companies for their supplier selection needs.

References

[1] J. Chai, J. N. Liu, and E. W. Ngai, “Application of decision-making techniques in supplier selection: A systematic review of literature,” Expert Systems with Applications, vol. 40, no. 10, pp. 3872–3885, 2013.

[2] L. Ferreira and D. Borenstein, “A fuzzy-Bayesian model for supplier selection,” Expert Systems with Applications, vol. 39, no. 9, pp. 7834–7844, 2012.

[3] S. M. Sreekumar, “A fuzzy multi-criteria decision making approach for supplier selection in supply chain management,” African journal of business management, vol. 3, no. 4, p. 168, 2009.

[4] Sreekumar and S. S. Mahapatra, “Supplier selection in supply chain management: a fuzzy multi-criteria decision-making approach,” International Journal of Services and Operations Management, vol. 8, no. 1, pp. 108–126, 2010.

[5] Ž. Živković, D. Nikolić, I. Mihajlović, P. Djordjević, and others, “Dependability Assessment of Supplier Performance based on the Fuzzy Sets Theory,” Volume of Management, Enterprise and Benchmarking in the 21st century III, pp. 43–56, 2016.

[6] C.-N. Liao and H.-P. Kao, “Supplier selection model using Taguchi loss function, analytical hierarchy process and multi-choice goal programming,” Computers & Industrial Engineering, vol. 58, no. 4, pp. 571–577, 2010.

[7] D. J. Bowersox, D. J. Closs, and M. B. Cooper, Supply chain logistics management, vol. 2. McGraw-Hill New York, NY, 2002.

[8] M. B. Ayhan, “A Fuzzy Ahp Approach For Supplier Selection Problem: A Case Study In A Gearmotor Company,” International Journal of Managing Value and Supply Chains, vol. 4, no. 3, pp. 11–23, Sep. 2013.

[9] K. G. GÜLEN, “Supplier selection and outsourcing strategies in supply chain management,” Journal of aeronautics and space technologies, vol. 3, no. 2, pp. 1–6, 2007.

[10] V. Jain, A. K. Sangaiah, S. Sakhuja, N. Thoduka, and R. Aggarwal, “Supplier selection using fuzzy AHP and TOPSIS: a case study in the Indian automotive industry,” Neural Computing and Applications, Aug. 2016.

[11] A. H. Lee, “A fuzzy supplier selection model with the consideration of benefits, opportunities, costs and risks,” Expert systems with applications, vol. 36, no. 2, pp. 2879–2893, 2009.

[12] A. Tas, “A Fuzzy AHP approach for selecting a global supplier in pharmaceutical industry,” African Journal of Business Management, vol. 6, no. 14, p. 5073, 2012.

[13] A. Beşkese and A. Şakra, “A model proposal for supplier selection in automotive industry,” in 14th International Research/Expert Conference TMT, 2010.

[14] E. Triantaphyllou, B. Shu, S. N. Sanchez, and T. Ray, “Multi-criteria decision making: an operations research approach,” Encyclopedia of electrical and electronics engineering, vol. 15, no. 1998, pp. 175–186, 1998.

[15] A. Mardani, A. Jusoh, K. MD Nor, Z. Khalifah, N. Zakwan, and A. Valipour, “Multiple criteria decision-making techniques and their applications – a review of the literature from 2000 to 2014,” Economic Research-Ekonomska Istraživanja, vol. 28, no. 1, pp. 516–571, Jan. 2015.

[16] K. Govindan, S. Rajendran, J. Sarkis, and P. Murugesan, “Multi criteria decision making approaches for green supplier evaluation and selection: a literature review,” Journal of Cleaner Production, vol. 98, pp. 66–83, 2015.

[17] H. S. Kilic, “An integrated approach for supplier selection in multi-item/multi-supplier environment,” Applied Mathematical Modelling, vol. 37, no. 14, pp. 7752–7763, 2013.

[18] N. Reinecke, P. Spiller, and D. Ungerman, “The talent factor in purchasing,” The McKinsey Quarterly, vol. 1, pp. 6–9, 2007.

[19] J. A. Siguaw and P. M. Simpson, “Toward assessing supplier value: usage and importance of supplier selection, retention, and value-added criteria,” Journal of Marketing Channels, vol. 11, no. 2–3, pp. 3–31, 2004.

[20] P. Parthiban, H. A. Zubar, and C. P. Garge, “A multi criteria decision making approach for suppliers selection,” Procedia Engineering, vol. 38, pp. 2312–2328, 2012.

[21] C. Kahraman, U. Cebeci, and Z. Ulukan, “Multi-criteria supplier selection using fuzzy AHP,” Logistics information management, vol. 16, no. 6, pp. 382–394, 2003.

[22] F.-H. F. Liu and H. L. Hai, “The voting analytic hierarchy process method for selecting supplier,” International journal of production economics, vol. 97, no. 3, pp. 308–317, 2005.

[23] V. Jain, S. Wadhwa, and S. G. Deshmukh, “Select supplier-related issues in modelling a dynamic supply chain: potential, challenges and direction for future research,” International Journal of Production Research, vol. 47, no. 11, pp. 3013–3039, 2009.

[24] A. Rodriguez, F. Ortega, and R. Concepción, “A method for the selection of customized equipment suppliers,” Expert

Systems with Applications, vol. 40, no. 4, pp. 1170–1176, 2013.
[25] F. Allag, R. Zegadi, S. Bouharati, L. Tedjar, and I. Bouharati, "Dynamic of air pollution and its effect on newborns: Analysis using fuzzy logic inference system," Wulfenia Journal, pp. 18–25, 2013.
[26] T. A. Jilani and S. M. A. Burney, "Multiclass Bilateral-Weighted Fuzzy Support Vector Machine to Evaluate Financial Strength Credit Rating," 2008, pp. 342–348.
[27] S. A. Burney, S. M. Ali, and S. Burney, "A survey of soft computing applications for decision making in supply chain management," in Engineering Technologies and Social Sciences (ICETSS), 2017 IEEE 3rd International Conference on, 2017, pp. 1–6.
[28] S. M. A. Burney, S. M. Ali, and M. S. Khan, "A Novel High Order Fuzzy Time Series Forecasting Method with Higher Accuracy Rate," International Journal of Computer Science and Network Security, vol 18, no 5, pp. 13–40, 2018.
[29] M. Khan, A. Manzoor, K. Rohail, S. M. Ali, A. Iftikhar, and M. Alam, "Soft computing applications in education management—A review," in Innovative Research and Development (ICIRD), 2018 IEEE International Conference on, 2018, pp. 1–4.
[30] A. Iftikhar, S. Musa, M. Alam, M. M. Su'ud, and S. M. Ali, "Application of Soft Computing Techniques in Global Software Development: state-of-the-art Review," International Journal of Engineering & Technology, vol. 7, no. 4.15, pp. 304–310, 2018.
[31] T. L. Saaty, "Decision making with the analytic hierarchy process," International journal of services sciences, vol. 1, no. 1, pp. 83–98, 2008.
[32] T. L. Saaty and L. G. Vargas, Models, methods, concepts & applications of the analytic hierarchy process, vol. 175. Springer Science & Business Media, 2012.
[33] Z. Güngör, G. Serhadlıoğlu, and S. E. Kesen, "A fuzzy AHP approach to personnel selection problem," Applied Soft Computing, vol. 9, no. 2, pp. 641–646, Mar. 2009.
[34] O. S. Vaidya and S. Kumar, "Analytic hierarchy process: An overview of applications," European Journal of operational research, vol. 169, no. 1, pp. 1–29, 2006.
[35] P. Ishtiaq, S. A. Khan, and M. Haq, "A multi-criteria decision-making approach to rank supplier selection criteria for hospital waste management: A case from Pakistan," Waste Management & Research, vol. 36, no. 4, pp. 386–394, Apr. 2018.
[36] O. Kilincci and S. A. Onal, "Fuzzy AHP approach for supplier selection in a washing machine company," Expert systems with Applications, vol. 38, no. 8, pp. 9656–9664, 2011.
[37] F. Dweiri, S. A. Khan, and A. Almulla, "A multi-criteria decision support system to rank sustainable desalination plant location criteria," Desalination, vol. 444, pp. 26–34, Oct. 2018.
[38] F. Dweiri, S. A. Khan, and V. Jain, "Production planning forecasting method selection in a supply chain: a case study," International Journal of Applied Management Science, vol. 7, no. 1, pp. 38–58, 2015.
[39] M. Benyoucef and M. Canbolat, "Fuzzy AHP-based supplier selection in e-procurement," International Journal of Services and Operations Management, vol. 3, no. 2, pp. 172–192, 2007.
[40] A. Samvedi, V. Jain, and F. T. S. Chan, "Quantifying risks in a supply chain through integration of fuzzy AHP and fuzzy TOPSIS," International Journal of Production Research, vol. 51, no. 8, pp. 2433–2442, Apr. 2013.
[41] P. J. M. Van Laarhoven and W. Pedrycz, "A fuzzy extension of Saaty's priority theory," Fuzzy sets and Systems, vol. 11, no. 1–3, pp. 229–241, 1983.
[42] J. J. Buckley, "Fuzzy hierarchical analysis," Fuzzy sets and systems, vol. 17, no. 3, pp. 233–247, 1985.
[43] D.-Y. Chang, "Applications of the extent analysis method on fuzzy AHP," European journal of operational research, vol. 95, no. 3, pp. 649–655, 1996.

Dr. S. M. Aqil Burney received M.Sc. (Statistics), M.Phil. (Risk Theory and Insurance –Statistics) from the University of Karachi (UoK) and Ph.D. (Mathematics) from Strathclyde University, Glasgow-UK along with many courses in Population Studies of UN, Computing. He has taught for more than 45 years at the UoK and extensively delivered lectures at other institutions and universities of Pakistan and abroad. He has been a Meritorious Professor at CS, UoK and HoD of Actuarial Sciences, Risk Management & Mathematics and Statistics at College of Computer Science & Information Systems, Institute of Business Management since 2014. His fields of interests are algorithmic analysis & design of multivariate time series, stochastic simulation and modelling, computer science, soft computing, risk theory, data sciences and fuzzy set theory. Dr. Aqil Burney is Chairman (elect) of the National ICT Committee for Standard PSQCA – Ministry of Science & Technology Govt. of Pakistan and Member of the National Computing Education Accreditation Council (NCEAC), Member of IEEE (USA), Member of ACM (USA), and Fellow of the Royal Statistical Society (UK) for 30 years.

Syed Mubashir Ali has completed his BS Computer Engineering from NUCES FAST and MS Information Technology from SZABIST. Currently pursuing PhD Computer Science from College of Computer Science & Information Systems, Institute of Business Management (IoBM), Karachi, Pakistan. He is working as a Senior Lecturer at IoBM. He has more than 15 publications in international peer-reviewed journals and conferences. His research interests are applications of soft computing techniques, human computer interaction, supply chain management, big data and predictive analytics and Gamification.