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A New Approach to Vendor Selection Problem with Impact Factor as an Indirect Measure of Quality

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Abstract: In the present study we use a new concept called impact factor of a vendor as an indirect measure of quality in vendor selection problem. A fuzzy-statistical comparative case study justifies the concept.

Key words: Vendor selection problem, z score, linear programming, fuzzy numbers, andrews plot, impact factor

INTRODUCTION

Evaluation of the company's vendors is considered an effective tool for rectification of defects, improving their ability to serve more satisfactorily and as a basis for making future purchasing decisions. A Vendor selection problem typically consists of four phases namely: Problem definition (recognition of the need for a new dealer), formulation of criteria, qualification of suitable suppliers and final selection of the ultimate suppliers (De Boer *et al*., 2001). The evaluation of vendors is done on a periodic basis and includes written evaluation aspects relating to quality, quantity, price, service etc. as obtained from the buyer, user and quality control and other concerned staff.

Dickson (1966), in one of the early works on supplier selection, identified over 20 supplier attributes which managers trade off when choosing a supplier. Since then a number of conceptual and empirical articles on supplier selection have appeared. The conceptual articles are examples of publications emphasizing the strategic importance of the supplier selection process. The articles highlight the trade-off among quality, cost and delivery performance measures in the supplier selection process.

Weber *et al*. (1991) reviewed the literature surrounding vendor selection criteria and identified surrounding vendor selection criteria and identified several basic techniques or models that appeared in studies over the previous 25 years. They found that the vast majority were linear weighting models, mathematical models such as Economic Order Quantity (EOQ) and a few probabilistic models. Since 1991, other techniques have been applied to the problem: analytic hierarchy process (Nydick and Hill, 1992; Barbarosoglu and Yazgac, 1997), multiobjective programming (Weber and Ellram, 1993), total cost of ownership (Ellram, 1995), statistical analysis (Mummalaneni *et al*., 1996; Petroni and Braglia, 2000), interpretative structural modeling (Mandal and Deshmukh, 1994), discrete choice analysis experiment (Verma and Pullman, 1998) and neural networks (Siying *et al*., 1997).

Fuzzy set theory can provide a valuable tool to cope with three major problematic areas of vendor selection: Imprecision, randomness and ambiguity. As far as imprecision is concerned it provides a powerful tool to weigh selection criteria importance. As far as randomness is considered, it is more effective than probabilistic approaches in that the selection problems should not use prediction based on previous events, since each selection case is not repeatable. As far as ambiguity is concerned it copes better than other methods with the treatment of linguistic variables. Fuzzy logic enables us to emulate the human reasoning process and make decisions based on vague or imprecise data. Albino *et al*. (1998) used fuzzy logic system to support vendor rating and compared to a neural network in order to evaluate the different system performances. Nassimbeni and Battain (2003) developed a vendor-rating tool based on fuzzy logic, a neural application and Ordinary Least Squares (OLS) regression. Kumar *et al*.(2004, 2006) used a fuzzy programming approach for vendor selection problem in a supply chain considering a fuzzy Multi-objective Integer Programming formulation and a fuzzy mixed integer goal programming formulation. Chou *et al*. (2006) used a fuzzy factor rating system to evaluate potential vendors based on modified re-buy situation.

Although each of these methodologies offers advantages under particular conditions, they do not provide a general workable methodology for combining multiple criteria into a single measure of supplier performance. We are extremely limited in making direct comparisons in terms of raw scores; we need a common

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scale before comparisons. Standard scores furnish one such common scale. In short fuzzy logic based approach seems to be particularly effective in decisions where fuzzy expressions are more natural for many human judgmental rules an statements than mathematical equations. Our approach is thus based on uncertainty reduction using fuzzy logic.

MATERIALS AND METHODS

Z-score: Suppose we are interested in determining which Vendor is more consistent in his abilities and which one has the greater variability within him. Would a comparison of the standard deviations of the two sets of raw scores give us the answer? The reply to most of these questions is in the negative. We are extremely limited in making direct comparisons in terms of raw scores for the reason that raw score scales are arbitrary and unique. We need a common scale before comparisons such as we have called for can be made. Standard scores furnish one such common scale.

A standard score scale has a mean of zero and a standard deviation of 1.0. Standard score z corresponding to a raw score X and to a deviation x.

$$z = \frac{X - M}{\sigma} \tag{1}$$

where deviation from mean M is X-M and σ is the standard deviation. (Garret, 1965; Guilford, 1973).

One shortcoming of the standard score is that half the scores will be negative in sign, which makes computation awkward. We overcome this shortcoming by adding a constant to all the scores to make them all positive.

We are also introducing a new term called the impact factor of the vendor defined as the ratio of the number of offers the vendor gets (from different customers or from the same customers on different occasions) divided by the number of types of goods produced by the vendor in a year. Higher impact factor will carry greater weightage. We supply the necessary mathematics and interpretation of this new concept below.

Let x be the no. of offers/year obtained by a particular vendor.

Let y be the no. of different types of goods produced/year by this vendor.

Then I.F = Impact Factor of the vendor = x/y

Clearly $y \neq 0$ as the vendor must produce goods of at least one kind/year in order to qualify to be a potential vendor (or else he is not considered in the analysis!).

Interpreting quality as judged by I.F.: To interpret quality as judged by the I.F. we consider the following four cases:

Case 1: If x = 0 i.e., x/y we define Quality =1 (as if % defective = 1 which is worst)

Case 2: If 0<x/y>1 define Quality = 1/IF = y/x

Case 3: If 0<x/y>∞, define Quality = 1- <x/y> = $1\text{-}(y/x)^{-1}$

Observe that in this case as x/y tends to infinity, Quality tends to 1. On the other hand, as y/x tends to 1, quality tends to zero. However it is understood here that quality will never be zero as no vendor can be perfect if judged through I.F. The case of y/x being 1 which is quite possible is being separately dealt with in case 4.

Case 4: If y/x = 1, we say that quality is the minimum expected for the vendor for in this case the vendor is getting as many offers as the number of different types of goods (either one offer for each type or more than one offer in some to compensate for no offer in others). In probabilistic terms since quality ε (0,1), we may define this minimum expected quality as the expectation of the minimum or first order statistic for a random sample from U (0,1) distribution. For practical purpose we shall take a large number of samples each of size equal to the number of vendors and find the minimum sample observation (value of first order statistic) for each sample. Next we find their mean, which gives an estimate of the minimum expected quality of the vendor for whom y/x = 1.

Evidently the final value of quality says Q will be in (0, 1). Hence we can safely apply the mathematics that we normally do for quality although the interpretation of quality as judged from the I.F. is different.

THE LINEAR MODEL

Notations:

R_i: Final ratings of ith Vendor (Here total of Z scores for ith Vendor)

X_i: Order quantity for ith Vendor

Vi: Capacity of ith Vendor

D: Demand for the period

q_i: Defect percent of ith Vendor

Q: Buyer's maximum acceptable defect rate

The objective function: The objective here is to maximize the total value of purchasing (TVP).

$$\text{Max (TVP)} = \sum_{i=1}^{n} R_i X_i \tag{2}$$

Constraints

Capacity constraints: As vendor i can provide up to V_i units of the product and its order quantity (X_i) should be equal or less than its capacity, these constraints are:

$$X_i \le V_i, I = 1, 2 \ldots n \quad (3)$$

On the other hand, aggregate Vendors' capacity should be equal or greater than demand, therefore,

$$\sum_{i=1}^{n} V_i \ge D \quad (4)$$

Demand constraint: As sum of the assigned order quantities to n vendors should meet the buyer's demand, it can be stated that

$$\sum_{i=1}^{n} X_i = D \quad (5)$$

Quality constraint: Since Q is the buyer's maximum acceptable defect rate and q_i is the defect rate of the ith vendor, the quality constraint can be shown as

$$\sum_{i=1}^{n} X_i q_i \le QD \quad (6)$$

(If quality represents impact factor of the vendor, q_i is the reciprocal of the i-th vendor's impact factor. With this understanding we are using the word quality without any loss in generality).

Final model: The final integrated linear programming model can be shown as

$$\text{Max (TVP)} = \sum_{i=1}^{n} R_i X_i \quad (7)$$

$$\left.\begin{array}{l} \sum_{i=1}^{n} X_i = D\text{(demand constraint)}, \\ \sum_{i=1}^{n} X_i q_i \le QD\text{(aggregate quality constraint)}, \\ \text{Xi = Vi i = 1,2, \&,n (Vendor's capacity constraints)}, \\ \text{Xi = 0, i = 1,2, \&, n (nonnegativity constraint)} \end{array}\right\} \quad (8)$$

EUCLIDEAN DISTANCE

The Euclidean distance between two vendors is given by

$$d_{ij} = \sqrt{\sum_{k=1}^{3} (Z_{ik} - Z_{jk})^2} \quad (9)$$

Where,

d_{ij} = The Euclidean distance between ith and jth vendor, $i \ne j = 1,2,3,4$.

Z_{ik} = Z score on k-th characteristic of i-th vendor, k=1,2,3.

Z_{jk} = Z score on k-th characteristic of j-th vendor.

CASE STUDY

Assume that the management of a JIT manufacturer decides to choose their best Vendors and assign their optimum order quantities to maximize the total value of purchasing. The main criteria for vendor selection are Cost, Quality and Service. According to the corporate strategies the Quality includes Defects and Process capability while Service involves On-time delivery, Response to changes. Four suppliers are included in the evaluation process and their Cost. Suppose the buyer wishes to find the best suppliers and their optimum order quantities, if the demand is 1000 units and the maximum acceptable defect rate is 0.02.

In order to solve this problem two types of calculations should be carried out: Z-score and Linear Programming (LP) optimization for both fuzzy and crisp case. The algorithm of the steps is defined as follows:

Step 1: Consider the information regarding quantitative information of vendors (Table 1). We take the reciprocal of quality since it is a negative quantitative factor.

Step 2: We calculate the Z-score for each vendor using data from Table 1 and 2 (both fuzzy and crisp). Table 3-5 show the various results of Z scores. The Z scores are calculated using Eq. (1). As far as fuzzy Z-scores are

Table 1:Vendors' quantitative information

	Cost	Quality	On-time del.	Capacity
Supplier 1	30	0.03	.95	400
Supplier 2	40	0.05	.98	700
Supplier 3	50	0.01	.85	600
Supplier 4	45	0.06	.92	500

N.B. Details of x-y values and Quality calculation using the four cases of sec 2.1 omitted

Table 2:Fuzzy data for the four vendors

Vendors	Cost	Quality	On-time delivery
Vendor A	(25,30,40)	(0.02,0.03,0.04)	(.94,.95,.97)
Vendor B	(30,40,45)	(0.04,0.05,0.06)	(.97,.98,.99)
Vendor C	(45,50,55)	(0,0.01,0.03)	(.80,.85,.90)
Vendor D	(40,45,50)	(0.03,0.06,0.09)	(.90,.92,.95)

Table 3: Crisp standard scores for the four vendors

Vendor	Cost scores	Quality scores	On-time delivery scores	Overall scores
Vendor A	-1.52	-.2714	.4124	-1.379
Vendor B	-.1689	-.6661	1.031	.196
Vendor C	1.182	1.7023	-1.649	1.2353
Vendor D	.5068	-.7648	-.20619	1.0654

Table 4: Crisp standard scores for the four vendors after addition of a constant

Vendor	Cost scores	Quality scores	On-time delivery scores	Overall scores
Vendor A	.48	1.7286	2.4124	4.621
Vendor B	1.8311	1.3339	3.031	6.196
Vendor C	3.182	3.7023	.351	7.235
Vendor D	2.5068	1.2352	1.7938	5.536

Table 5: Fuzzy standard scores for the four vendors

Vendors	Cost	Quality	On-time delivery
Vendor A	(-1.27,-1.52,-1.34)	(-.2027,-.4167,-.6550)	(.5763, .4124,.5075)
Vendor B	(-.633,-.169,-.446)	(1.1486, .625, .2183)	(1.044,1.031,1.104)
Vendor C	(1.27,1.18,1.34)	(-1.55,-1.458,-1.092)	(-1.604,-1.649,-1.582)
Vendor D	(.633, .507, .446)	(.4730,1.1458,1.5284)	(-.0467,-.2062,-.0896)

Table 6: Defuzzified standard scores for the four vendors

Vendors	Cost	Quality	On-time delivery	Overall scores
Vendor A	-1.38	-.4248	-.2758	-2.0806
Vendor B	-.416	.6640	-.6755	-.4247
Vendor C	1.26	-1.3680	1.698	1.59
Vendor D	.529	1.0491	-.7470	.8311

Table 7: Defuzzified standard scores for the four vendors after addition of a suitable constant

Vendors	Cost	Quality	On-time delivery	Overall scores
Vendor A	.6249	1.575	1.724	3.924
Vendor B	1.584	2.664	1.325	5.573
Vendor C	3.263	.632	3.698	7.593
Vendor D	2.529	3.049	1.253	6.831

concerned we use the same formula as for crisp case, except that we defuzzify it using Eq. (10). Table 6 and 7 show the defuzzified values of the Z-scores.

Step 3: Once the Z-score have been calculated we use these Z-scores as coefficients of the objective function (i.e., R_{ij}). Using Eq. (7) and (8) as LPP formulations we calculate the order quantities to be allocated to the vendors.

Step 4: In order to find the best order quantities the TVP is shown in the following programming, maximized as:

$\text{Max TVP} = 4.621x_1 + 6.196x_2 + 7.235x_3 + 5.536x_4$ (Fuzzy case).

Subject to:

$0.03x_1 + 0.05x_2 + 0.01x_3 + 0.06x_4 = 20$

$x_1 + x_2 + x_3 + x_4 = 1000$

$x_1 = 400$

$x_2 = 700$

$x_3 = 600$

$x_4 = 500$

$x_i = 0$, I=1,2,3,4.

The above LPP has been solved using LINDO 6.1 optimization software package. The optimal solution for the above formulation is :

$$TVP_{crisp} = 6347.08$$

where $x_1 = 300, x_2 = 100, x_3 = 600$ and $x_4 = 0$.

$$TVP_{fuzzy} = 6318.85$$

where $x_1 = 333.33, x_2 = 0, x_3 = 600$ and $x_4 = 66.67$.

ANDREWS PLOT

It is always a good idea to plot data in whatever way seems appropriate. It helps the analyst get a feel for his data and may suggest relationships between variables. The analyst can also spot subjectively any outliers, detect natural clustering of observations and to check on distributional assumptions.

With more than three variables pictorial representation becomes impractical and alternative ways must be found (e.g., parallel co-ordinates). Andrews (1972) suggested a complete different approach for representing each p-variate observation by a function f (t) plotted over the range $(-\pi, \pi)$ of t. For the r-th observation this function is defined as

$$f_r(t) = \frac{x_{r_1}}{\sqrt{2}} + x_{r_2}\sin t + x_{r_3}\cos t + x_{r_4}\cos t + x_{r_4}\sin 2t + x_{r_5}\cos 2t + ...$$

Apart from the first term, this function is a mixture of sine and cosine waves and will produce some sort of wave pattern depending on the observed values of the p variables. Observations that are close together in p-dimensional space should give wave patterns, which are somewhat similar. Induced Andrews (1972) showed that if the distance between two functions is defined in the obvious way by $\int_{-\pi}^{\pi} [f_r(t) - f_s(t)]^2 dt$ then this is proportional to the squared Euclidean distance between X_r and X_s.

Table 8: Quota allocations for vendors (fuzzy and crisp case)

Vendor number	Fuzzy case	Crisp case
1	$X_1 = 333.33$	$X_1 = 300$
2	$X_2 = 0$	$X_2 = 100$
3	$X_3 = 600$	$X_3 = 600$
4	$X_4 = 66.67$	$X_4 = 0$

Table 9: Euclidean distance between the vendors

(Vendor A, Vendor B)	(Vendor A, Vendor C)	(Vendor A, Vendor D)	(Vendor B, Vendor C)	(Vendor B, Vendor D)	(Vendor C, Vendor D)
1.538	3.93	2.176	3.823	1.41	2.937

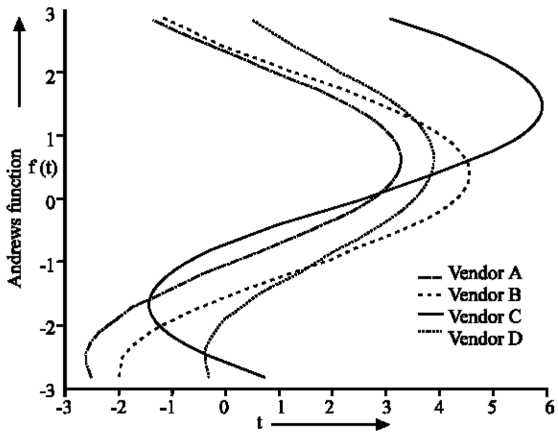

Fig. 1: Andrews function f (t) representing four vendors A, B, C, D

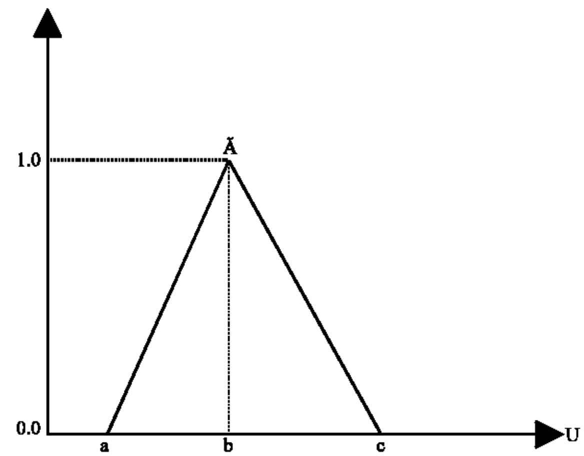

Fig. 2: Triangular Fuzzy number

Remarks 1: The Andrews curve will not show up relationships between variables but do appear to be useful for finding clusters and outliers.

Remarks 2: One drawback of the method is that it depends on the order in which the variables are labeled. The remedy lies in labeling the variables in decreasing order of importance i.e., x_1 representing the most important variable etc.

The Andrew's plot in our case is as shown in Fig. 1. The comparative fuzzy set analysis is shown in Appendix

APPENDIX

Fuzzy concepts: In 1965, Prof. Lofti A. Zadeh laid the foundation of fuzzy sets. Let U be the universe of discourse $U = \{u_1, u_2, \ldots, u_n\}$. A fuzzy set Ã of U is a set of ordered pairs

$$\{(u_1, f_{\tilde{A}}(u_1)), ((u_2, f_{\tilde{A}}(u_2), \ldots, (u_n, f_{\tilde{A}}(u_n))\}$$

Where is $f_{\tilde{A}}, f_{\tilde{A}} : U -> [0,1]$, the membership of Ã and $f_{\tilde{A}}(u_i)$ indicates the grade of membership of u_i in Ã.

Definition 1: Fuzzy number is a fuzzy subset in the universe of discourse U that is both convex and normal.

Definition 2: The α-cut Ãα of the fuzzy set Ã in the universe of discourse U is defined by

$$\tilde{A}_\alpha \, f_A(u_i) \geq \alpha, u_i \in U \text{where} \, \alpha \in [0,1].$$

Definition 3: According to Kaufmann and Gupta (1991), a fuzzy number Ã of the universe of discourse U may be characterized by a triangular distribution function parameterised by a triplet (a, b, c) shown in Fig. 2. The membership function of the fuzzy number Ãis defined as

$$f_{\tilde{A}}(u) = \begin{cases} 0, & u < a \\ \dfrac{u-a}{b-a}, & a \leq u \leq b, \\ \dfrac{c-u}{c-b}, & b \leq u \leq c, \\ 0, & u > c. \end{cases}$$

Let Ã and $\tilde{B}$ be two fuzzy numbers (TFN) parameterised by the triplet say (a_1, a_2, a_3) and (b_1, b_2, b_3), respectively.

Then the operations of fuzzy numbers are expressed as:

$\tilde{A} (+) \tilde{B} = (a_1, a_2, a_3)(+)(b_1, b_2, b_3) = (a_1+b_1, a_2+b_2, a_3+b_3)$,
$\tilde{A} (-) \tilde{B} = (a_1, a_2, a_3)(-)(b_1, b_2, b_3) = (a_1-b_3, a_2-b_2, a_3-b_1)$,
$\tilde{A} (*) \tilde{B} = (a_1, a_2, a_3)(x)(b_1, b_2, b_3) = (a_1b_1, a_2b_2, a_3b_3)$,
$\tilde{A} (\div) \tilde{B} = (a_1, a_2, a_3)(\div)(b_1, b_2, b_3) = (a_1/b_3, a_2/b_2, a_3/b_1)$.

Figure 3 Shows operations addition and multiplication on two TFNs.

Definition 4: Defuzzification of a triangular fuzzy number (a, b, c) is equal to

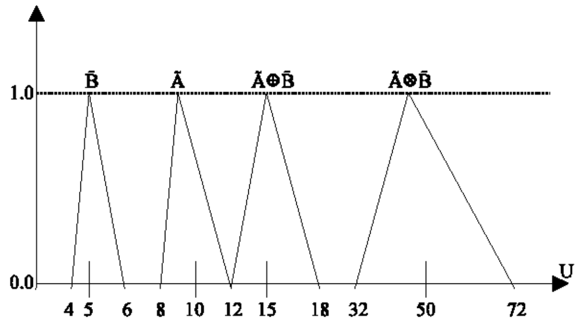

Fig. 3: Fuzzy number operations

$$e = \frac{a + 2*b + c}{4} \quad (10)$$

CONCLUSION AND SUGGESTIONS

We consider a flexible method, which can reflect the corporate strategy in the vendor selection process. A dynamic TVP model is suggested to establish good linkage between vendor selection and buyer's company's policy. This model assigns order quantities to vendors such that the total value of purchasing becomes maximum using z-scores and linear programming. This model also enables the management to make a trade off between several tangible and intangible factors with different priorities.

It is shown that the use of Z scores and impact factor as a mark of quality (if quality is less it is expected that the impact factor of the Vendor will be less) are useful in a Vendor Selection Problem. Statistical and fuzzy approaches are both equally good as verified through LPP (Table 8). Table 9 shows Euclidean distance between vendor pairs (Andrew's plot Fig. 1).

An interesting finding is that $TVP_{crisp} = 6347.08 > TVP_{fuzzy} = 6318.85$. We will not be surprised if this has to do with the impact factor of the vendor being used as a new quality characteristic because it is to be remembered that the vendor C who got the highest allocation (= 600) actually also had the largest total Z score (which is undesirable) but was it was he who had the highest impact factor (lowest quality 0.01). In some situations where figures for % defectives are not available or the customer does not consider them as reliable as claimed by the vendors or even if they are available and reliable, the customer wants a quality assurance over and above what the vendor claims, must we not recommend the impact factor of the vendors as an alternative quality-measure albeit in an indirect sense? [Concluded].

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REFERENCES

Andrews, D.F., 1972. Plots of high dimensional data. Biometrics, 28: 1972.

Albino, V., A.C. Garavelli and M. Gorgoglione, 1998. Fuzzy logic in vendor rating: A comparison between a fuzzy logic system and a neural Network. Fuzzy Econ. Rev., 3: 25-47.

Barbarosoglu, G. and T. Yazgac, 1997. An application of the analytic hierarchy process to the supplier selection problem. Prod. Inve. Manage. J. First Quarter, pp: 15-21.

Chatfield, C. and A.J. Collins, 1980. Introduction to Multivariate Analysis, Chapman and Hall.

Chou, S.Y., C.Y. Shen and Y.H. Chang, 2006. Vendor selection in a modified re-buy situation using a strategy aligned fuzzy approach. Int. J. Prod. Res., 1: 21.

Dickson, G.W., 1966. An analysis of vendor selection systems and decisions. J. Purchasing, 2: 5-17.

De Boer, L., E. Labro and P. Morlacchi, 2001. A review of methods supporting supplier selection. Eur. J. Purchasing and Supply Manage., 7: 75-89.

Ellram, L., 1995. Total cost of ownership: An analysis approach for purchasing. Int. J. Phy. Distribution and Logistics Manage., 25: 4-23.

Guilford, 1973. Fundamental Statistics in Psychology and Education, McGraw-Hill Kogakusha Ltd.

H. E. Garret, 1965. Statistics in Psychology and Education, Longmans, Green, 1966 and Vakils, Feffer and Simons.

Kaufmann, A. and M.M. Gupta, 1991. Introduction to Fuzzy arithmetic theory and applications. Van Nostrand Reinhold, New York.

Manoj Kumar, Prem Vrat and Ravi Shankar, 2006. A fuzzy programming approach for vendor selection problem in a supply chain. Int. J. Prod. Econ., 101: 273-285.

Manoj Kumar, Prem Vrat and R. Shankar, 2004. A fuzzy goal programming approach for vendor selection problem in a supply chain. Compu. Indus. Eng., 46: 69-85.

Mummalaneni, V., K.M. Dubas and C. Chao, 1996. Chinese purchasing managers' preferences and trade-offs in supplier selection and performance evaluation. Industrial Marketing Manage., 25: 115-124.

Mandal, A., Deshmukh, S.G., 1994. Vendor Selection using interpretative structural modelling (ISM). Int. J. Operations and Prod. Manage., 14: 52-59.

Nassimbeig, G. and F. Battain, 2003. Evaluation of supplier contribution to product development: Fuzzy and neuro-fuzzy based approaches. Int. J. Prod. Res., 41: 2933-2956.

Nydick, R.L. and R.P. Hill, 1992. Using the analytic hierarchy process to structure the supplier selection procedure. J. Purchasing and Materials Manage., 25: 31-6.

Patton, W.W., 1996. Use of human judgment models in industrial buyer's vendor selection decisions. Industrial Marketing Manage., 25: 135-149.

Petroni, A. and M. Braglia, 2000. Vendor selection using principal component analysis. Journal of supply chain Management: A global review of Purchasing and Supply, 36: 63-69.

Siying Wei, Jinlong Zhang and Zhicheng Li, 1997. A supplier system using a neural network. IEEE International Conference on Intelligent Processing Systems Beijing, China.

Weber, C.A. and L.M. Ellram, 1993. Supplier selection using multiobjective programming: A decision support systems approach. Int. J. Phys. Distribution and Logistics Manage., 23: 3-14.

Verma Rohit, Madeleine and E. Pullman, 1998. An analysis of the supplier selection process. Omega, 26: 739-750.

Weber, C.A., J.R. Current and R. Benton, 1991. Vendor selection criteria and methods. Eur. J. Operational Res., 50: 2-18.

Zadeh, L.A., 1965. Fuzzy Sets, Information and Control 8: 338-353.