A MULTICRITERIA DECISION MAKING METHODOLOGY FOR SELECTION OF SUPPLIERS IN SUSTAINABLE SUPPLY CHAIN

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Abstract

Liberalization, privatization, globalization of economies coupled with growing global population has resulted in various kinds of pollutions that can have a severe impact on environment and human life. The concept of sustainable supply chain increases in this regard. Sustainable development stands for not only meeting the requirements of present generation but also of future generations in meeting their own needs. A key issue faced by top managers in sustainable supply chain is selection of appropriate suppliers. Suppliers tend to have varied strengths and weakness on different parameters as quality, price, service, technical capability, financial strength, geographical location, reciprocal arrangements, etc., related to procurement process. But the selection of appropriate suppliers for a sustainable supply chain is a multi-criteria decision making problem containing qualitative and quantitative attributes. This study aims to efficiently assist the decision makers in determining the most appropriate suppliers in context of sustainable supply chain using a combination of analytical hierarchy process (AHP) and technique for order preference by similarity to ideal solution (TOPSIS). A numerical example from a case company is included to demonstrate the steps of the proposed model.

Keywords:*Sustainable supply chain, suppliers,Analytical Hierarchical Process; TOPSIS.*

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1. Introduction

Supply chains have seen a radical transformation in their operation since the last decade due to number of factors. Increasing competition on a global scale, shortened product life cycles, changing preferences of customers, concerns to environment are some of them. Also, liberalization, privatization, globalization of economies coupled with growing global population has resulted in various kinds of pollutions that can have a severe impact on environment and human life. The concept of sustainable supply chain increases in this regard. Sustainable development stands for not only meeting the requirements of present generation but also of future generations in meeting their own needs. A key issue faced by top managers in sustainable supply chain is selection of appropriate suppliers. Supplier selection is one of the critical issues faced by operations and purchasing managers to maintain competitive advantage (Chen et al., 2006).

An organization has to take into consideration a number of actors for evaluation of suppliers. Here a careful analysis of the products/services offered by suppliers needs due consideration. Some of the important criteria are cost, quality, delivery, serviceability, geographical location, flexible working arrangements, credit strength, etc. A careful analysis of these factors reveals that supplier selection problems are a multi-criteria decision making problem that needs consideration of both tangible and intangible factors (Sarkis and Talluri, 2002). To these factors, if the concept of sustainability is also introduced, supplier selection process becomes more complex. Incorporation of strategic and sustainability factors into supplier selection problems builds long–term resiliency of a supply chain (Seuring and Muller, 2008; Zhu et al., 2008).

In the recent years supplier selection with concerns to environment have gained prominence (Handfield et al., 2002; Sarkis, 2006). Hutchins and Sutherland (2008) report that supplier selection incorporating general sustainability issues and other social sustainability dimensions are scarcely found in literature. Sustainable development generally follows a triple-bottom line approach that takes economic, environmental and social development into consideration (Gauthier, 2005). Literature reveals that social factors as human right abuses, child labour, health and safety of staff and customers need to be added to supplier selection process (Rivoli, 2003).

The triple-bottom-line approach incorporating economic, environmental and social factors into supplier selection can result in increase of a company's image and would be beneficial for an organization in the long run. Selection of appropriate suppliers for sustainable supply chain is a key strategic issue for top management in an organization. A combination of multi-criteria decision making approaches using analytical hierarchy process (AHP) and technique for order preference by similarity to ideal solution (TOPSIS) has been used in research for selection of suppliers in sustainable supply chain.

This paper is further organized as follows. Section 2 provides the literature review related to methods adopted by researchers for supplier selection problems. The proposed TOPSIS-AHP method is discussed in section 3. In section 4, we apply the proposed method in company interested in selection of suppliers for sustainable supply chain. This is followed by discussions of this research and its applications.

2. Literature review

Literature review reveals that researchers have adopted different methods for selection of suppliers. Analytical hierarchical process (AHP) as a methodology has been used by researchers for selection of suppliers (Chan, 2003; Bayazit, 2005). Mandal and Deshmukh (1994) used interpretive structural model (ISM) for showing inter-relationships among different supplier attributes and their levels of importance. Case based reasoning has been used for evaluation of supplier's environmental management performance (Humphreys et al., 2003). Choy et al., (2003a, 2003b) used artificial neural network and intelligent supplier selection relationship management for selecting and benchmarking potential suppliers. Liu et al., (2000) applied data envelopment Analysis (DEA) for evaluation of overall performances of suppliers in a manufacturing firm. Razaei and Davoodi (2011) used multi-objective programming for lot-sizing with supplier selection. Lee et al., (2009) used goal programming methodology for selection of suppliers in case of high-tech industry.

In addition, literature reveals that researchers have also used hybrid methods, i.e. combination of two or more multi-criteria decision making methodologies for selection of suppliers. Ghodsypour and O'Brien (1998) used a combination AHP and linear programming approaches for selection of suppliers containing tangible and intangible factors such that the total value of purchasing becomes maximum. Kannan et al., (2009) used a combination of ISM and TOPSIS methodologies in a fuzzy environment for selection of best third party reverse logistics providers. Haq and Kannan (2009) used AHP and grey relational analysis for selection of appropriate vendors. Zhang and Feng (2007) used fuzzy-AHP methodology for selection of third party reverse logistics providers. It is observed from literature reviewthat there is not much work reported till date for selection of suppliers in context of sustainable supply chain using a combination of TOPSIS-AHP method and this research is an attempt in this regard.

3. TOPSIS-AHP Method

As discussed, it can be seen that supplier selection in context of sustainable supply chain is a strategic decision making problem that calls for consideration of both tangible and intangible factors. Many attributes of supplier selection as cost, quality, reliability, pollution, resource consumption, healthand safety of staff and customers, etc., are qualitative and quantitative in nature. One of the advantages of AHP methodology is that it can be used to deal with tangible and intangible factors in the light of subjective judgments in the process of decision making (Saaty, 1980). TOPSIS method simultaneously considers the distance to the ideal solution and negative-ideal solution for each alternative and helps to select the closest relative to the ideal solution as the best alternative (Hwang and Yoon, 1981). Thus, in order to reap advantages associated with both of these methods, a combined multi-criteria decision making methodology using AHP and TOPSIS has been used in this research for selection of suppliers in the context of sustainable supply chain. This methodology is illustrated in the following steps:

Step 1:A decision matrix 'D' having '*n*' criteria/attributes and '*m*' alternatives is represented as:

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

Here x_{ij} is the performance of i^{th} alternativewithrespect to j^{th} attribute.

Step2: The normalized decision matrix for the above matrix is obtained as:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad \text{where } j = 1, 2 \ldots. n \tag{2}$$

Step3:In this step, the relative importance of various attributes with respect to overall objective be determined. Weightages to attributes according to their importance needs to be given. In this research we have used nine-point preference scale of Saaty (1980) for construction of pair-wise comparison matrices. Reflexive property between the criteria is also taken care by this scale. For example, if a criterion 'A' is 7 times more important compared to another criterion 'B', then 'B' will be 1/7 times as important as 'A'.

Let Brepresent an *n* x *n* pair-wise comparison matrix,

$$B = \begin{bmatrix} 1 & b_{12} & \cdots & b_{1n} \\ b_{21} & 1 & \cdots & b_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ b_{n1} & b_{n2} & \cdots & 1 \end{bmatrix} \tag{3}$$

In this matrix, diagonal elements are self-compared. Thus these elements in equal importance. Thus, b_{ij}=1, where i=j, i, j=1, 2….n.

The importance degree of considered attributes is calculated using normalization of the geometric mean (NGM) method in this research. If $w_{i\ denotes}$ the importance degree for the i^{th} attribute, then:

$$w_i = \frac{\left(\prod_{j=1}^{n} b_{ij}\right)^{1/n}}{\sum_{i=1}^{n}\left(\prod_{j=1}^{n} b_{ij}\right)^{1/n}}, \text{ i, j} = 1, 2\ldots\ldots \text{n.} \tag{4}$$

Consistency check is carried out for ensuring that the pair-wise comparison matrix done is reasonable and acceptable.

Let P denote an *n*-dimensional column vector that is used to describe the sum of weighted value of importance of degrees of attributes. Then,

$P = [P_i]_{n \times 1} = BW^T$, i= 1, 2, …..n (5)

where:

$$BW^T = \begin{bmatrix} 1 & b_{12} & \cdots & b_{1n} \\ b_{21} & 1 & \cdots & b_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ b_{n1} & b_{n2} & \cdots & 1 \end{bmatrix} \begin{bmatrix} w_1, & w_2, & \cdots & w_n \end{bmatrix} = \begin{bmatrix} p_1 \\ p_2 \\ \cdots \\ p_n \end{bmatrix} \quad (6)$$

Consistency values of attributes can be represented by vector:

$PV = [pv_i]_{1xn}$ with a typical element pv_i defined as: $pv_i = (p_i/w_i)$, i= 1, 2,…n.

Care should be taken that inconsistency among pair-wise comparison matrix is avoided. Saaty(1980) has suggested use of maximum eigen value (λ_{max}) to calculate the effectiveness of the judgment for this purpose.

λ_{max} is calculated as:

$$\lambda_{max} = \left(\frac{\sum_{i=1}^{n} pv_i}{n} \right) \text{,i= 1, 2 ….n} \quad (7)$$

Consistency index (CI) is estimated as:

$$CI = \left(\frac{\lambda_{max} - n}{n - 1} \right) \quad (8)$$

Consistency ratio (CR) is used as a guide for checking consistency of evaluation. CR is calculated as:

$$CR = \frac{CI}{RI} \quad (9)$$

Where RI denotes average random index (Saaty, 1980). The evaluation of importance of degrees of attributes is considered reasonable if value of CR is below 0.10.

Step4:By multiplying each column of the matrix r_{ij} by weight w_j, the weighted normalized matrix is obtained as:

$$v_{ij} = w_j . r_{ij} \tag{10}$$

Step5:Here the ideal solutions (v^+) and negative ideal solutions (v^-) are calculated as follows:

(11)

$$v^- = \{v_1^-, \quad v_2^-, \quad ....., \quad v_n^-\} = \left\{ \left(\min_i v_{ij} | j \in J \right), \left(\max_i v_{ij} | j \in J' \right) | i = 1,2......m \right\} \tag{12}$$

Here J and J' are associated with beneficial and non-beneficial attributes respectively.

Step6:The Euclidean separation distance between the ideal solution (S_i^+) and negative ideal solution (S_i^-) for each alternative is calculated as:

$$S_i^+ = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^+ \right)^2}, \ i = 1, 2, ...m \tag{13}$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^- \right)^2}, \ i = 1, 2, ...m \tag{14}$$

Step 7:The relative closeness to the ideal solution of each alternative is calculated as:

$$C_i = \left(\frac{S_i^-}{S_i^+ + S_i^-} \right), \ i = 1, 2,......m \tag{15}$$

Step 8:Alternatives under consideration are ranked in descending order of C_i^*. A larger value of C_i^* indicates better performance of alternatives.

4. Illustrative example of proposed model applied to a case computer company

The TOPSIS-AHP method presented in this research has been evaluated in an actual computercompany, which was interested in the selection of suppliers in their organization.The company had 6 potential suppliers (A, B, C, D, E and F) and the best one among them was to be chosen. The case company identified ten important attributes relevant to sustainability as they deemed it necessary for suppliers that they intended to choose. These attributes were quality of products delivered (QTY), price (PRI), timing of delivery (TIM), using new technologies (UNT), information sharing (INS), financial stability (FSY), health and safety of staff and customers (HSY), customer privacy (CPY), environmental management system (EMS) and resource consumption (RCN). Among these attributes QTY (in defects per million opportunities (DPMO)), PRI (in rupees), TIM (in days), RCN (lakh gallons of water per month) are quantitative in nature having absolute numerical values. Attributes UNT, INS, FSY, HSY, CPY, and EMS have qualitative measures and for these a ranked value judgment on a scale of 1-5 (here 1 corresponds to lowest, 3 is moderate and 5 corresponds to highest) is suggested. Attributes QTY, UNT, INS, FSY, HSY, CPY and EMS are beneficial attributes were high values are desired. Whereas attributes PRI, TIM and RCN are non-beneficial attributes for which low values are preferred. Also, as QTY is measured in defects per million opportunities, low values of them are preferred. The data for all suppliers with respect to various attributes are given in Table 1.

Table 1: Data for all suppliers with respect to various attributes

Supplier	QTY	PRI	TIM	UNT	INS	FSY	HSY	CPY	EMS	RCN
A	900	13	50	5	4	3	5	3	4	24
B	233	10	45	4	3	4	5	4	5	35
C	500	10	35	4	2	3	2	5	3	32
D	450	11	40	3	5	5	4	3	2	28
E	300	11	25	3	4	5	3	4	5	25
F	100	12	30	4	4	4	5	4	5	23

The analysis and the implementation of the TOPSIS-AHP model are presented in the following steps:

Step1: Based upon the information available, the decision matrix is constructed which represents the performance of various reverse logistics providers with respect to different attributes:

	QTY	PRI	TIM	UNT	INS	FSY	HSY	CPY	EMS	RCN
A	900	13	50	5	4	3	5	3	4	24
B	233	10	45	4	3	4	5	4	5	35
C	500	10	35	4	2	3	2	5	3	32
D	450	11	40	3	5	5	4	3	2	28
E	300	11	25	3	4	5	3	4	5	25
F	100	12	30	4	4	4	5	4	5	23

Step2: The decision matrix is normalized using equation (2) as shown below:

	QTY	PRI	TIM	UNT	INS	FSY	HSY	CPY	EMS	RCN
A	0.7561	0.4731	0.5307	0.5241	0.4313	0.3000	0.4903	0.3145	0.3922	0.3478
B	0.1958	0.3639	0.4777	0.4193	0.3235	0.4000	0.4903	0.4193	0.4903	0.5071
C	0.4201	0.3639	0.3715	0.4193	0.2157	0.3000	0.1961	0.5241	0.2942	0.4637
D	0.3781	0.4003	0.4246	0.3145	0.5392	0.5000	0.3922	0.3145	0.1961	0.4057
E	0.2520	0.4003	0.2654	0.3145	0.4313	0.5000	0.2942	0.4193	0.4903	0.3622
F	0.0840	0.4367	0.3184	0.4193	0.4313	0.4000	0.4903	0.4193	0.4903	0.3333

Step3: In this research, four experts two from the computer hardware industry and other two from academia were consulted for making pair-wise comparison of attributes. Two industry experts were the senior managers of different companies in operations area. These experts from industry and academia were well conversant with concepts of sustainable supply chain management having an experience of over ten years in this area. The pair-wise comparison matrix as given by experts is:

	QTY	PRI	TIM	UNT	INS	FSY	HSY	CPY	EMS	RCN
QTY	1	4	1/3	1/2	5	5	5	7	1/2	1/5
PRI	1/4	1	1/3	1/4	3	4	5	5	1/5	1/5
TIM	3	3	1	3	5	5	6	7	1/3	1/4
UNT	2	4	1/3	1	5	5	6	8	1/3	1/4
INS	1/5	1/3	1/5	1/5	1	3	4	4	1/6	1/6
FSY	1/5	1/4	1/5	1/5	1/3	1	2	3	1/6	1/7
HSY	1/5	1/5	1/6	1/6	1/4	1/2	1	3	1/7	1/8
CPY	1/7	1/5	1/7	1/8	1/4	1/3	1/3	1	1/8	1/7
EMS	2	5	3	3	6	6	7	8	1	3
RCN	5	5	4	4	6	7	8	7	1/3	1

The normalized weights of the attributes computed using equation (4) are: QTY= 0.0996, PRI =0.0577, TIM=0.1442, UNT =0.1158, INS=0.0377, FSY=0.0263, HSY=0.0204, CPY=0.0145, EMS=0.2486 and RCN=0.2353.

λ_{max} value is 11.33211and that of CR is 0.099, which is less than allowable value of 0.10. Thus, there are total consistencies in judgments made by experts and the pair-wise comparison matrix is free from any undue bias.

Step4:The weighted normalized matrix is computed as:

	QTY	PRI	TIM	UNT	INS	FSY	HSY	CPY	EMS	RCN
A	0.0753	0.0273	0.0765	0.0607	0.0163	0.0079	0.0100	0.0046	0.0975	0.0818
B	0.0195	0.0210	0.0689	0.0486	0.0122	0.0105	0.0100	0.0061	0.1219	0.1193
C	0.0418	0.0210	0.0536	0.0486	0.0081	0.0079	0.0040	0.0076	0.0731	0.1091
D	0.0377	0.0231	0.0612	0.0364	0.0203	0.0132	0.0080	0.0046	0.0488	0.0955
E	0.0251	0.0231	0.0383	0.0364	0.0163	0.0132	0.0060	0.0061	0.1219	0.0852
F	0.0084	0.0252	0.0459	0.0486	0.0163	0.0105	0.0100	0.0061	0.1219	0.0784

Step5:Using equations (11) and (12) the ideal (best)and negative-ideal (worst) solutions are calculated as: v_1^+=0.0084 , v_2^+ =0.0210, v_3^+=0.0383, v_4^+=0.0607, v_5^+=0.0203, v_6^+=0.0132, v_7^+=0.01, v_8^+=0.0076, v_9^+=0.1219, v_{10}^+=0.0784 and v_1^-=0.0753, v_2^- =0.0273, v_3^-=0.0765, v_4^- =0.0364, v_5^-=0.0081,v_6^-=0.0079, v_7^-=0.004, v_8^-=0.0046, v_9^-=0.0488, v_{10}^-=0.1193.

Step6:The Euclidean separation distances are computed using equations (13) and (14) as:s_1^+=0.08148, s_2^+=0.05437, s_3^+=0.07094, s_4^+=0.08735, s_5^+=0.03089, s_6^+=0.01578 and s_1^- =0.0669, s_2^-=0.0936, s_3^-=0.0504, s_4^-=0.0493, s_5^-=0.1030, s_6^-=0.1127.

Step7:The relative closeness to the ideal solution of each alternative is calculated using equation (15) as:C_1=0.4507, C_2=0.6325, C_3=0.4152, C_4=0.3607, C_5=0.7692, C_6=0.8771.

Step8:Based on the relative closeness values, the case company can choose suppliers for their operations as F-E-B-A-C-Din decreasing order of preference. It is emphasized here that these results should be seen in the light of the characteristics of the case company and the inputs provided experts in the pair-wise comparison of attributes.

5. Conclusion

The selection of the suppliers for sustainable supply chain is a strategic level decision that needs to be taken by top management of companies. With increase in environmental and social issues becoming relevant, selection of suppliers practicing these principles is to be preferred and this research assumes significance in this regard.

The TOPSIS-AHP method presented in this paper can be helpful for selection of appropriate suppliers as it relates various attributes with alternatives available to the decision maker. The proposed model not only guides decision makers for selection of appropriate suppliers but also enables them to visualize the impact of various criteria on the alternatives while arriving at the final solution. One of the important contributions of this research is that it can simultaneously take into account any number of qualitative and quantitative attributes and gives a logical approach for selection of suppliers.

This research has a few limitations also. While using AHP methodology, the pair-wise comparison of attributes affecting supplier selection was subjectively performed by experts from industry and academia. An experts' knowledge and familiarity with the firm and also biasing of experts to some of these attributes might have influenced final results. In this research, we have attempted to minimize this limitation through consistency ratio check (Saaty, 1980).

Extensions to this research are also possible. Analytical Network Process (ANP), a more advanced approach that can consider complex interrelationships among decision levels and attributes could be attempted. User friendly software could be developed on basis of the proposed model.

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