ENHANCING SUPPLY CHAIN PERFORMANCE BY SUSTAINABLE SUPPLIER SELECTION AND ORDER SPLITTING STRATEGIES

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ABSTRACT

In today's dynamic and uncertain business environment, every manufacturing or service firm does outsource activity in the form of procurement of raw materials, semi-finished and finished goods, technology etc. Therefore, suppliers are the key players to help the firms to be competitive in the market. Firms are dependent on the suppliers to meet the customer demands. Total dependence on a single supplier may create huge problems to that firm. Natural disaster, new political rules etc. happening at supplier side may disrupt or seize the flow of supply to firm. Consequently, selecting suitable set of sustainable suppliers is a crucial activity for any organization. In this research, sustainable suppliers are selected based on set of criteria, cost, risk, flexibility and environmental responsibility. A novel approach involving fuzzy numbers, which make it easier to capture the decision maker's subjective assessment related to supplier selection criteria, are applied to make accurate and consistent sustainable supplier selection decisions. The proposed approach follows the two-stage decision making process. In the first stage, selection of suitable sustainable suppliers and splitting order among them takes place. In the second stage, the impact of order splitting strategy on supply chain performance is examined. The efficacy and intricacy of the developed approach is validated using a real-life case.

Keywords: Supply chain management, Supplier selection, Order splitting, Performance measurement.

1. INTRODUCTION

Selecting suitable suppliers is a key strategic decision in supply chain management. Supply chain management is gaining importance because of the need for prosperity and survival of an industrial organization and is designed to respond to the needs of the market with speed and at minimum cost. Supplier selection decisions has gained great importance in the supply chain management due to factors such as globalization, increased value added in supply and accelerated technological change. A key and perhaps the most important process of the purchasing function is the efficient selection of suppliers, because it brings significant savings for the organization.

Suppliers have a direct and significant impact on the cost, quality and lead time of products and services needed to meet firm's market demand. It is necessary to define supply chain management.

Supply chains are Life cycle processes comprising physical, information, financial, and knowledge flows whose purpose is to satisfy end-user requirements with products and services from multiple linked suppliers. Supply chain management can be described as the design, maintenance, and operation of supply chain processes for satisfaction of end user needs. Firms following the Just-In- Time production and Total Quality Management to use a single supplier. It helps to build a long-term supplier relationship to improve the service quality. Due to long term relationship, a company's supply chain creates one of the strongest barriers to entry for competitors. On the other hand, outsourcing takes place when an organization transfers the ownership of traditional functions and value-added activities to suppliers. Outsourcing is particularly useful if,

(i) Specialized skills are required,
(ii) The organization is to focus on its core competencies, and
(iii) The outsourcing partner can deliver products or services quicker and more reliably, at less cost, or at consistently better quality.

Supplier selection processes are considered as multi-criteria decision making (MCDM). And it is a group decision making process. Subjective estimates often appear in the decision making while dealing with supplier selection criteria. This is because of large number of decision members' involvement and their experience. Many times, selection criteria are conflicting in nature. This is a challenging task to select suppliers by incorporating subjective judgments of decision makers and trade-off between conflicting criteria. Sometimes decision makers have vague or incomplete information about the selection criteria. Supplier selection processes need a method which takes care of such subjective estimates, conflicting criteria. There is no best way to select suppliers, that's why organizations use a variety of different approaches, implementing the one that suits best depending on the company's requirements. ELECTRE (Elimination and Choice Translating Reality) is an approach to multi-criteria decision making (Benayoun *et al.*1966, Roy 1985) which considers the uncertainty and vagueness in the decision process. In the fuzzy ELECTRE method linguistic variables are used.

For an enterprise, totally depending on a single supplier might have huge negative impact on its business processes. To bypass such a critical situation, it is better to have multiple suppliers rather than a single supplier. In general, this research intends to study the supplier selection criteria, a methodology for supplier selection process and proposes a model for order splitting and evaluating supply chain performance. Every manufacturing or service firm does outsource activity in the form of procurement of raw materials, semi-finished and finished goods, technology etc. Therefore, suppliers are the key players to help the firms to be competitive in the market. Firms are dependent on the suppliers to meet the customer demands. Total dependence on a single supplier may create huge problems to that firm. Natural disaster, new political rules etc. happening at supplier side may disrupt or seize the flow of supply to firm. Therefore, selecting suitable set of suppliers is a crucial activity for any organization. The proposed research work differentiates from others reported in the literature in following respect: One, we are using a fuzzy ELECTRE approach for decision making in supplier selection. Two, we have proposed a methodology for order splitting strategy, considering supply chain performance. The proposed approach follows the two-stage decision making process. In the first stage, selection of suitable suppliers and splitting order among them takes place. In the second stage, the impact of order splitting strategy on supply chain performance is examined. The goals of this study are to, (1) Select the suitable suppliers and split the order among selected suppliers; (2) Develop a model for order splitting and evaluating supply chain performance; and (3)

Study the impact of order splitting strategies on supply chain performance. For achieving the first objective, suppliers are selected based on a set of criteria using the proposed Fuzzy ELECTRE method. For selection of criteria and selection of methodology detailed literature review has been done. A model is developed for order splitting and evaluating supply chain performance, to achieve second objective and third objective is achieved through a real industry case.

2. LITERATURE REVIEW

The selection of a supplier is perhaps the most important step in creating a successful alliance. The selection of an appropriate supplier is an important factor affecting eventual buyer-supplier relationship. If the process is done correctly, a higher quality, longer lasting relationship is more attainable. Supplier selection is an integral component of relationship success. Also, these processes affect the supply chain performance.

Selecting the right supplier is important because of following reasons:

(i) Today's business environments are becoming dynamic due to fast changing market conditions, customer demand, roles of competitors etc. the task of supplier selection is not a frequent activity. Only those firms can survive such dynamic environments that are able to meet the market requirements and customer expectations. This requires a good supplier selection process involving wide set of selection criteria.

(ii) The increasing globalization of world trade and internet facilitated communication provides purchaser opportunities for sourcing in worldwide. This global sourcing increases number of suppliers and increases the difficulties in obtaining the required information about these suppliers. Purchaser may have to rely solely on publicly available information.

(iii) There is a need that the suppliers to be assessed against multiple and often conflicting criteria, between which trade-off s are essential.

Some authors have identified several criteria for supplier selection, such as the net price, quality, delivery, historical supplier performance, capacity, communication systems, service, and geographic location, among others (Dickson 1966; Dempsey 1978; Weber, Current, and Benton 1991). There are some other Supplier selection criteria on which organization can gain competitive advantage such as reliability, risk, environmental factor, political factor, flexibility and financial, technological, organizational capabilities etc. These criteria are a key issue in the supplier assessment process since it measures the performance of the suppliers. Experts agree that no best way exists to select suppliers, and thus organizations use a variety of approaches. The overall objective of the supplier selection process is to reduce risk and maximize overall value to the purchaser. An organization must select suppliers it can do business with over an extended period. The supplier selection problem is characterized as a multi-criteria decision Making (MCDM) problem. In general supplier selection problems adhere to uncertain, imprecise and subjective data. The degree of uncertainty, the number of decision-makers and the nature of the criteria must be carefully considered to solve this problem. Another factor complicating the decision is that some criteria may conflict each other. Such as the supplier offering the lowest price may not have the best quality or the supplier with best quality may not deliver on time. Therefore, it is necessary to make a trade-off between conflicting quantitative and qualitative factors to find the best suppliers. Table 1 summarizes various supplier selection methods including identifying parameters used, advantages and disadvantages.

Table 1. Comparison of the supplier selection methods

Method	Reference	Quantitative/Qualitative parameters	Advantages	Disadvantages
Categorical	Timmerman (1986)	✓ Quality ✓ Delivery ✓ Service ✓ Price	✓ The evaluation process is clear and systematic ✓ Inexpensive ✓ Requires a minimum performance data	✓ Attributes are weighted equally ✓ Subjective ✓ Imprecise
Weighted Point	Timmerman (1986)	✓ Quality ✓ Delivery ✓ Service ✓ Price	✓ Attributes are weighted by importance	✓ Subjective ✓ Difficult to effectively consider qualitative criteria
Cost ratio	Timmerman (1986)	✓ Quality ✓ Delivery ✓ Service ✓ Price	✓ Subjectivity is reduced ✓ Flexibility	✓ Complexity and requirement for a developed cost accounting system ✓ Performance measures (cost ratios) are artificially expressed in the same units
Total Cost of Ownership	Ellram (1995)	✓ Price ✓ Quality costs ✓ Unreliable delivery service cost ✓ Transport cost ✓ Ordering costs ✓ Inspection costs	✓ Substantial cost savings ✓ Allows various purchasing policies to be compared with one another	✓ Complex
Analytic Hierarchical Process	Nydick & Hill (1992)	✓ Quality ✓ Price ✓ Delivery ✓ Service	✓ Simplicity ✓ Captures both qualitative and quantitative criteria	✓ Inconsistency on the method
Neural Network	Siying Wei (1997)	✓ Performance ✓ Quality ✓ Geography ✓ Price	✓ Saves a lot of time and money of system development	✓ Lack of expertise ✓ Requires a software

Multi-criteria decision making provides an effective framework for comparison based on the evaluation of multiple conflicting criteria. It is difficult to find the best way to select supplier. Companies use variety of different methods to deal with. Therefore, the most important issue in the process of supplier selection is to select or develop a suitable method to select the right supplier. ELECTRE (Elimination and Choice Translating Reality) is a popular approach to multi-criteria decision making. The ELECTRE approach was first introduced in (Benayoun *et al.* 1966). Due to decision maker's experience and feelings, subjective estimates often appear in the process of supplier selection. To deal with these problems Bellman and Zadeh (1970) and Zimmermann (1978) introduced fuzzy sets into MCDM field. Fuzzy logic enables the decision makers to emulate the human reasoning process with vague or imprecise data. Considering the fuzziness in the decision data and group decision-making process, linguistic variables are employed to evaluate the weights of all criteria and the ratings of each alternative with respect to each criterion.

3. METHODOLOGY

Two models are developed which are used in this study. Model 1 is Fuzzy ELECTRE (Elimination and Choice Translating Reality) which is used for supplier selection. This model is based on linguistic variables and fuzzy numbers. Model 2 is used for splitting orders among selected suppliers and to evaluate the performance of supply chain.. For instance, age is a linguistic variable if its values are assumed to be the fuzzy variables labeled 'not young', 'young' and 'very young' rather than the actual numbers. The concept of linguistic variable provides a means for the approximate characterization of phenomena that are too complex or too ill defined to be amenable to description in conventional quantitative terms. Fuzzy sets and fuzzy logic are powerful mathematical tools for modeling uncertain systems in industry. A fuzzy set is an extension of a crisp set. Crisp sets only allow full membership or non-membership, whereas fuzzy sets allow partial membership. A fuzzy number M is a convex normalized fuzzy set of the real line R such that (Zimmermann 1992):

- It exist such that one $x \in R$ with $\mu M(x) = 1$;
- $\mu M(x)$ is a piecewise continuous.

It is possible to use different fuzzy numbers depending on the situation. In applications it is often convenient to work with triangular fuzzy numbers (TFNs) because of their computational simplicity. In this study, TFNs are adopted in the fuzzy ELECTRE method. Triangular fuzzy numbers can be defined as a triplet (a, b, c) where the parameters a, b, and c, respectively, indicate the smallest possible value, the most promising value, and the largest possible value that describe a fuzzy event. A triangular fuzzy number M is shown in Figure 1.

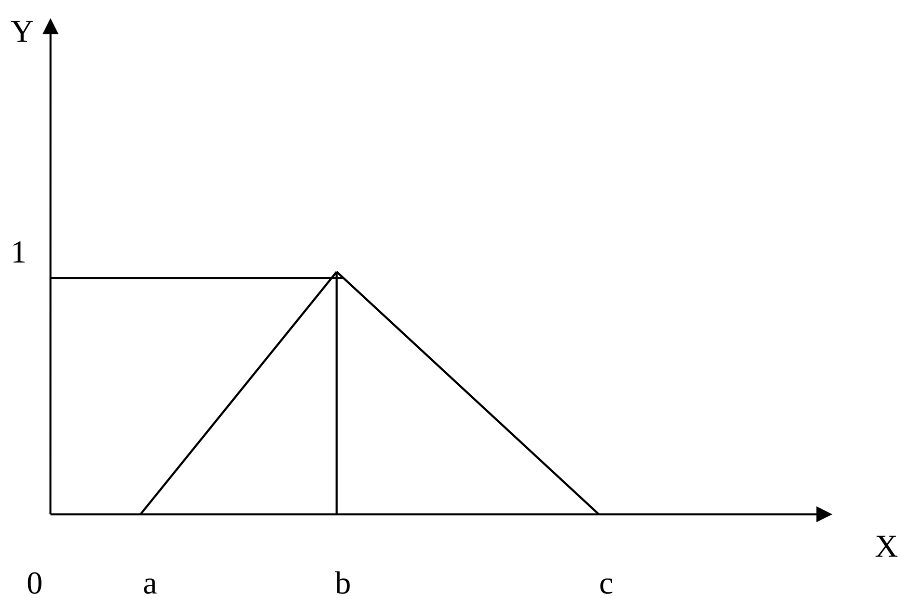

Figure 1. An example of triangular membership function

The basic concept of the ELECTRE method is how to deal with outranking relation by using pair wise comparisons among alternatives under each criterion separately. The outranking relationship of two alternatives, denoted as $\mathbf{A}1 \rightarrow \mathbf{A}2$, describes that even though two alternatives 1 and 2 do not dominate each other mathematically, the decision maker accepts the risk of regarding $\mathbf{A}1$ as almost surely better than $\mathbf{A}2$. Another peculiarity which differentiates ELECTRE from other methodologies is that it is not compensative, which means that a very bad score in one objective function is not compensated by good scores in other objectives.

Supplier selection criteria

In this study, Model 1 considers quantitative and qualitative criteria such as cost, risk, flexibility and environmental responsibility to determine suitable suppliers.

Cost (C1): Cost is considered as one of the most important criteria for supplier selection. Different factors of cost should be considered, such as:

Cost of product:

- Product price: The product cost is most certainly incremental in the decision-making process and it is often subjected to intensive negotiations before final price is set. However, the important aspect is that the best price does not always need to be the lowest; rather it is the most competitive price.
- Freight cost: The freight cost includes transportation cost, inventory cost, handling and package cost, damages during transportation, and insurance cost.
- Extra cost: Extra cost includes extra processing cost, maintenance cost, warranty cost, and other costs related to the manufacturing of the product when using the material provided by the supplier.

Cost of relationship: The cost to form a satisfactory buyer-supplier relationship, including financial cost, human resources, and coordinating and controlling cost.

Risk (C2): Risk can be broadly defined as a chance of danger, damage, loss, injury or any other undesired consequences. A more scientific definition of risk was provided by the Royal Society (1992): “The probability that a particular adverse event occurs during a stated period of time, or results from a particular challenge”. The risk factors have the significant capability to affect the selection process of the supplier. The risk factors discussed here can take care of some of the relevant issues like Supply constraint, Buyer-supplier constraint, Supplier’s profile, Geographical location, Political stability and effect of Terrorism on supplier selection process which requires much attention.

Flexibility (C3): Flexibility is the ability to implement different processes and apply different facilities to achieve the same goal. While selecting flexibility as supplier selection criteria, different dimensions of flexibility should be considered.

- *Volume flexibility*: The ability to adjust product volume as demanded by the buyer.
- *Product mix flexibility*: The ability to adjust product mix as demanded by the buyer.
- *Customization*: The ability to customize product as demanded by the buyer.
- *Process flexibility*: The ability to adjust manufacturing process as demanded by the buyer.
- *Emergency order processing*: The ability to fill emergency orders with required amount in a required time.

Environmental responsibility (C4): With growing worldwide awareness of environmental protection, increasing government regulation and stronger public awareness in environmental protection, firms today simply cannot ignore environmental issues if they want to survive in the global competitive market. Due to this buyer today are learning to purchase goods and services from suppliers that can provide them with low cost, high quality, short lead time, and at the same time with greater environmental responsibility. Various factors of product and services should be considered, which are essential for environment protection.

Green product: The factors that show the efforts of supplier in producing green product.

- Recycle: The level of recycling the products.
- Green packaging: The level of green materials used in packaging.

Pollution control: The factors that show the control of supplier in producing pollution.

- Air emission: The quantity control and treatment of hazardous emission such as SO_2, NH_3, CO, etc.
- Waste water: The quantity control and treatment of waste water.
- Solid waste: The quantity control and treatment of solid waste.

Environment management: The factors that show the efforts of supplier in environment management based on whether the supplier has environment related certificates such as ISO 14000.
In the remaining section, the two models used in this study are described.

Model 1: An algorithm for fuzzy ELECTRE method (Sevkli, Mehmet) for supplier selection
Figure 2 outlines various steps which constitute fuzzy ELECTRE method.

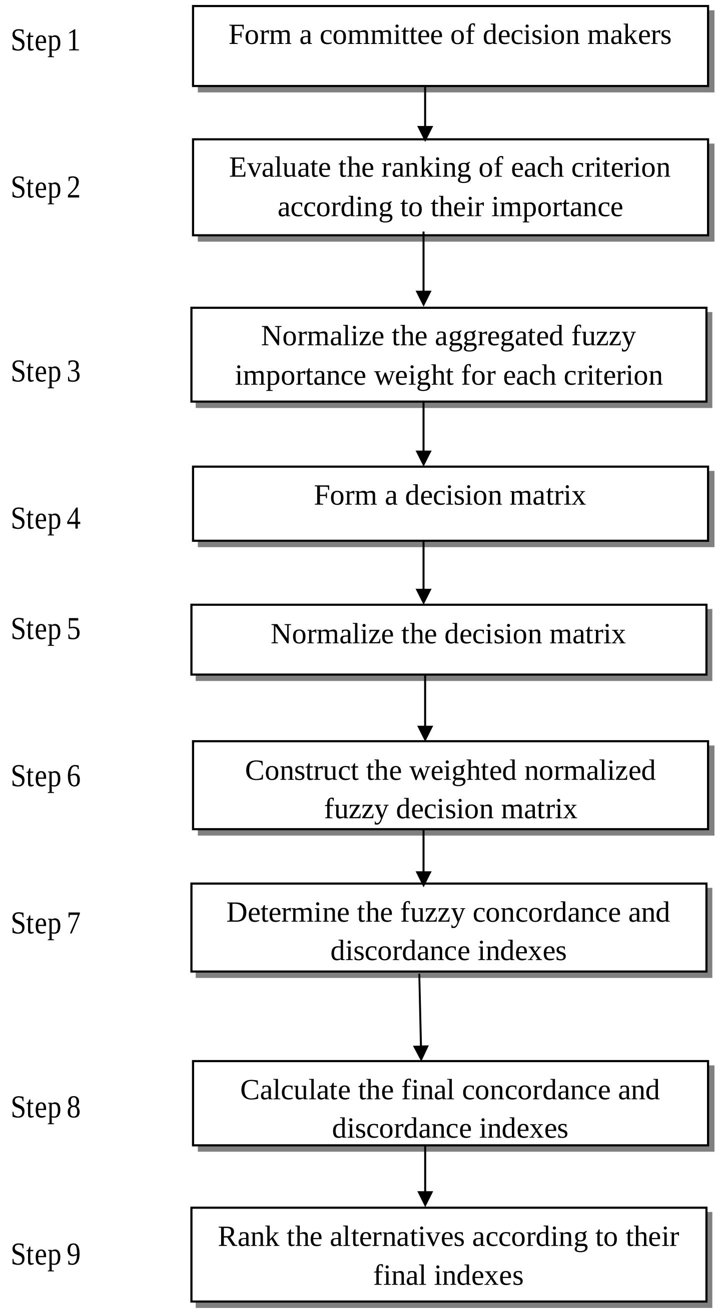

Figure 2. The steps of the fuzzy ELECTRE method. (Sevkli, Mehmet)

Details about various steps shown in Figure 3 are described below:

Step 1: Form a team of decision makers. These decision makers are from different functional areas of the organization. Determine the supplier selection criteria with the help of decision maker. These criteria are ranked according to their relative importance. Calculate aggregated fuzzy importance weights and their normalized aggregate fuzzy importance weight.

Step 2: Measure the performance of suppliers with respect to each selection criteria. This gives a decision matrix denoted by X = (x_{ij}) m*n Suppose a MCDM problem has *m* alternatives (A1,

$A_2,\ldots,A_m$) and n decision criteria ($C_1, C_2,\ldots, C_n$).

Step 3: Normalize the decision matrix $X = (x_{ij})\ m*n$ considering whether the objective of supplier selection criteria is that of minimization or maximization.
Calculate r_{ij}, which represents the normalized criteria,

$$r_{ij} = \frac{1/x_{ij}}{\sqrt{\sum_{i=1}^{m} 1/x_{ij}^2}} \quad (1)$$

for minimization objective, where $i = 1,2,..,m$ and $j = 1, 2, \ldots, n$,

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad (2)$$

for maximization objective, where $i = 1,2,..,m$ and $j = 1, 2, \ldots, n$.

Step 4: calculate the weighted normalized decision matrix $V = (v_{ij})\ m*n$

$$v_{ij} = r_{ij} * w_j \quad , \quad (3)$$

where $i = 1, 2,.., m$ and $j = 1, 2,\ldots,n$;

w_j is aggregated fuzzy importance weight for each criterion and $\sum_{j=1}^{n} wj = 1$.

Step 5: determine the fuzzy concordance and discordance sets. For each pair of alternatives A_p and A_q ($p, q = 1,2,.., m$) the set of criteria is divided into two distinct subsets. If alternative A_p is preferred to alternative A_q for all criteria, the concordance set is composed. This can be written as,

$$C(p, q) = \{j \mid V_{pj} > V_{qj}\} \quad (4)$$

where V_{pj} is the weighted normalized rating of alternative A_p with respect to the jth Criterion. In other words, C (p, q) is the collection of attributes where A_p is better than or equal to A_q.

The complement of C (p, q), the discordance set, contains all criteria for which A_p is worse than A_q. This can be written as,

$$D(p, q) = \{j \mid V_{pj} < V_{qj}\} \quad (5)$$

Step 6: calculate the final concordance and discordance indexes.

Concordance index of C(p, q) is defined as,

$$Cpq = \sum_{j*} w_{j*} \tag{6}$$

where j* are attributes contained in the concordance set C (p, q).

The discordance index D (p, q) represents the degree of disagreement in ($A_p \rightarrow A_q$) and can be defined as,

$$D_{pq} = \frac{\sum_{j\#} | Vpj\# - Vqj\# |}{\sum_j | Vpj - Vqj |} \tag{7}$$

where $j^{\#}$ are attributes contained in the discordance set D (p, q) and V_{ij} is the weighted normalized evaluation of alternatives i on criterion j.

Step 7: Rank the alternatives according to their final indexes.

Outranking relationship; the method defines that A_p outranks A_q when $C_{pq} \geq \bar{C}$ and $D_{pq} \leq \bar{D}$, where $\bar{C}$ and $\bar{D}$ are the averages of C_{pq} and D_{pq}, respectively.

The final concordance and discordance indices are computed using the following equations.

$$C^*_{pq} = \sqrt[z]{\prod_{z=1}^{Z} Cpq}\ , \tag{8}$$

$$D^*_{pq} = \sqrt[z]{\prod_{z=1}^{Z} Dpq}\ , \quad \text{where } Z = 3 \tag{9}$$

This formula can be considered as the defuzzification procedure. The dominance relationship of alternative A_p over alternative A_q becomes stronger with a larger final concordance index C_{pq} and a smaller final discordance index D_{pq}.

Model 2: Methodology for order splitting and supply chain performance evaluation

We start with the definition of reliability. Reliability is the ability of an item or a system to perform its intended function under stated operation condition for a given period of time.

Figure 3 is used to determine reliability of a system when the components are connected in parallel. When components A, B, C are connected in parallel having R(A), R(B) and R(C) reliabilities

respectively, then reliability of the system is given as,
Reliability of the system R (SS') = [1-(1-R (A))*(1-R (B))*(1-R (c))] 10)

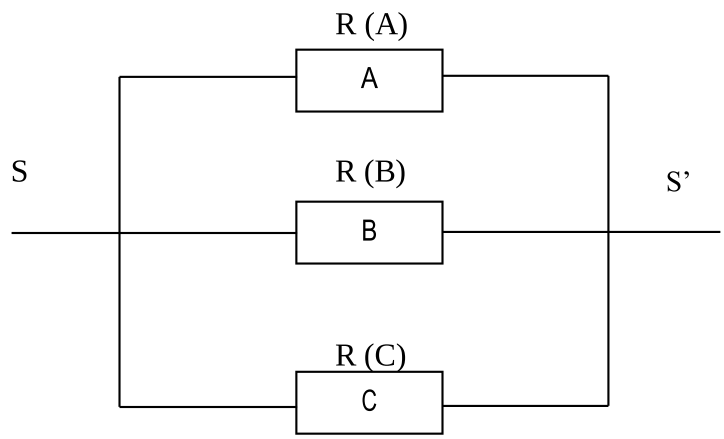

Figure 4. Components are connected in parallel

Analogy of reliability concept to suppliers and supply chain performance

Component A-------------------- supplier 1

Reliability of component A...........................performance index (PI) of supplier 1

Component B------------------- supplier 2

Reliability of component B...........................performance index (PI) of supplier 2

Component C--------------------supplier 3

Reliability of component C...........................performance index (PI) of supplier 3

Reliability of the system…… supply chain performance

Once the suitable suppliers are selected based on model 1, the next step is to split the order among selected suppliers and a supply chain performance. We have proposed methodology for order splitting and supply chain performance evaluation. The proposed methodology consists of following steps.

Step1: Rank the suppliers according to fuzzy ELECTRE. Generate random numbers equal to number of suppliers. Normalize the generated random numbers to assure that sum of random number equal to one. These normalized random numbers are called as average weights. Assign the average weights to selected suppliers. Assignment of average weights such that the most preferable supplier should have highest weight, second preferable supplier have lower than previous one etc.

Step2: Assign the weight for each supplier with respect to each selection criteria, assignment of weights such that assigned weights should not be greater than average assigned weight in step1.

Step3: Obtain the average of normalized aggregated fuzzy importance weight for each selection criteria, which are obtained from fuzzy ELECTRE method.

Step4: Calculate performance index (PI) for each supplier.
We compute the sum of the product of each assigned weight explained in step2 and the average of normalized aggregated fuzzy importance to obtain performance index.

Step5: Calculate supply chain performance:
Supply chain performance calculated by using equation (10)

Step6: Obtain the new weights for each supplier with respect to each selection criteria by dividing the supply chain performance to old weights which are discussed in step2.

Step7: Perform step 4 and step 5 until supply chain performance improves.

Step8: Where the supply chain has highest performance for that step calculate average weights for each supplier. Normalize these average weights and split the order according to normalized average weight.

4. APPLICATIONS OF MODELS

The application of the supplier selection fuzzy ELECTRE model and order splitting and supply chain performance evaluation model was undertaken in an industry X India's plant in North East to select the suitable suppliers in actual industrial scenario.

About the company

A company X in India is a UK based company which specializes in making earthmovers and lifters. It is the fastest growing company in the Indian earthmoving and construction equipment industry. The company is a pioneer in the industry and has been recording excellent growth rates. The company has ambitious development and expansion plans through launching revolutionary products and adherence to world class company's X corporate identity norms. In India, company X has a park of over 80,000 machines. Out of two Construction equipment sold in India, one is of the company X.
Company X in India offers a diverse range of Backhoe Loaders, Wheeled Loaders, Excavators, Skid Steer loaders, Telehandlers, Compactors and Pick and Carry Crane. However, the plant in north east of India is famous for the highly appreciated and high utility earth-mover named the 3DX Backhoe Loader.

Outsourcing operations in the company

Company X India relies heavily on outsourcing for its back-end operations. The company works with a wide range of suppliers in and around Faridabad. Being one of the biggest brands, Company X commands a lot of authority in designing and operations of its suppliers. Some of the parts that are outsourced include: Cabins, Shovel, Bucket, Steel Plates, Engines, Lights and Other smaller machine parts.

The supplier selection in company X is done via a rigorous process of supplier-evaluation where-in a supplier has to prove its mettle on various technical and managerial levels. Company X continuously interacts with its suppliers so as to help them grow with the company. However, the exercise of order splitting is mainly cost-driven. The recent performance of suppliers is also considered, and it gets reflected in small increase or decrease in the supplies. However, the criteria like risk, flexibility and environmental responsibility are not analyzed rigorously.

Application of Model 1 in Company X

A team of decision makers is formed; these decision makers are from different functional areas of the organization (**Step 1**). Decision makers are asked to rank these criteria according to their relative importance. A decision maker's team consists of K decision makers (i.e. D1, D2… DK) who are responsible for ranking (Y_{jk}) for each criterion (i.e. C1, C2… Cn) (**Step 2**). Then the aggregated fuzzy importance weight for each criterion described as Triangular Fuzzy Numbers (TFN),

wj = (aj, bj, cj)

The aggregated fuzzy importance weight can be determined by first calculating aj, bj and cj as follows

$$a_j = \min_k\{Y_{jk}\}, \quad bj = \frac{1}{K}\sum_{k=1}^{K} Y_{jk}, \quad c_j = \max_k\{Y_{jk}\} \tag{11}$$

for k = 1, 2,…,K and j = 1, 2,…, n

The aggregated fuzzy importance weight for each criterion is normalized as follows (**step 3**),

$W_j = (w_{j1}, w_{j2}, w_{j3})$,

Where,

$$w_{j1} = \frac{1/aj}{\sum_{j=1}^{n} 1/aj}, \qquad w_{j2} = \frac{1/bj}{\sum_{j=1}^{n} 1/bj}, \qquad w_{j3} = \frac{1/cj}{\sum_{j=1}^{n} 1/cj} \tag{12}$$

The normalized aggregated fuzzy importance weight matrix is constructed as,

$W = [w_1, w_2, \ldots\ldots, w_n]$.

The normalized aggregated fuzzy importance weight matrix is constructed as, W = [w1, w2… wn]. The linguistic scale used for the four supplier selection criteria in company X was based on Figure 5.

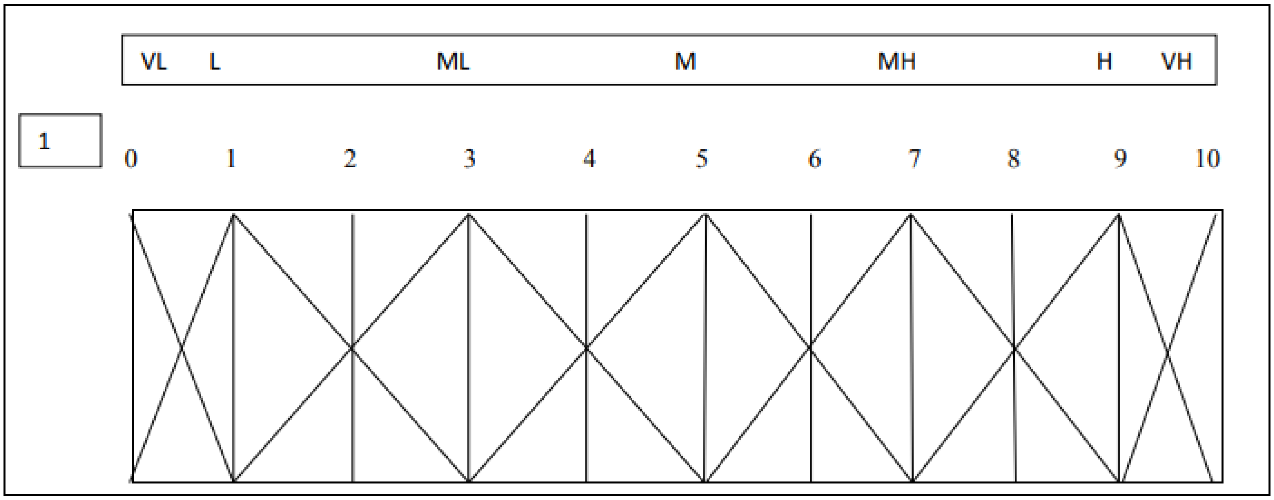

Figure 5. Linguistic scale for supplier selection criteria

The linguistic scale in Figure 1 enabled assignment of linguistic variables to each supplier selection criterion shown in Table 2.

Criteria (j) Decision makers (k) →

Criteria										
C1	VH	H	H	H	VH	MH	MH	VH	H	MH
C2	H	H	MH	M	ML	VH	ML	M	VH	ML
C3	M	MH	H	H	ML	VH	MH	H	ML	H
C4	H	VH	M	MH	ML	H	VH	H	MH	H

Table 2. Assignment of Linguistic variables to each criterion

The aggregated fuzzy importance weights determined by first calculating aj, bj and cj using equation (11):

$a_1 = 5$, $b_1 = 8.7$, $c_1 = 10$,

$a_2 = 1$, $b_2 = 6.4$, $c_2 = 10$,

$a_3 = 1$, $b_3 = 7.1$, $c_3 = 10$,

$a_4 = 1$, $b_4 = 7.8$, $c_4 = 10$

Normalized aggregated fuzzy importance weights w_{j1}, w_{j2}, and w_{j3} for j=1, 2, 3 and 4 are determined by utilizing equation (12) which uses values of a_j, bj and c_j for j=1, 2, 3 and 4 just calculated. For example, $w_{11} = (1/5) / ((1/5) +1+1+1) = 0.061$.
Similarly, $w_{21} = 0.313$, $w_{31} = 0.313$, $w_{41} = 0.313$,
$w_{12} = 0.213$, $w_{22} = 0.289$, $w_{32} = 0.261$, $w_{42} = 0.237$,
$w_{13} = 0.25$, $w_{23} = 0.25$, $w_{33} = 0.25$, $w_{43} = 0.25$.
The above calculated values of w_{j1}, w_{j2}, and w_{j3} for j=1, 2, 3 and 4 are added to Table 3.

criterion	W_{j1}	W_{j2}	W_{j3}
Cost (w_1)	0.061	0.213	0.25
Risk (w_2)	0.313	0.289	0.25
Flexibility (w_3)	0.313	0.261	0.25
Environmental responsibility (w_4)	0.313	0.237	0.25
Total	1.000	1.000	1.00

Table 3. Normalized aggregated fuzzy importance weight matrix (W) (**Step 3**)

Input data provided by company

The model was applied on the supply of headlight. Each backhoe loader consists of four headlights.
The headlights are supplied to the company X by three main suppliers:

- SPA Pvt. Ltd.
- ML Pvt. Ltd.
- NL

Table 4 shows data pertaining to three suppliers.

Table 4. Suppliers' data details

Next. we normalize the decision matrix according to equation (1) and equation (2) shown in table 6 (**Step 5**)

	Min cost	Min risk	Max flexibility	Max Environmental responsibility
A	0.560	0.692	0.598	0.602
B	0.604	0.554	0.556	0.564
C	0.579	0.461	0.566	0.564

Table 6. Normalized decision matrix

The next step is to determine weighted normalized decision matrix (**Step 6**). Considering different weights of each criterion, the weighted normalized decision matrix is computed by multiplying the importance weight of the evaluation criteria and the values in the normalized decision matrix. The weighted normalized decision matrix V for each criterion is defined as

$V = [V_{ij}]_{m*n}$ for i = 1, 2, …,m and j = 1, 2,…,n,

where $V_{ij} = r_{ij} * W_j$ (13)

Weighted normalized decision matrices are shown in table 7, table 8 and table 9. Weighted normalized decision matrix (V_1):

	Min cost	Min risk	Max flexibility	Max Environmental responsibility
A	0.034	0.216	0.187	0.188
B	0.036	0.173	0.177	0.176
C	0.035	0.144	0.177	0.176

Table 7. Weighted normalized decision matrix (V_1)

Weighted normalized decision matrix (V_2):

	Min cost	Min risk	Max flexibility	Max Environmental responsibility
A	0.129	0.199	0.156	0.142
B	0.139	0.160	0.147	0.133

C	0.133	0.133	0.147	0.133

Table 8. Weighted normalized decision matrix (V_2)

Weighted normalized decision matrix (V_3):

	Min cost	Min risk	Max flexibility	Max Environmental responsibility
A	0.140	0.173	0.149	0.150
B	0.151	0.138	0.141	0.141
C	0.144	0.115	0.141	0.141

Table 9. Weighted normalized decision matrix (V_3)

Calculation of concordance and discordance index

The concordance and discordance indexes are calculated by using equation (4) and (5) respectively. The concordance and discordance indexes for weighted normalized decision matrix (V_1):

Concordance index C (pq)	Discordance index D (pq)
C (AB) = 0.687	D (AB) = 0.641
C (AC) = 0.687	D (AC) = 0.757
C (BA) = 0.313	D (BA) = 0.358
C (BC) = 0.626	D (BC) = 1.00
C (CA) = 0.313	D (CA) = 0.242
C (CB) = 1.00	D (CB) = 0.00

Table 10. Concordance and discordance indexes for weighted normalized decision matrix (V_1)

The concordance and discordance indexes for weighted normalized decision matrix (V_2):

Concordance index C (pq)	Discordance index D (pq)

C (AB) = 0.729	D (AB) = 0.582
C (AC) = 0.729	D (AC) = 0.750
C (BA) = 0.289	D (BA) = 0.417
C (BC) = 0.498	D (BC) = 1.00
C (CA) = 0.289	D (CA) = 0.25
C (CB) = 1.00	D (CB) = 0.00

Table 11. Concordance and discordance indexes for weighted normalized decision matrix (V_2)

The concordance and discordance indexes for weighted normalized decision matrix (V_3):

Concordance index C (pq)	Discordance index D (pq)
C (AB) = 0.75	D (AB) = 0.555
C (AC) = 0.75	D (AC) = 0.05
C (BA) = 0.25	D (BA) = 0.444
C (BC) = 0.50	D (BC) = 1.00
C (CA) = 0.25	D (CA) = 0.265
C (CB) = 1.00	D (CB) = 0.00

Table 12. Concordance and discordance indexes for weighted normalized decision matrix (V_3)

Fuzzy ELECTRE Results

The final concordance and discordance indexes are computed using the following equation (8) and (9) respectively.
$\bar{C} = 0.59$ and $\bar{D} = 0.425$

	Wj1	Wj2	Wj3	Final index	Overall outranking $C(p, q) \geq \bar{C}$ and $D(p, q) \leq \bar{D}$

C(A, B)	0.687	0.729	0.75	0.721	
C(A, C)	0.687	0.729	0.75	0.721	(A,C)
C(B, A)	0.313	0.289	0.25	0.282	
C(B, C)	0.626	0.498	0.50	0.538	
C(C, A)	0.313	0.289	0.25	0.282	
C(C, B)	1.00	1.00	1.00	1.00	(C,B)
D(A, B)	0.641	0.582	0.555	0.591	
D(A, C)	0.757	0.75	0.05	0.305	
D(B, A)	0.358	0.417	0.444	0.404	
D(B, C)	1.00	1.00	1.00	1.00	
D(C, A)	0.242	0.25	0.265	0.252	
D(C, B)	0.00	0.00	0.00	0.00	

Table 13. Fuzzy ELECTRE Results

By using fuzzy ELECTRE approach supplier A is identified as the most preferable supplier. Supplier C is second preferable and supplier B is identified as least preferable supplier.

Application of model 2 in company X

Suppliers are ranked according to fuzzy ELECTRE. Model 2 is applied to split the order among selected suppliers and evaluate the supply chain performance as explained in section 3.7

Step 1: Random numbers: 0.273, 0.3, And 0.916

Normalized random numbers: 0.184, 0.2, 0.616

	C1	C2	C3	C4	Average weight
A					0.616
C					0.20
B					0.184

Table 14. Assigning average weight to each supplier

Step2: Assign the weight for each supplier with respect to each selection criteria.

	C_1	C_2	C_3	C_4	Average weight
A	0.60	0.71	0.50	0.65	0.616
C	0.24	0.14	0.20	0.25	0.20
B	0.17	0.19	0.19	0.18	0.184

Table 15. Assigning weight to each supplier and criteria

Step3: Obtain the average of normalized aggregated fuzzy importance weight for each selection criteria, which are obtained from fuzzy ELECTRE method (from table 3).

Criterion	$W_{average}$
C_1	0.18
C_2	0.28
C_3	0.27
C_4	0.27

Table 16. Average of normalized aggregated fuzzy importance weight

Step4: Performance index (PI) for each supplier

PI of supplier A = 0.617, PI of supplier C = 0.203,
PI of supplier B = 0.183

Step5: supply chain performance calculated by using equation (10) based on PI values for suppliers A, B and C.
Supply chain performance = [1 - (1- 0.617)(1-0.203)(1- 0.183)] = 0.75

Step8: after repeating step6 and step7 a final matrix is obtained as,

	C_1	C_2	C_3	C_4	Average weight
A	0.97	1.14	0.79	1.04	0.985
C	0.37	0.21	0.29	0.38	0.312
B	0.25	0.28	0.28	0.27	0.27

Table 17. Improved weight matrix

PI of supplier A = 0.987,

PI of supplier C = 0.306,

PI of supplier B = 0.217

Supply chain performance = [1 - (1- 0.987)(1-0.306)(1- 0.217)] = 0.993

Average weights for each supplier

Average weights for supplier A = 0.985,

Average weights for supplier C = 0.312,

Average weights for supplier B = 0.27

Normalized average weights for each supplier

Normalized average weights for supplier A = 0.628,

Normalized average weights for supplier C = 0.199,

Normalized average weights for supplier B = 0.172

If Split the order according to normalized average weight then supply chain has 99.3% performance.

Order for supplier A = 1300 * 0.628 = 816.4 ≡ 817,

Order for supplier C = 1300 * 0.199 = 258.7 ≡ 259,

Order for supplier B = 1300 * 0.172 = 223.6 ≡ 224.

Supply chain performance for company X according to their order splitting strategy

Average weights for each supplier can be calculated as follows,

Average weight for supplier A = 650 / 1300 = 0.50,

Average weight for supplier C = 300 / 1300 = 0.23,

Average weight for supplier B = 350 / 1300 = 0.27

Consider calculated average weights for each supplier as normalized average weights.

Therefore, performance index (PI) for each supplier is,

PI for supplier A = 0.5,

PI for supplier C = 0.23,

PI for supplier B = 0.27

Supply chain performance calculated by using equation (10)

Supply chain performance = [1 – (1- 0.5) * (1 – 0.23) * (1 – 0.27)] = 0.718

Supply chain performance of company X = 71.8 %

5. RESULTS AND DISCUSSION

Application of model 1 and model 2 in Company X

Application of model 1 fuzzy ELECTRE for supplier selection shows that SPA Pvt. Ltd. is the most preferable supplier and ML Pvt. Ltd. is the least preferable while NL is in between them.

Orders placed by JCB

Suppliers	Order placed
SPA Pvt. ltd	650
NL pvt ltd	300
ML	350

Table 18. Orders placed by company X

Table 18 indicates that SPA ltd. receives huge orders. In fact, ML provides cheaper rates than SPA. However, SPA has been a long-time partner for company X. ML and NL pvt ltd are comparatively new. This is the prime reason why SPA has the largest share.
As discussed in previous section, supply chain performance of company X is 71.8 %.

Application of model 2 for order splitting and supply chain performance evaluation shows that splitting the orders according to following table 19, supply chain has highest performance i.e. 99.3%.

Suppliers	Place order
SPA pvt ltd.	817
NL	259
ML Pvt. Ltd.	224

Table 19. Placing order according to model 2

Results show that if company X place orders according to proposed model (table 19) instead of its own strategy (table 18) then they have 99.3 % supply chain performance instead of 71.8 %.

6. CONCLUSION AND FUTURE WORKS

The supplier selection decision is crucial to the success of manufacturing firm. Suppliers are selected based on set of criteria, cost, risk, flexibility and environmental responsibility. These criteria cannot be measured quantitatively and precisely using traditional decision-making tools such as crisp ELECTRE. To overcome this deficiency, fuzzy numbers, which make it easier to capture the decision maker's subjective assessment related to supplier selection criteria, are applied to make accurate and consistent supplier selection decisions.

Drawing on a real case the findings indicate that, of the three alternative suppliers in our case, supplier A was found to be the most favorable, supplier C was the second favorable supplier and supplier B was the least favorable supplier under the fuzzy ELECTRE approach.

A model is proposed for order splitting and evaluating supply chain performance. Proposed model suggest that split the order according to normalized average weights. Splitting order according to normalized average weights indicate that supply chain has highest performance.

The major contributions of this study are the application of fuzzy ELECTRE for supplier selection decision and development and application of model for order splitting and supply chain performance evaluation drawing on a real industry case.

This research can also be extended by incorporating additional selection criteria such information sharing and trust. Adding more alternative suppliers that encompass both domestic and international suppliers may serve as another avenue for future research.

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