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Supplier Selection Criteria and Methods in Supply Chains: A Review

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***Abstract*—**An effective supplier selection process is very important to the success of any manufacturing organization. The main objective of supplier selection process is to reduce purchase risk, maximize overall value to the purchaser, and develop closeness and long-term relationships between buyers and suppliers in today's competitive industrial scenario. The literature on supplier selection criteria and methods is full of various analytical and heuristic approaches. Some researchers have developed hybrid models by combining more than one type of selection methods. It is felt that supplier selection criteria and method is still a critical issue for the manufacturing industries therefore in the present paper the literature has been thoroughly reviewed and critically analyzed to address the issue.

***Keywords*—**Supplier selection, AHP, ANP, TOPSIS, Mathematical Programming.

I. Introduction

IN most industries, the cost of raw materials and component parts represents the largest percentage of the total product cost. For instance, in high technology firms, purchased materials and services account for up to 80% of the total product cost. Therefore, selecting the right suppliers is the key to procurement process and represents a major opportunity for companies to reduce costs across its entire supply chain. Choosing the right method for supplier selection effectively leads to a reduction in purchase risk and increases the number of JIT suppliers and TQM production. Supplier selection problem has become one of the most important issues for establishing an effective supply chain system.

For many years, the traditional approach to supplier selection has been to select suppliers solely on the basis of price. However, as companies have learned that the sole emphasis on price as a single criterion for supplier selection is not efficient, they have turned into to a more comprehensive multi-criteria approach. Recently, these criteria have become increasingly complex as environmental, social, political, and customer satisfaction concerns have been added to the traditional factors of quality, delivery, cost, and service. The realization that a well-selected set of suppliers can make a strategic difference to an organization's ability to provide continuous improvement in customer satisfaction drives the search for new and better ways to evaluate and select suppliers. The use of multiple suppliers provides greater flexibility due to the diversification of the firm's total requirements and fosters competitiveness among alternative suppliers. Keeping in view the strategic importance of the supplier's role in the functioning of supply chains the researchers have developed number of criteria, methods and models for supplier selection. The relevant literature has been thoroughly reviewed and presented below.

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II. Literature Review

Weber, C. A. et al. [1] reviewed, annotated, and classified 74 related articles which have appeared since 1966. Specific attention was given to the criteria and analytical methods used in the vendor selection process. In response to the increased interest in Just-In-Time (JIT) manufacturing strategies, and analysis of JIT's impact on vendor selection was also discussed by the authors.

Degraeve, Z. et al. [2] focused on a combinatorial auction where a bidder can express his preferences by means of a so-called ordered matrix bid. Authors gave an overview of how this auction works and elaborated on the relevance of the matrix bid auction. The methods to verify whether a given matrix bid satisfies a number of properties related to micro-economic theory were developed. Finally, authors investigated how a collection of arbitrary bids can be represented as a matrix bid.

Tung and Torng [3] presented a fuzzy decision-making approach to deal with the supplier selection problem in supply chain system. In this work linguistic values are used to assess the ratings and weights for various factors. These linguistic ratings can be expressed in trapezoidal or triangular fuzzy numbers. Then, a hierarchy multiple criteria decision-making (MCDM) model based on fuzzy-sets theory is proposed to deal with the supplier selection problems in the supply chain system. According to the concept of the TOPSIS, a closeness coefficient is defined to determine the ranking order of all suppliers by calculating the distances to the both fuzzy positive-ideal solution (FPIS) and fuzzy negative-ideal solution (FNIS) simultaneously.

Lewis [4] suggested that of all the responsibilities that related to purchasing, none was more important than the selection of a proper source. As long as supplier relationship management (SRM) concept is concerned, Companies are trying to build long-term and profitable relationships with suppliers. There has been an evolution in the role and structure of the purchasing function through the nineties. The purchasing function has gained great importance in the supply chain management due to factors such as globalization,

increased value added in supply, and accelerated technological change.

Zeng, A. Z. [5] developed an integrated optimization framework for joint decisions of sourcing and lot sizing for sustaining time-based competitiveness. Author developed an optimization procedure that can be conveniently implemented on a spreadsheet to determine the optimal number of sources and the lot size and the sensitivity analysis shows that the impact of transportation on the sourcing and lot sizing decisions is significant.

Aissaoui, et al. [6] extended previous survey papers by presenting a literature review that covers the entire purchasing process, considers both parts and services outsourcing activities, and covers internet-based procurement environments such as electronic marketplaces auctions. In view of its complexity, authors focused especially on the final selection stage that consists of determining the best mixture of vendors and allocating orders among them so as to satisfy different purchasing requirements.

Tahriri, F. et al. [7] state that in today's highly competitive environment, an effective supplier selection process is very important to the success of any manufacturing organization. Supplier selection is a multi-criterion problem which includes both qualitative and quantitative factors (criteria). A trade-off between these tangible and intangible factors is essential in selecting the best supplier. Authors further discussed and compared the advantages and disadvantages of different selection methods concerning supplier selection especially the Analytic Hierarchy Process (AHP).

Burton, T.T. [8] states that for many firms, purchases from outside vendors account for a large percentage of their total operating costs. The raw material purchased for most U.S. firms constitutes 40-60% of the unit cost of a product. For large automotive manufacturers, the cost of components and parts purchased from outside vendors may total more than 50% of sales. Purchased material and services represent up to 80% of total product costs for high technology firms.

Abratt [9] analyzed the buying behavior of purchasers of high technology laboratory instrumentation process and identifies and determines the relative importance of the factors influencing supplier selection. Research was undertaken with 54 organizations.

Sharland et al. [10] empirically examined the impact of cycle time on supplier selection and on the effectiveness of long-term relationships with suppliers, as reflected in the commitment and trust developed. Authors observed that initial cycle time is not a significant predictor of trust and commitment in the context of supplier-buyer long-term relationships. However, cycle time reduction along with consistently high quality were found to be significant predictors of trust and commitment in long-term relationships

Lin et al. [11] identified the factors affecting the supply chain quality management. Authors observed that Quality Management (QM) practices are significantly correlated with the supplier participation strategy and this influences tangible business results, and customer satisfaction levels. It is further observed that QM practices are significantly correlated with the supplier selection strategy.

Gonzalez et al. [12] developed a methodology to analyze the variables involved in the supplier management process and it is illustrated with a case study of the chair manufacturing industry. The results indicate that the supplier selection process appears to be the most significant variable as it helps in achieving high quality products and customer satisfaction. Total Nine variables related to the supplier selection process were analyzed. Each of these variables was then evaluated through an experimental design using statistical information based on three factors, namely, quality, cost and productivity.

Humphreys et al. [13] presented a framework for integrating environmental factors into the supplier selection process. Traditionally, companies consider factors like quality, flexibility, etc. when evaluating supplier performance. However, environmental pressure is increasing, resulting in many companies beginning to consider environmental issues and the measurement of their suppliers' environmental performance. Authors developed a decision support tool which should help companies to integrate environmental criteria into their supplier selection process. Finally, a knowledge-based system is constructed based on the proposed framework.

Yan and Wei [14] described a mini-max principle based procedure of preference adjustments with a finite number of steps to find compromise weights. Authors thoroughly discuss the problem of the existence of multiple optimal solutions and define a set of very worst preference order, which is independent of the selection of optimal solutions. Finally it is proved that compromise weights can be achieved within a finite number of adjustments on preference orders.

Svensson [15] investigated the models of supplier segmentation and supplier selection criteria. Empirical illustrations of supplier segmentation based on the perspectives of a VM and its suppliers are presented. One of the models consists of two dimensions: the supplier's commitment to a VM; and the commodity's importance to a VM. In extension, another model of dynamic relationship strategies is introduced. It consists of four relationship strategies towards suppliers in the automotive industry, such as family, business partner, friendly, and transactional.

Lee et al. [16] proposes a methodology which identifies the managerial criteria using information derived from the supplier selection processes and makes use of them in the supplier management process. For this methodology, authors propose the supplier selection and management system (SSMS) that includes purchasing strategy system, supplier selection system, and supplier management system, and explained how the SSMS is applied to a real supply chain. The methodology identifies the managerial criteria using information derived from supplier selection process and makes use of them in the supplier management process. The effectiveness of supplier management with managerial criteria was verified by a t-test and a correlation analysis.

Pearson and Ellram [17] states that one important domain of management is the selection and evaluation of suppliers. Authors examined and explore the techniques currently used to select and evaluate suppliers by studying a sample of small

and large firms in the electronics industry.

Verma and Pullman [18] examines the difference between managers' rating of the perceived importance of different supplier attributes and their actual choice of suppliers in an experimental setting. Authors use two methods: a Likert scale set of questions, to determine the importance of supplier attributes; and a discrete choice analysis (DCA) experiment, to examine the choice of suppliers. The results indicate that although managers say that quality is the most important attribute for a supplier, they actually choose suppliers based largely on cost and delivery performance.

Dulmin and Mininno [19] made the effort to highlight those aspects that are crucial to process qualitative and quantitative performance measures. The contribution of a multi-criteria decision aid method to such problems is investigated, together with how to allow for a simultaneous change of the weights, generating results that can be easily analyzed statistically, performing an innovative sensitivity analysis.

Monczka et al. [20] suggested seven step methodology for supplier selection and evaluation process. These steps are: Recognition of Need for Supplier Selection, Identify Key Sourcing Requirements and Criteria, Determine Sourcing Strategy, Identify Potential Supply Sources, Pre-qualification of Potential Suppliers, Determine Method for Final Selection and Select Suppliers and Reach Agreement.

De Boer, L. [21] stated that so far the application of outranking methods in purchasing decisions has not been suggested in purchasing or operations research literature. Authors have shown by means of a supplier selection example, that an outranking approach may be very well suited as a decision making tool for initial purchasing decisions.

Weber, C.A. [22] reviews, annotates, and classifies 74 related articles which have appeared since 1966. Specific attention is given to the criteria and analytical methods used in the vendor selection process. In response to the increased interest in Just-In-Time (JIT) manufacturing strategies, and analysis of JIT's impact on vendor selection is also presented. Finally, conclusions and potential areas for future research are presented.

Li and Fun [23] proposed a supplier performance measure using the concept of dimensional analysis to obtain an index called the VPI (Vendor Performance Index). Usually the performance criteria used in supplier performance evaluation include quantitative and qualitative criteria. Here a new supplier performance measure is proposed as an alternative to the VPI. For qualitative criteria, a two-directional consideration is used instead of a one-directional approach, which results in only a single score. The fuzzy bag method is used to compensate for blindness in human judgment. Then all scores for quantitative and qualitative criteria are combined in an intuitive sum of weighted averages called the SUR.

Weber, C.A. et al. [24] describe three approaches for the selection and negotiation with vendors who were not selected. Furthermore, it describes how in certain situations two multi-criteria analysis tools, multi-objective programming and data envelopment analysis, can be used together for this selection and negotiation process. The paper describes non-cooperative vendor negotiation strategies where the selection of one vendor results in another being left out of the solution.

Weber and Desai [25] demonstrated the use of data envelopment analysis for measuring vendor performance and efficiency. An algorithm is employed for determining points of vendor efficiency on multiple criteria. This study then demonstrates how parallel coordinates graphical representation can be used to display the efficiency of vendors on multiple criteria, and, in so doing, visually identify benchmark values on these criteria for negotiating with inefficient vendors.

Weber and Ellram [26] explore the use of a multi-objective programming approach as a method for supplier selection in a just-in-time (JIT) setting. Based on a case study, develops a model of JIT supplier selection which allows for simultaneous trade-offs of price, delivery and quality criteria. A multi-objective programming decision support system is seen as advantageous because such an environment allows for judgment in decision making while simultaneously trading off key supplier selection criteria.

Maggie and Tummala [28] formulated an AHP-based model and applied it to a real case study to examine its feasibility in selecting a vendor for a telecommunications system. The use of the proposed model indicates that it can be applied to improve the group decision making in selecting a vendor that satisfies customer specifications. Also, it is found that the decision process is systematic and that using the proposed AHP model can reduce the time taken to select a vendor.

Hill and Nydick [29] have shown how AHP can be used to structure the supplier selection process. This method of selection is described, and a detailed, hypothetical example of how AHP can be used also is provided. Finally, a framework is presented that any buying organization can adapt to fit its specific set of needs.

Liu and Hai [30] compared the weighted sum of the selection number of rank vote, after determining the weights in a selected rank in order to decide the total ranking of the suppliers. This investigation presents a novel weighting procedure in place of AHP's paired comparison for selecting suppliers. It provides a simpler method than AHP that is called voting analytic hierarchy process, but which does not lose the systematic approach of deriving the weights to be used and for scoring the performance of suppliers.

Ellram, L. M. [33] examines case studies of 11 firms which use total cost of ownership concepts in purchasing. Based on the case study data and the literature, barriers and benefits associated with the total cost of ownership approach are discussed. The total cost of ownership models used by the case study firms are classified by type as dollar-based or value-based. The total cost of ownership models are then further classified by their primary usage: supplier selection or supplier evaluation. This cross classification reveals a strong relationship between model type and model usage.

Elanchezhian, C. [34] used a versatile technique namely multi criteria decision making (MCDM) technique which involves the analytical network process (ANP) and technique

for order performance by similarity to ideal solution (TOPSIS) method to select the best vendor. Authors developed standard software in a suitable platform such as VB, .NET and MS access.

Min, H. [35] proposes multiple attribute utility theory which can help purchasing professionals to formulate viable sourcing strategies in the changing world marketplace particularly for international supplier selection. Authors considered the factors including political situations, tariff barriers, cultural and communication barriers, trade regulations and agreements, currency exchange rates, cultural differences, ethical standards, quality standards and so forth.

Sanayei, A. et al. [39] proposed an integrated approach of multi-attribute utility theory (MAUT) and linear programming (LP) for rating and choosing the best suppliers and defining the optimum order quantities among selected ones in order to maximize total additive utility.

Shyur and Shih [40] proposed a hybrid model for supporting the vendor selection process. First, the vendor evaluation problem is formulated by the combined use of the multi-criteria decision-making (MCDM) approach and a proposed five-step hybrid process, which incorporates the technique of an analytic network process (ANP). Then the modified TOPSIS is adopted to rank competing products in terms of their overall performances. The newly developed ANP will eventually yield the relative weights of the multiple evaluation criteria, which are obtained from the nominal group technique (NGT) with interdependence.

III. Various Criteria for Supplier Selection

On the basis of the literature reviewed above it has been observed that the basic criteria typically utilized for selecting the suppliers are pricing structure, delivery, product quality, and service etc. While most buyers still consider cost to be their primary concern, few more interactive and interdependent selection criteria are increasingly being used by the manufacturers. The various important criteria for the supplier selection as observed from the literature reviewed above are:

- Price
- Quality
- Delivery
- Performance History
- Warranties & Claims Policies
- Production Facilities and Capacity
- Technical Capability
- Financial Position
- Procedural Compliance
- Reputation and Position in Industry
- Desire for Business
- Repair Service
- Attitude
- Packaging Ability
- Labor Relations Record
- Geographical Location
- Amount of Past Business
- Reciprocal Arrangement

It has been observed from the literature that the price, delivery, and quality continued to be considered most important criteria by most of the researchers. With economic globalization, companies choose suppliers globally from anywhere in the world. For instance, developing countries are becoming more competitive because of their low labor and operating costs.

IV. Various Supplier Selection Methods

Various supplier selection methods as observed in the literature have been classified in to a number of broader categories. Fig. 1 presents various supplier selection methods as discussed in the literature. Some of the most commonly used methods for supplier selection are discussed briefly here.

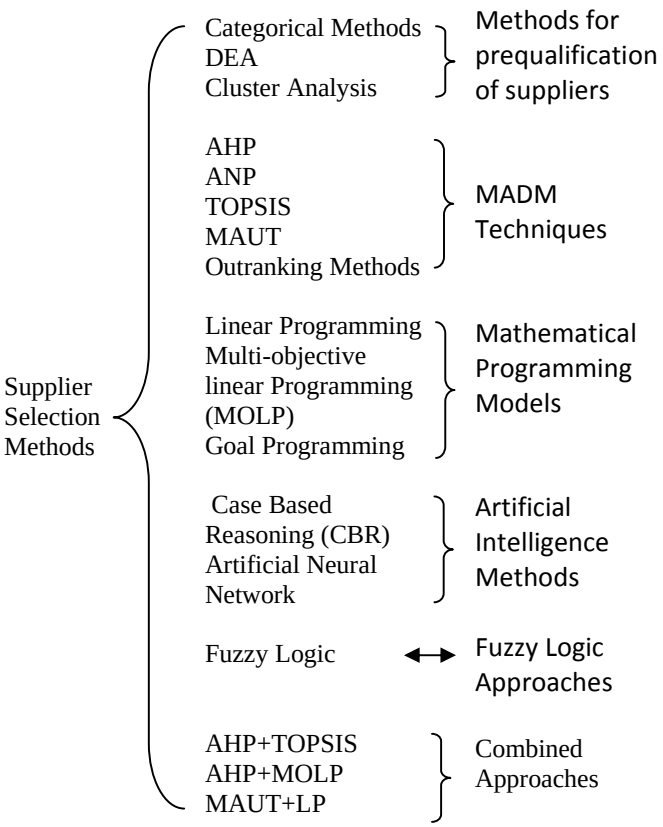

Fig. 1 Various Supplier Selection Methods

V. Methods for Prequalification of Suppliers

Prequalification is the process of reducing the set of all suppliers to a smaller set of acceptable suppliers. The various methods available under this category are:

A. Categorical Methods

Basically, categorical methods are qualitative models. Based on historical data and the buyer's experience, current or familiar suppliers are evaluated on a set of criteria. After a supplier has been rated on all criteria, the buyer gives an overall rating. The primary advantage of the categorical approach is that it helps structure the evaluation process in a

clear and systematic way.

B. Data Envelopment Analysis (DEA)

DEA is a classification system that splits suppliers between two categories, 'efficient' or 'inefficient'. Suppliers are judged on two sets of criteria, i.e. outputs and inputs. DEA considers a supplier to have a relative efficiency of 100% if he produces a set of output factors that is not produced by other suppliers with a given set of input factors. Weber et al. [27], [28], and [29] have primarily discussed the application of DEA in supplier selection in several publications.

C. Cluster Analysis (CA)

CA is a basic method from statistics which uses a classification algorithm to group a number of items which are described by a set of numerical attribute scores into a number of clusters such that the differences between items within a cluster are minimal and the differences between items from different clusters are maximal. This classification is used to reduce a larger set of suppliers into smaller more manageable subsets. Hinkle et al. [27] were the first to report this.

VI. Multi Attribute Decision Making (MADM) Techniques

A vendor selection problem usually involves more than one criterion and these criteria often conflict with each other. So MADM techniques are implemented to solve the problem. Some of the MADM techniques are:

A. Analytical Hierarchical Process (AHP)

Analytical Hierarchical Process (AHP) is a decision-making method developed for prioritizing alternatives when multiple criteria must be considered and allows the decision maker to structure complex problems in the form of a hierarchy, or a set of integrated levels. This method incorporates qualitative and quantitative criteria. The hierarchy usually consists of three different levels, which include goals, criteria, and alternatives. Because AHP utilizes a ratio scale for human judgments, the alternatives weights reflect the relative importance of the criteria in achieving the goal of the hierarchy [32], [34].

B. Analytic Network Process (ANP)

Analytic Network Process (ANP) [31] is a comprehensive decision-making technique that captures the outcome of the dependence and feedback within and between the clusters of elements. Analytical Hierarchy Process (AHP) serves as a starting point for ANP. Analytical Network Process (ANP) is a more general form of AHP, incorporating feedback and interdependent relationships among decision attributes and alternatives. ANP is a coupling of two parts, where the first consists of a control hierarchy or network of criteria and sub-criteria that controls the interactions, while the second part is a network of influences among the elements and clusters [32].

C. Total Cost of Ownership (TCO) Models

TCO-based models for supplier choice basically consists of summarization and quantification of all or several costs associated with the choice of vendors and subsequently adjusting or penalizing the unit price quoted by the supplier. Total Cost of Ownership (TCO) as stated by Ellram [33] is a methodology and philosophy, which looks beyond the price of a purchase to include many other purchase-related costs.

D. Technique for the Order Performance by Similarity to Ideal Solution (TOPSIS)

Another favorable technique for solving MADM problems is the TOPSIS. According to the concept of the TOPSIS, a closeness coefficient is defined to determine the ranking order of all suppliers and linguistic values are used to assess the ratings and weights of the factors. TOPSIS is based on the concept that the optimal alternative should have the shortest distance from the positive ideal solution (PIS) and the farthest distance from the negative ideal solution (NIS) [34].

E. Multiple Attribute Utility Theory (MAUT)

The MAUT proposed by Min, H. [35] is also considered a linear weighting technique. The MAUT method has the advantage that it enables purchasing professionals to formulate viable sourcing strategies and is capable of handling multiple conflicting attributes. However, this method is only used for international supplier selection, where the environment is more complicated and risky [36].

F. Outranking Methods

Outranking methods are useful decision tool to solve multi-criteria problems. These methods are only partially compensatory and are capable of dealing with situations in which imprecision is present. Lot of attention has been paid to outranking models, primarily in Europe. However, so far, in the purchasing literature there is no evidence of applications of outranking models in purchasing decisions [21].

VII. Mathematical Programming (MP) Models

Mathematical programming models often consider only the quantitative criteria. Mathematical programming models allow decision makers to consider different constraints in selecting the best set of suppliers. Most importantly, mathematical programming models are ideal for solving the supplier selection problem because they can optimize results using either single objective models or multiple objective models [6], [20], and [27]. Some of these models are:

A. Multi-Objective Models

These models deal with optimization problems involving two or more coinciding criteria.

B. Goal Programming Models

Another important tool is Goal Programming (GP). Unlike most mathematical programming models, goal programming provides the decision maker (DM) with enough flexibility to set target levels on the different criteria and obtain the best compromise solution that comes as close as possible to each one of the defined targets.

VIII. Artificial Intelligence Methods

Artificial Intelligence (AI) models are computer-based

systems trained by the decision maker using historical data and experience. These systems usually cope very well with the complexity and uncertainty involved in the supplier selection process. Some of the AI models are:

A. Case-Based-Reasoning (CBR) Systems

CBR systems fall in the category of the so-called artificial intelligence (AI) approach. Basically, a CBR system is a software-driven database which provides a decision-maker with useful information and experiences from similar, previous decision situations. CBR is still very new and only few systems have been developed for purchasing decision-making [43].

B. Artificial Neural Network (ANN)

The ANN model saves money and time. The weakness of this model is that it demands specialized software and requires qualified personnel who are expert [42].

IX. Fuzzy Logic Approach

In this method, linguistic values are used to assess the ratings and weights for various factors. These linguistic ratings can be expressed in trapezoidal or triangular fuzzy numbers. Since human judgments including preferences are often vague and cannot estimate his preference with an exact numerical value. The ratings and weights of the criteria in the problem are assessed by means of linguistic variables. One can convert the decision matrix into a fuzzy decision matrix and construct a weighted-normalized fuzzy decision matrix once the decision-makers' fuzzy ratings have been pooled. Finally a closeness coefficient of each alternative is defined to determine the ranking order of all alternatives [4], [26].

X. Combined Approaches/ Hybrid Methods

Some authors have combined decision models from different steps in the supplier selection process. Degraeve and Roodhoft [37] developed a model combining mathematical programming model and TCO. Ghodsupour and O'Brien [38] had integrated AHP and Linear Programming to consider both tangible and intangible factors in choosing the best suppliers. Sanayei et al. [39] presented an effective model using both MAUT and LP for solving the supplier selection problem. Shyur [40] present an effective model using both ANP and modified TOPSIS, to accommodate the criteria with interdependencies. Boran [41] has proposed a multi criteria group decision making approach using fuzzy TOPSIS, to deal with uncertainty.

XI. Conclusion

The issues of supplier selection have attracted the interest of researchers since the 1960s, and research studies in this area have increased. Several authors have pointed out the importance of supplier selection by emphasizing the impact that decisions throughout the entire supply chain have, from procurement of raw materials to delivery of finished products to final customers. In order to help decision makers or purchasers make sound decisions with respect to supplier selection, researchers have developed different criteria and decision methods and models dealing with different aspects of the supplier selection process. This paper throws light on supplier selection criteria and methods. Based on review, it would not be irrational to suggest that the supplier selection issues need further attention in order to harmonize the combination of qualitative and quantitative criteria to develop the best criteria and methods for the selection of the best suppliers.

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