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Supplier selection problem: A state-of-the-art review

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A R T I C L E I N F O

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A B S T R A C T

In the global competitiveness and growing market environment, "Actual competition is not between firms against firm, than supplier against supplier". Globally in the fastest market development world gets closer and closer. Consumers prefer fast delivery, economical product, excellent service and high quality product with desired service level. For successful management of this supply chain, supplier considered as the base source for all processes. Therefore, an efficient supplier selection and evaluation process needs to be incorporate. The main purpose of this paper is to provide an extensive state-of-the-art literature review and critique of the studies related to various aspects of supplier selection problem over the past two decades. Research papers appearing in the reputed and leading international journals from 1991 to 2011 are gathered and analyzed. Primary focus is given on more than 200 published and unpublished works. It has been referred extensively to carry out state-of-the-art review for supplier selection problem. Finally, paper provides future perspective based on current research trends available in the published literature.

1. Introduction

Now-a-day business organizations realize that in the highly competitive business scenario single company cannot survive anymore. Every company should always have a better connection with other to discuss their issues and helps for outsourcing. Organization identifies the effective medium for keeping connection with other in the form of supplier. Even though the product of the company is best, supplier perform major role to propel the business in this scenario. As business organizations become more dependent on suppliers, the direct and indirect consequence of poor decision-making about supplier selection becomes more severe. As a result, an effective and efficient supplier selection and evaluation process becomes very important to the success of any manufacturing/Service organization. In general, supplier selection problem falls under purchasing department. The critical objective of the purchasing department is to procure right product at the right cost in the right quantity with the right quality at the right time from the right source. This requires executing effective decisions concerning supplier selection and evaluation.

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Boer (2001) developed rough positioning of decision methods in supplier selection as shown in Fig. 1, which shows a possible array of methods that are available in the literature.

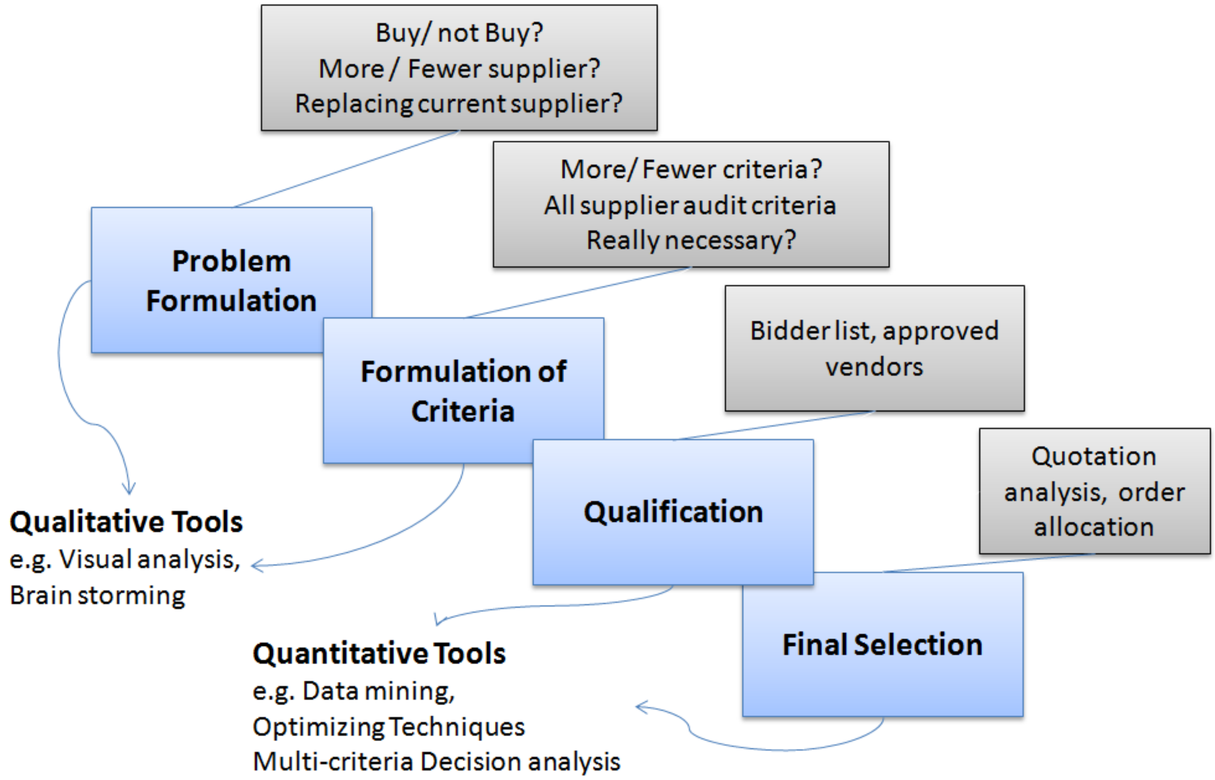

Fig. 1. Rough Positioning of decision methods in supplier selection (Boer 2001)

To identify the past and current trends the paper reviews the published and unpublished literature of the multi-criteria decision making approaches for supplier selection problem. Inference of the review data is gathered and analyzed to get the answer of following: (i) which supplier selection criteria have been paid more attention? (ii) Which approaches/methods have been prevalently applied? (iii) Is there any inadequacy of the methods and selection criteria need to be focused more? Based on the inadequacy, if any, some improvements and possible scope for future work is recommended. Sometime company prefers to have new supplier rather than existing one for many reasons. First, there may be some new existing suppliers, which are superior to firm's existing suppliers. Second, existing suppliers may go out of business, or their living cost demand may be increasing. Third, the buyer may need additional suppliers simply to drive competition, reduce supply disruption risks, or to meet other business objectives such as supplier diversity.

The paper is organized as follows. Section 2 presents classification of supplier selection problem. Section 3 describes existing mathematical models for supplier selection. In the section 4, scope for future work on supplier selection is provided followed by the concluding remarks.

2. Review of criteria affecting supplier selection problem

This section describes various criteria and their sub-criteria, which directly or indirectly influence on the supplier selection problem. Chan (2007) focused on the cost, quality, service, risk factors as important criteria. Swift (1995) discussed the other criteria such as product, availability, dependability, experience and price. Hamphyeys (2003) mainly concentrated on environmental issues in supplier selection and gave quantitative and qualitative environmental criteria. Handfeild (2002) gave criteria such as product attributes, waste management system, labeling/ certification, packaging/ reverse logistics, compliance to government regulations.

Fig. 2 shows most of the criteria and their sub-criteria, which are directly or indirectly influencing on supplier decision process. These criteria are described in the following section:

2.1 cost

This criterion is one of the important criteria in assessing the global supplier because it can dictate the international procurement cost. Profit maximization cannot be achieved without the cost minimization. In the current global market, the firm must find a low cost supply base where it can minimize its purchase price, import duties, documentation cost, transportation cost, communication cost and cost of investigating the potential supplier's past performances and financial background. This criterion associated with the product cost, tariff and taxes, total logistics/ freight cost as sub-criteria

2.2. Quality

Each organization prefers high quality product purchase from the supplier; it causes supplier satisfaction and more response to buyer. Most important factors leading to overseas sourcing are high quality of foreign products resulting from the emphasis placed on quality at the source. Conformance to specification, lead time, quality assessment techniques and process capability are the sub-criteria to the quality that considered here.

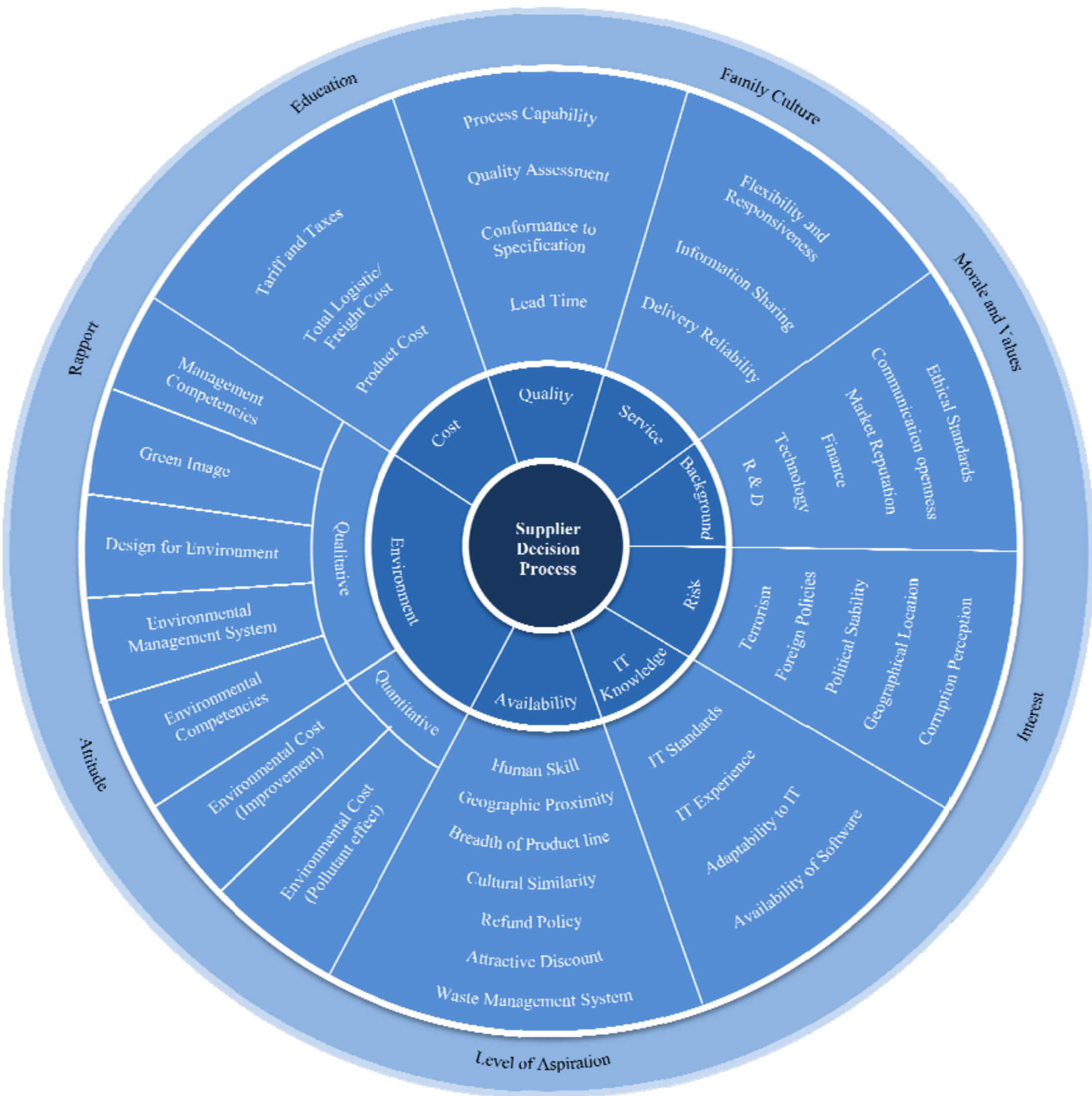

Fig. 2. Criteria and their sub-criteria affecting on supplier selection process

2.3 Services

The supplier's prime interest with the manufacturers can be observed in terms of service provided by the supplier. It may help in increasing supplier's base and getting more and more orders. Both supplier and manufacturers exchange information sharing to get good service. It checks supplier's ability to meet customer response to resolve their problems efficiently and within a time. Service criterion deals with delivery reliability, information sharing, flexibility and responsiveness.

2.4. Backgrounds

In the global point of view it is very important to get the right and reliable information about supplier's background. The performance and past history of the suppliers help in selecting the best global supplier of particular product. Manufacturers can do some documentation of the information of supplier and their past performance and on that basis can select supplier. The supplier information files include the name of each supplier, a list of material available from each supplier, the supplier's quality records, the supplier's overall desirability and general information concerning the supplier's plant and management. The different characteristics of the supplier should be checked based on past performance to decide the superiority of the organization over other. Here author talks about R & D development, new technology, financial background, market reputation, communication openness, and supplier's ethical standards.

2.5. Risk factors

Despite all factors considered here, risk is the most important one and highly influences on supplier selection. Consequently, the global supplier selection decision is most strongly affected by perceived risks. The shock of 9/11 was to be a wake-up call to the uncertainty of a global environment. The pirate threat to transport ships has also a major point in the international point of view. Sudden rise and fall in the stock market may make the company's financial status unstable. For effective managing of supply risks, we need to require the identification and monetization of risk events, probability of occurrence, and the firm contingencies for alternative sources of supply. Risk and uncertainty lens are the newest and perhaps some of the most important capabilities and contributions, which could be made for a firm's competitiveness and viability. The risk factors, affecting the selection process of the global supplier are taken into account in the present work

2.6 IT Knowledge

Information is crucial to supply chain performance because it provides the foundation in which supply chain processes execute transactions and managers make decision. In short, without information a manager can only make a decision blindly. Therefore, information makes the supply chain visible to a manager. With this visibility, a manager can make decisions to improve the supply chain's performance. In many ways, information is the most important of the four supply chain drivers because without it, none of the other drivers can be used to deliver a high level of performance. IT has very good role in the successful operation of an organization and interaction with others. Success of an organization depends on how well IT is employed in the organization. In the traditional way, everything was done by manually so there might be chances to go wrong with the product. Nowadays responsiveness, flexibility, ways of managing, etc. all depend on the level of the IT used in the organizations. These days market survey is possible without physically going to the market and various decisions that have to taken for the efficient operation of a company can be taken quickly and easily with the help of IT. Ease of communication, fast response to the query of customers is possible very quickly, and the IT makes the world very small. Now, managers must know how information is gathered and analyzed. This is where IT comes into play. IT uses hardware and software throughout a supply chain to gather, analyze, and act on information necessary to make a good decision.

2.7 Availability

This is the criterion which help the supplier as additional benefit while selection process. Breadth of product line, geographic proximity, human skill, waste management system, attractive discount, cultural similarity and refund policies are the sub-criteria, which act as value added services given by the particular supplier.

2.8 Environment

Environmentally sensitive purchasing can make good business sense. It has two components: (1) the purchase of materials and items, which are recyclable and (2) the environmental and liability issues associated with the use and discharge of hazardous materials anywhere in the supply chain. Purchasing and supply management, environmental engineer and attorney of the firm should study the firm's value chain to identify the possible uses and disposal methods for environmentally hazardous substances and materials. Some aspects of environmentally sound packaging are required by regulators while others are decisions made by each packager. Investors, employees, management, and customers can influence corporate decisions and help to set policies. When investors seek to purchase stock, companies known for their positive environmental policy can be attractive, potential stockholders and investors see this as a solid decision: lower environmental risks lead to more capital at cheaper rates. Companies that highlight their environmental status to consumers can boost sales as well as product reputation. Going green is often a sound investment that can help to grow company well.

3. **Classification of supplier selection problem**

An extensive literature review is conducted using supplier related phrases such as supplier selection, vendor selection, supplier in supply chain management, supplier performance, supplier evaluation, buyer-supplier relationship etc. as keywords on major databases like EBSCO, Scopus, Emerald, Elsevier's Science direct, Proquest and IEEE, etc.. More than 150 refereed journal articles appeared between 1991 to 2011 in most rated journals such as, International Journal of Production Research, International Journal of Production Economics, IEEE Transactions on Engineering Management, Expert System and Applications, Supply Chain Management An international Journal, European Journal of Purchasing and supply Management, Computers and Industrial Engineering, European Journal of Operational Research, Information Sciences, International Journal of Purchasing and material management, Logistic Information System, Applied Mathematical Modeling, Industrial Marketing Management, Computers and operations Research, International Journal of Physical Distribution and Logistics Management, Journal of Operations Management, Integrated Manufacturing Systems, Applied Mathematics and Computer Science and many more. Fig. 3 presents the list of papers published in the literature under various categories such as AHP, ANP, DEA, and Fuzzy-AHP etc.

The list of paper selected for review mainly focus on the conceptual, selection criteria, mathematical modeling, methodologies used, and case study based on the supplier selection problem.
Conceptual paper: These include articles, which deal with the SS process and provide a logical or conceptual approach to selection of suppliers. ***Supplier selection Criteria paper:*** papers that include studies on criteria used to select or evaluate suppliers. Some of these papers are based on surveys, while others are theoretical. ***Mathematical modeling:*** includes papers that use mathematical modeling techniques and other heuristics. These articles included specific numerical examples to apply the methods. ***Methodology paper:*** articles providing methods to solve SS problems. These articles provide a framework or specific approach to solve SS problems but do not necessarily show the application. ***Case study:*** includes articles that provide detailed applications of SS methodologies as they are used in companies or countries/regions.

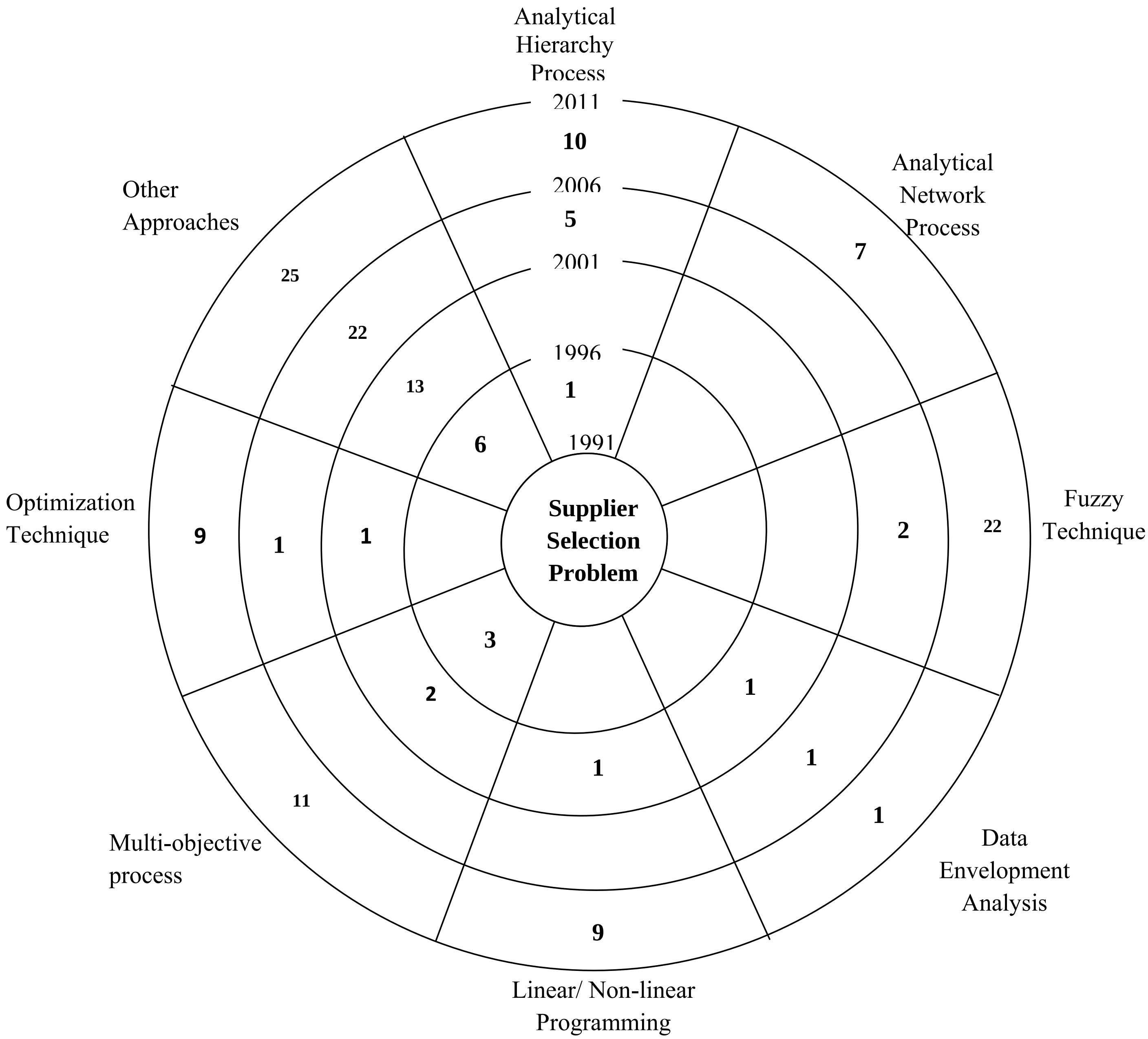

Fig. 3. Solution methodology based categorical distribution of papers from 1991 to 2011

AHP:

- **1991-1995:** Nydick (1992)
- **1996-2000:**
- **2001-2005:** Khurrum (2003), Bayzit (2005), Handfield (2002), Bhutta (2002), Hwang (2005)
- **2006-2010:** Vaidya (2006), Demirates (2009), Gencer (2007), Razim (2010), Chia-Wei (2009), William (2008), Kukungul (2009), Yang (2006), Wang (2009), Liao (2010)

ANP:

- **2006-2010:** Gencer (2007), Demirtas (2009), Vinod (2011), Bayzit (2006), Wu (2009), Razmi (2010), Chia-Wei (2009)

FUZZY (Fuzzy-AHP; Fuzzy-ANP, Fuzzy-TOPSIS):

- **2001-2005:** Manoj (2004), Kahraman (2003)
- **2006-2010:** Chen- Tung (2006), Lee (2009), Famuyiwa (2008), Vinod (2011), Liao (2010), Boran (2009), Wang (2009), Bayrak (2007), Chan (2007), Yucel (2011), Wang (2008), Wang (2005), Shahanaghi (2009), Sevkli (2010), Punniyamoorthy (2011), Pang (2006), Onut (2009), Lee (2009), Ku (2009), Guneri (2009), Chamodrakas (2010), Amin (2011)

DEA:

- **1991-1995:**
- **1996-2000:** Charles (1996)
- **2001-2005:** Liu (2003)
- **2006-2010:** Ramanathan (2007)

Linear/Non-Linear programming:

- **1991-1995:**
- **1996-2000:** Ghodsypour (1998)
- **2001-2005:**
- **2006-2010:** Ozgen (2006), Guneri (2009), Amid (2006), Vencheh (2011), Razmi (2010), Liao (2010), lee (2009), Ku (2010), Famuyiwa (2008)

Multi-Objective Process:

- **1991-1995:** Bay (1992), Hockey (1994), Weber (1993)
- **1996-2000:**
- **2001-2005:** Lasch (2005), Dulmin (2003)
- **2006-2010:** Thomas (2008), Ozgen (2006), Sanayei (2010), Demirtas (2008), Liao (2007), Desheng (2010), Shou-yan (2008), Yeh (2011), Surjandari (2010), Sawik (2010), Amid (2006)

Optimization Techniques (GA/ SA etc):

- **1991-1995:**
- **1996-2000:** Weber (2000)
- **2001-2005:**Ding (2005)
- **2006-2010:** Yeh (2011), Liao (2010), Lee (2009), Ku (2009), Mohammadi (2009), Ebrahim (2009), Chen (2010)

Others:

- **1991-1995:** Weber (1991), Swift (1995), Naude (1993), Houshyar (1992), Ellram (1995), Akinc (1993)
- **1996-2000:** Weber (1998), Verma (1998), Patton (1996), Motwani (1999), Maloni (1997), Gunasekaran (2000), Degraeve (2000), Choi (1996), Chakraborty (1996), Carr (1999), Boer (1998), Vollman (1998)
- **2001-2005:** Zarandi (2002), Tracey (2001), Semra (2003), Meixell (2005), Lummus (2003), Keah (2001), Kannan (2002), Humhreys (2003), Hong (2005), Handfield (2002), Ferhan (2003), Davidrajuh (2003), Choy (2002), Chan (2004), Boer (2001), Bharadwaj (2004), Basnet (2005), Altinoz (2001), Agrell (2004), Aaronson (2004), Lee (2001)
- **2006-2010:** Ya (2010), Xu (2010), William (2010), Wagner (2007), Wadhwa (2007), Vanteddu (2011), Thomas (2008), Tarofder (2007), Tahiri (2008), Sevkli (2010), Saen (2007),

Punniyamoorthy (2011), Liu (2011), Lee (2009), Kuo (2010), Kelmenis (2010), Jain (2009), Huang (2007), Chunguang (2010), Chang (2011), Behzadian (2010), Aksoy (2011), Aissaoui (2007), Adiel (2007)

Other papers focuses on Applications based, Criteria selection, Supplier-buyer relationship, Case study, ELECTRE Method, Supply chain Management framework, *etc.* Fig. 3 reviews that in early 1990 fewer works on supplier selection problem were published and broadly the attention towards supplier selection problem has been increasing. One may conclude that work in supplier selection is getting popular among researchers and academician. We would like to mention that the Fig. 2 and Fig. 3 are based on the papers published in leading and reputed journals mentioned in Table 1 below. However, there can be more papers on supplier selection problem published on other national and international journals. Fig. 4 shows the frequency distribution of the published papers since 1991.

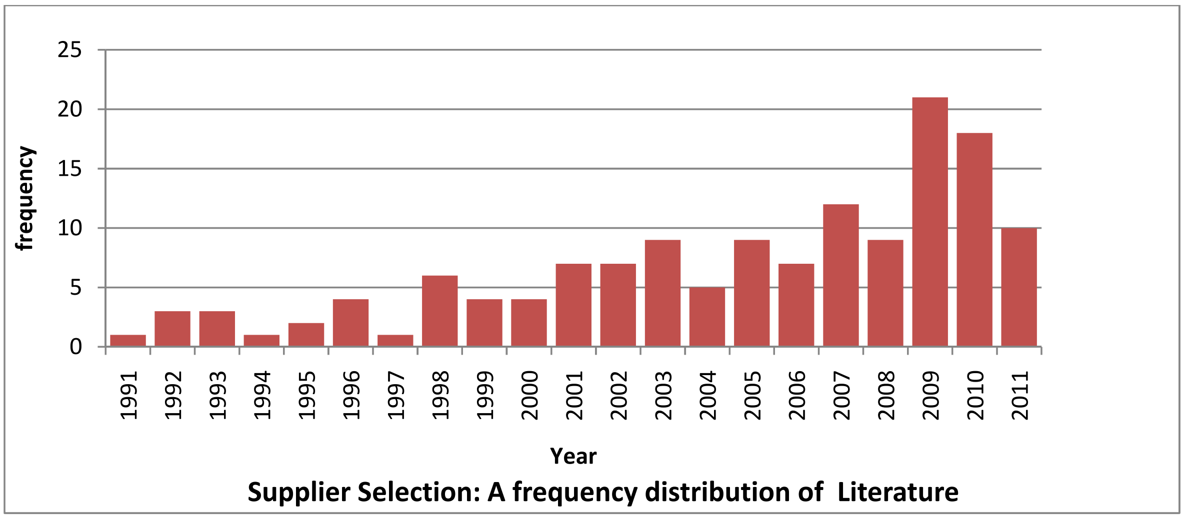

Fig. 4. Frequency of papers on Supplier selection: A literature review

Table 1 shows the number of papers related to supplier selection problem in selected reputed journals from 1991-2011. Author could found most of the relevant papers from various journals, still there could be more papers available in the same or other journals.
Table 2 presents the list of techniques applied in solving supplier selection problem in last two decades. Review of the methodologies and its analytical model are presented and discuss in the following sub sections.

3.1 Analytic Hierarchy Process:

AHP is a technique used in multi-criteria decision making problem. It is developed by Satty (1970) which provided a framework to cope with multiple-criteria, situations involving intuitive, rational, qualitative and quantitative aspects (Bhutta et al., 2002). Generally, the AHP has three levels: the goal, the criteria and the alternatives. For the supplier selection problem, the goal is the best supplier; the criteria can be quality, on-time delivery, price and the alternatives are the sets of suppliers. The AHP is used as a framework to formulize the evaluation of tradeoffs between the conflicting selections criteria associated with the various suppliers. This is the main reason for choosing AHP as solution methodology for solving the supplier selection problem, which involves many intangible factors, but still requires a logical and rational control of decisions (Nydick et al., 1992).

Akarte et al. (2001) developed a web-based AHP system to evaluate the casting suppliers with respect to eighteen criteria. Chan (2003) developed an interactive selection model with AHP to facilitate decision makers in selecting suppliers. Liu and Hai (2005) applied AHP to evaluate and select suppliers.

Table 1
List of Journals and the frequency of the papers published during 1991-2011

	Name of Journal	References	Frq
1	Applied Mathematical Modelling	Abginechi (2010), Gencer (2007), Kokangul (2009), Kuo (2010)	4
2	Asian Journal of Marketing	Tarofder (2007)	1
3	Computers and Industrial Engineering	Liao (2007), Manoj (2004)	2
4	Computers and Operations research	Adiel (2007), Aissaoui (2007), Basnet (2005), Demirtas (2009), Houshyar (1992), Wadhwa (2007)	6
5	Decision Support System	Bay (1992)	1
6	European Journal of Marketing	Naude (1993)	1
7	European Journal of operational Research	Behzadian (2010), Degraeve (2000), Desheng (2010), Handfield (2002), Maloni (1997), Saen (2007), Vaidhya (2006), Wagner (2007), Wang (2008), Weber (1998), Weber (1993), William (2008), William (2010)	13
8	European Journal of Purchasing and Supply Management	Boer (2001), Boer (1998), Keah (2001)	3
9	Expert Systems with Applications	Aksoy (2011), Amin (2011), Boran (2009), Chamodrakas (2010), Chang (2011), Choy (2002), Guneri (2009),Hong (2005), Kelmenis (2010), Lee (2009), lee (2009), Lin (2009), Onut (2009), Punniyamoorthy (2011), Sanayei (2010), Shou-Yan (2008), Vinod (2011), Wu (2009), Ya (2010), Yeh (2011), Yucel (2011)	20
10	Global Journal of Flexible Systems Management	Lummus (2003)	1
11	IEEE Transactions on Neural Networks	Golmohammadi (2009)	1
12	IEEE Transactions on Engineering Management	Lee (2001), Thomas (2008)	2
13	Industrial Marketing Management	Bharatwaj (2004), Da Silva (2002), Patton (1996)	3
14	Information Sciences	Ozgen (2006)	1
15	Integrated Manufacturing Systems	Motwani (1999)	1
16	International Journal of Advanced Manufacturing Technology	Razmi (2010)	1
17	International Journal of Applied Mathematics and Computer Science	Zarandi (2002)	1
18	International Journal of Computer Integrated Manufacturing	Ding (2005), Guneri (2009), Vencheh (2011)	3
19	International Journal of Management Science	Verma (1998)	1
20	International Journal of Operations and Production Management	Beamon (1999), Chakrborty (1996), Masella (2000)	3
21	International Journal of Physical Distribution and Logistics Management	Ellram (1995), Ellram (1999), Hockey (1994), Lasch (2005)	4
22	International Journal of Production Economics	Agrell (2004), Amid (2006), Awasti (2009), Chen (2006), Chunguang (2010), Famuyiwa (2008), Ghodypour (2001), Ghodypour (1998), Huang (2007), Liao (2007), Lin (2005), Vanteddu (2011)	12
23	International Journal Of Production Research	Che (2010), Jain (2009), Liu (2003), Sevkli (2010), Wang (2009)	5
24	International Journal of Purchasing and Materials Management	Nydick (1992)	1
25	Journal of Business research	Swift (1995)	1
26	Journal of Manufacturing Technology Management	Yang (2006)	1
27	Journal of Operations Management	Akinc (1993), Carr (1999), Krause (1998)	3
28	Omega	Chan (2007), Demirtas (2008), Sawik (2010)	3
29	Production Planning and Control	Bayrak (2007)	1
30	Supply Chain Management	Charles (1996)	1
31	Supply Chain Management: an International Journal	Bhutta (2002), Khurrum (2003), Liu (2003), Ramanathan (2007), Tracey (2001), Weber (2000)	6
32	The Journal of Supply Chain Management	Kannan (2002)	1

3.2 Analytic Network Process

It is found that supplier evaluating factors influence each other, therefore internal interdependency is needed to be considered in the evaluation process of suppliers. ANP is a technique where it can tackle such type of problem effectively. Ten evaluating criteria were proposed by Bayzit (2006), which were classified into supplier's performance and capability clusters. To formulate interrelationships among all criteria, each of them was considered as a controlling factor for a pair-wise comparison matrix. Later Gencer and Gürpinar (2007) implemented an ANP model in an electronic company to evaluate and select the most appropriate supplier with respect to various supplier evaluating criteria, which classified into three clusters. The interrelationships among the criteria were considered in the selection process.

*3.3 Data Envelopment Analysis***:**

Weber (1996) demonstrated the use of data envelopment analysis (DEA) as a tool for measuring the performance of vendors on multiple criteria and for use in vendor negotiations. Ramanathan (2007) presented the efficiency of using DEA in supplier selection problems especially when multiple conflicting criteria have to be considered. DEA identifies an 'efficient frontier' from the inputs and outputs to be evaluated creating Decision Making Units (DMU's) and then the efficiency of each of these DMUs are compared to the 'efficient frontier'. Identifying the most efficient Decision making unit. This method can be applied to SS.

3.4 Linear and Non-Linear programming:

This approach is especially suitable to just-in-time scenarios (Weber, 1993). The analysis occurs in a decision support system environment. A multi-objective programming decision support system allows for judgment in decision making while simultaneously trading off key supplier selection criteria. An additional flexibility of this model is that it allows a varying number of suppliers into the solution and provides suggested volume allocation by supplier.

3.5 Fuzzy set Technique:

Fuzzy sets are sets whose elements have degrees of membership. Fuzzy sets have been introduced by Lotfi A. Zadeh (1965) as an extension of the classical notion of set. In classical set theory, the membership of elements in a set is assessed in binary terms according to a bivalent condition- an element either belongs or does not belong to the set. By contrast, fuzzy set theory permits the gradual assessment of the membership of elements in a set; this is described with the aid of a membership function valued in the real unit interval [0, 1]. Fuzzy sets generalize classical sets, since the indicator functions of classical sets are special cases of the membership functions of fuzzy sets, if the latter only take values 0 or 1. Fuzzy set theory has proven advantages within vague, imprecise and uncertain contexts and it resembles human reasoning in its use of approximate information and uncertainty to generate decisions. It was specially designed to mathematically represent uncertainty and vagueness and provide formalized tools for dealing with the imprecision intrinsic to many decision problems. Fuzzy set theory implements classes and grouping of data with boundaries that are not sharply defined (i.e. fuzzy). Fuzzy set theory includes the fuzzy logic, fuzzy arithmetic, fuzzy mathematical programming, fuzzy graph theory and fuzzy data analysis, usually the term fuzzy logic is used to describe all of these. The major contribution of fuzzy set theory is its capability of representing vague data.

3.6 Multi-Objective Process:

It is especially appropriate in situations where there are a variety of uncontrollable and unpredictable factors affecting the decision as it is capable of handling multiple conflicting attributes inherent in international supplier selection,. It also enables the purchasing manager to evaluate 'what if' scenarios associated with changes in company policy (Hokey 1994, Sanayei 2010)

*3.7 Optimization Techniques***:**

Several optimization techniques have been applied in supplier selection problem. Among the more commonly applied techniques are Dynamic Programming (Masella,2000), Linear programming (Ghodsypour et al.,1998, Ozgen 2006), and Multi-Objective Programming (Weber et al., 1993, Thomas 2008, Sanayei 2008, Demirtas 2008). Masella (2000) proposed four different vendor selection systems (VSSs) depending on the timeframe (short term versus long term) and on the content (logistic versus strategic) of the co-operative customer/supplier relationships, it develops framework, different sets of measures, deriving from a non-conventional model of the supplier based on the dynamic system and on the resource-based approach. Ding et al. (2005) presented a Genetic Algorithm based optimization methodology for supplier selection. The proposed method provided possible configuration of the selected suppliers, including transportation modes. Each configuration was then evaluated with respect to the key performance indicators. This methodology is composed of three basic modules: a genetic algorithm (GA) optimizer, a discrete-event simulator and a supply chain modeling framework.

3.8 Others:

Total cost of ownership (TCO) is a methodology, which looks beyond the price of a purchase to include many other purchase-related costs. This approach has become increasingly important as organizations look for ways to better understand and manage their costs (Ellram,1995).

Table 2
Supplier selection Literature review

	Technique	Author	Methodology
1	Analytical Hierarchy Process	Khurrum (2003), Vaidya (2006), Bayazit (2005), Nydic (1992), Demirates (2009), Gencer (2007), Razim (2010), Handfield (2002), Chia-Wei (2009), William (2008), Kokungul (2009), Bhutta (2002), Yang (2006)	AHP provides a framework to cope with multiple criteria situations involving intuitive, rational, qualitative and quantitative aspects.
2	Data Envelopment Analysis	Charles/Weber(1996), Ramanathan (2007), Liu (2003)	DEA is an optimization method of mathematical programming used to generalize single-input/ single-output technical efficiency measure to the multiple-input/ multiple-output case by constructing a relative efficiency score as the ratio of a single virtual output to a single virtual input.
3	Linear Programming	Ghodsypour (1998), Ozgen (2006), Guneri (2009)	When capacity constraint exist problem become more complex LP is used to consider tangible and intangible factors.
4	Fuzzy Goal Programming	Chen-Tung (2006), Manoj (2004), Lee (2009), Famuyiwa (2008), Vinod (2011), Liao (2010)	Problem with more than one goal having different priorities fuzzy goal Programming can handle this problem and gives better result.
5	Fuzzy TOPSIS	Boran (2009), Wang (2009)	It uses to ranking of the alternatives by considering order preference by similarity to the ideal solution.
6	Multi-objective Criteria	Thomas (2008), Ozgen (2006), Sanayei (2010), Demirtas (2008)	The use of a multi-objective programming approach is generally used in the just-in-time scenarios. The analysis occurs in a decision support system environment
7	Case Studies	Semra (2010), Choy (2004), Chan (2004), Onut (2009), Gencer (2007)	Application of methods in the advanced technology industry. Study of Telecommunication company.
8	Decision Support System	Shou-Yan (2008), Bay (1992),	Uses Knowledge DSS for computer performance management, supplier selection based on a strategy aligned fuzzy SMART approach developed.
9	Analytical Network Process	Gencer (2007), Demirtas (2009)	ANP helps to identified and considering the interdependency between criteria.
10	Multi-attribute Utility Theory	Hokey (1994), Sanayei (2010)	Use of MAUT, can help purchasing professionals to formulate viable sourcing strategies, as it is capable of handling multiple conflicting attributes inherent in international supplier selection
11	Dynamic Programming	Masella (2000)	By setting Input Variables as Control & Environmental variables, State Variables as the internal workings of the organization, and the Output variables as the performance achieved by the organization based on the selection of suppliers made.

TCO may include, in addition to the price paid, elements such as order placement costs, research costs, transportation costs, receiving, inspecting, holding and disposal costs and so on. (Handfield et al., 2002) explored the understanding of TCO using the product life-cycle approach. They noted that the costs related to a product are directly related to where the product is in its life cycle. Though there are other selection and evaluation approaches closely aligned with TCO such as life cycle costing (Ellram,1999) and cost-based supplier performance evaluation (Handfield et al.,1999) among others. Table 2 presents the list of research papers where various solution techniques are applied in solving supplier selection problem.

4. Mathematical models in supplier selection problem

4.1 Fuzzy Multi-Objective Models:

A general multi objective model for the supplier selection problem proposed by Weber (1993) is as follows:

Min $Z_1, Z_2, \ldots, Z_k$

Max $Z_{k+1}, Z_{k+2}, \ldots, Z_p$

Such that, $x \in X_d$

Where $Z_1, Z_2, \ldots, Z_k$ are the negative objectives or criteria-like cost, late delivery, etc. and $Z_{k+1}, Z_{k+2}, \ldots, Z_p$ are the positive objectives or criteria such as quality, on time delivery, after sale service and so on. X_d is the set of feasible solutions which satisfy the constraint such as buyer demand, supplier capacity, etc. A typical linear model for supplier selection problem is:

Min Z_1; Max Z_2, Z_3

subject to,

$$Z_1 = \sum_{i-1}^{n} P_i X_i$$

$$Z_2 = \sum_{i-1}^{n} F_i X_i$$

$$Z_3 = \sum_{i-1}^{n} S_i X_i$$

$$\sum_{i=1}^{n} X_i \geq D$$

$X_i \leq C_i$ i = 1,2,…, n

$X_i > 0$ i = 1,2, …,

where D is demand over period, X_i is the number of units purchased from the *ith* supplier, P_i is per unit net purchased from supplier *i*, c_i is capacity of *ith* supplier, F_i is percentage of quality level of *ith* supplier, S_i is percentage of service level of *ith* supplier, *n* is number of suppliers.

Fuzzy multi objective linear model for supplier selection problem addressed by Amid *et. al.* (2006) is given below:

Their model find a vector *x* which minimizes objective function Z_k and maximizes objective function Z_l.

$$Min\ Z_k = \sum_{i=1}^{n} c_{ki} x_i \qquad k = 1,2,\dots,p$$

$$Max\ Z_l = \sum_{i=1}^{n} c_{li} x_i \qquad l = p+1, p+2,\dots,q$$

Such that:

$x\ \varepsilon\ X_d$,

$$X_d = \begin{Bmatrix} x/g(x) = \sum_{i=1}^{n} a_{ri} x_i \le b_r, \\ r = 1,2,\dots,m, x \ge 0 \end{Bmatrix}$$

Where c_{ki}, c_{li}, a_{ri} and b_r can be crisp or fuzzy values.

Cheng-Yuan Ku et. al. (2009) considered the global supplier selection problem and explained the integrated fuzzy-AHP and fuzzy-goal programming approach. Supplier selection problem is a typical multi objective decision making problem. Therefore, it often has some conflict sourcing goal, such as price, quality and location. To maximize the utility function and fulfill the decision maker's aspiration levels, fuzzy-goal programming (Zimmerman 1978; Narasinhan 1980) was implemented in solving these decision making problems. Further, these decision makers can define linguistic priorities in membership functions on goal values by considering fuzzy theory.

A mathematical formulation of fuzzy-goal programming is defined as follows:

Maximize λ

Subject to:

$\lambda - \mu_k(f_k(X)) \le 0 \qquad k = 1, 2, \dots, n$

X Є F, (F is feasible set).

Where λ is the extra continuous variable, $f_k(X)$ is the linear function of the k^{th} goal, and $\mu_k(f_k(X))$ is the fuzzy membership function of the k^{th} objective.

The preference based membership functions are expressed as follows:

$$\mu_k(f_k(X)) = \begin{cases} 1, & \text{if } f_k(X) \ge g_k, \\ \dfrac{(f_k(X) - l_k)}{g_k - l_k}, & \text{if } l_k < g_k \qquad \text{for } f_k(X) \gtrsim g_k, \\ 0, & \text{if } f_k(X) \le l_k \end{cases}$$

$$\mu_k(f_k(X)) = \begin{cases} 1, & \text{if } f_k(X) \le g_k, \\ \dfrac{(\mu_k - (f_k(X))}{\mu_k - g_k}, & \text{if } g_k < f_k(X) < \mu_k \qquad \text{for } f_k(X) \lesssim g_k, \\ 0, & \text{if } f_k(X) \ge \mu_k \end{cases}$$

Where l_k and μ_k are, respectively, the lower and upper limits for the k^{th} goal $f_k(X) \gtrsim (\lesssim) g_k$ indicates the k^{th} fuzzy goal approximately being greater than or equal to (roughly less than or equal to) the aspiration level g_k.

4.2 Nonlinear Multi Objective:

Aguezzoul and Ladet (2007) proposed a nonlinear multi-objective model formulation for the supplier selection by considering transportation policies as follows:

Variables that are considered here are:

n = number of suppliers;
D = unit time demand of buyer;
Q = ordered quantity to all suppliers in each period;
Q_i = ordered quantity to i^{th} suppliers in each period;
A_i = ordering cost per order, of i^{th} supplier;
P_i = purchase price of i^{th} supplier;
C_i = production capacity of i^{th} supplier;
l_i = lead-time required by i^{th} supplier;
T_i = average transit time from i^{th} supplier to buyer;
L = Lead-time imposed by the buyer;
r = holding rate of the buyer;
r_i = holding rate of i^{th} supplier;
rt_i = in-transit holding rate of i^{th} supplier;
d_i = distance from i^{th} supplier to buyer;
Cf_i = fixed shipping cost of i^{th} supplier; and
Cv_i = variable shipping cost of i^{th} supplier.
Decision variables:
X_i = fraction of Q allocated to i^{th} supplier

$$Y_i = \begin{cases} 1 \ \ if\ X_i \Phi 0 \ (i\text{th supplier is selected}) \\ \qquad\qquad 0 \ \ if\ X_i = 0 \end{cases}$$

In addition, D/Q is the number of periods during the time considered.

The total cost (C_{total}) can be written as:

$$C_{total} = \sum_{i=1}^{n} \left[\left(\frac{D}{Q}\right) (d_i Cf_i Y_i + Q X_i Cv_i) + \left(\frac{D}{Q}\right) A_i Y_i + D X_i P_i \left(rt_i T_i + (r_i + r) \frac{X_i Q}{2D} \right) \right]$$

As Q is the optimum order quantity, it can be calculated by using the derivative of C_{total}:

$$\frac{C_{total}}{Q} = 0 => Q = \sqrt{2D \frac{\sum_{i=1}^{n} (A_i + d_i Cf_i) Y_i}{\sum_{i=1}^{n} P_i X_i^2 \,(r_i + r)}}$$

By substituting for Q in C_{total}, it becomes:

$$C_{total} = \sqrt{2D \left(\sum_{i=1}^{n} (A_i + d_i Cf_i) Y_i\right) \left(\sum_{i=1}^{n} P_i X_i^2 \,(r_i + r)\right)} + \sum_{i=1}^{n} D X_i (rt_i T_i P_i + Cv_i)$$

Aguezzoul and Ladet (2007) also had shown a expression of an appropriate performance measure for delivery to the buyer which is given by Pan (1989).

$$LT_{total} = \sum_{i=1}^{n} l_i X_i$$

This expression must by less than the lead-time imposed by the buyer. This implies that the long lead-time of one supplier is compensated by the short lead-time of other suppliers.

The mathematical formulation of the nonlinear multi objective programming (NMOP) is given as follow:

Min $Z = (C_{\text{total}}, LT_{\text{total}})$

Such that,

$X_iD \le C_i \quad i=1,n$ ...supplier production capacity restriction

$\sum_{i=1}^{n} l_i X_i \le L$ …aggregate performance measure for delivery for all suppliers

$\sum_{i=1}^{n} X_i = 1$ …Demand placed with the set of n suppliers

$\varepsilon Y_i \le X_i \le Y_i \quad i=1,n$ …an order is placed if only he is selected

$Y_i = 0,1 \quad i=1,n$ …binary requirements on the Y_i variables

4.3 Fuzzy-AHP Approach

Chan *et. al.* (2008) presented a fuzzy-Analytical Hierarchy Process based approach for supplier selection at global level. First, he applied fuzzy synthetic extent analysis to calculate the weights for the different criteria and sub criteria and finally applied AHP method to calculate final weights of the suppliers. Decision is made on the basis of maximum weights gained by the supplier. The fuzzy-AHP approach discussed in his paper is as follows:

If the object set is represented as $X = \{x_1, \cdots, x_n\}$ and the goal or objective set as, $U = \{u_1, u_2, \ldots, u_m\}$, then according to the concept of extent analysis (Chang 1991, 1996), each object is taken and extent analysis for each goal U_i is performed respectively. The m extent analysis values for each object are denoted as $M_{gi}^1, \cdots, M_{gi}^m$ where i=1, 2,..., n.

where, $M_{gi}^1, \cdots, M_{gi}^m$ are triangular fuzzy numbers. M_{gi}^m represents the value of the extent analysis of the i^{th} object for m^{th} goal. The value of fuzzy synthetic extent with respect to the i^{th} object is defined as:

$$S_i = \sum_{j=1}^{m} M_{gi}^j \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j \right]^{-1}$$

S_i gives the synthetic values and calculated by above equation. The value of $\sum_{j=1}^{m} M_{g_i}^j$ can be found by performing the fuzzy addition operation of m extent analysis values from a particular matrix such that: $\sum_{j=1}^{m} M_{g_i}^j = \left(\sum_{j=1}^{m} n_{1j}, \sum_{j=1}^{m} n_{2j}, \sum_{j=1}^{m} n_{3j} \right)$ and the value of $\left[\sum_{j=1}^{n} \sum_{j=1}^{m} M_{g_i}^j \right]$ can be obtained by performing the fuzzy addition operation of $M_{g_i}^j \, (j = 1, \cdots, m)$ such that $\sum_{j=1}^{m} M_{g_i}^j = \left(\sum_{j=1}^{m} n_{1j}, \sum_{j=1}^{m} n_{2j}, \sum_{j=1}^{m} n_{3j} \right)$ and $\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^j \right]^{-1}$ can be calculated by the inverse of the previous equation as follows:

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} n_{3i}}, \frac{1}{\sum_{i=1}^{n} n_{2i}}, \frac{1}{\sum_{i=1}^{n} n_{1i}}\right)$$

The degree of possibility of $M_1 = (l_1, m_1, u_1) \geq M_2 = (l_2, m_2, u_2)$ is defined as:

l, m, u notations represents lower, middle and upper value of M_i.

$$V(M_1 \geq M_2) = \sup_{x \geq y}\left[\min(\mu_{M_1}(x), \mu_{M_2}(y))\right]$$

When a pair (x,y) exists such that $x \geq y$ and $\mu_{M_1}(x) = \mu_{M_2}(x) = 1$, then we have

$V(M_1 \geq M_2)=1$. Since M_1 and M_2 are convex fuzzy numbers so, $V(M_1 \geq M_2) = 1$ if $m_1 \geq m_2$ and $V(M_2 \geq M_1) = hgt(M_1 \cap M_2) = \mu_{M_1}(d)$, where d is the ordinate of the highest intersection point D between μ_{M_1} and μ_{M_2} when $M_1 = (l_1, m_1, u_1)$ and $M_2 = (l_2, m_2, u_2)$ then ordinate of D is computed is computed as shown in Fig. 5.

$$V(M_2 \geq M_1) = \text{hgt}\,(M_1 \cap M_2) = \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}.$$

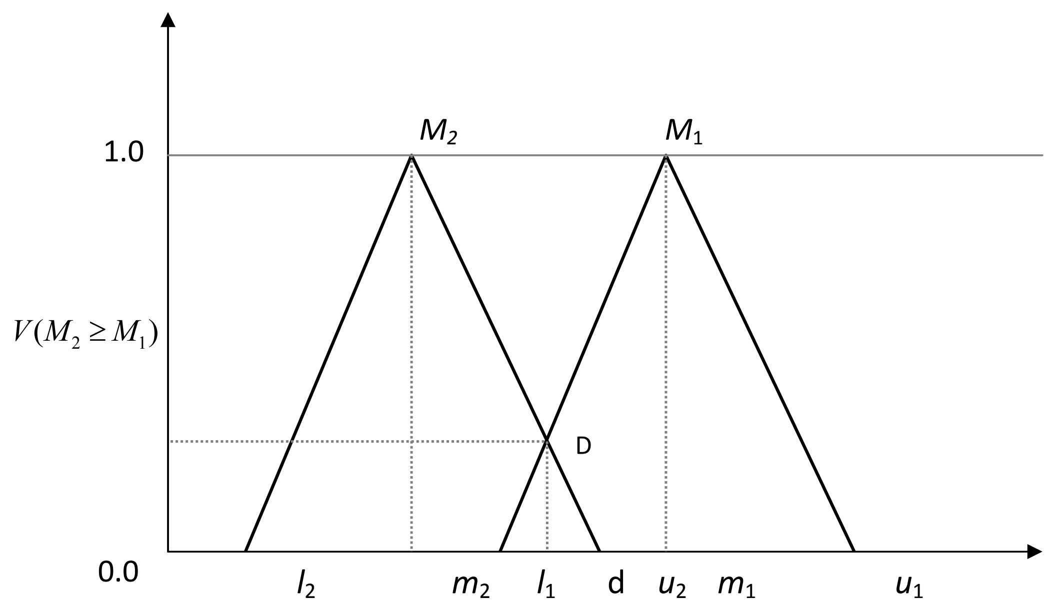

Fig. 5. Intersection between M_1 and M_2

For the comparison of M_1 and M_2, both the values of $V(M_1 \geq M_2)$ and $V(M_2 \geq M_1)$ are required. The degree of possibility for a convex fuzzy number to be greater than k convex fuzzy numbers M_i (i= 1, 2,….., k) can be defined by,

$$V(M \geq M_1, M_2, \ldots, M_k) = V[(M \geq M_1) \text{ and } (M \geq M_2) \ldots \text{ and } (M \geq M_k)] = \min V(M \geq M_i), \quad i=1, 2, \ldots, k$$

Here, *min* represents minimum value, and *P* indicates possibility.

If $min(p_i) = min\ V(S_i \geq S_k)$,

For k=1, 2,….. , n $k \neq i$. then the weight vector is given by,

$$W_p = (\min(p_1), \min(p_2), ..., \min(p_n))^T,$$

W_p is the weights among possibilities of minimum values.

Where P_i (i = 1, 2,….. , n) are n elements.

After normalizing W_p, we get the normalized weight vectors

$$W = (w(p_1), w(p_2), ... , w(p_n))^T,$$

Where W is a non fuzzy number and this gives the priority weights of one alternative over other.

4.4 Analytical Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) developed by Thomas L. Saaty in 1970, is a structured technique for dealing with complex decisions. The AHP provides a comprehensive and rational framework for structuring a decision problem. Users of the AHP first decompose their decision problem into a hierarchy of more easily comprehended sub-problems, each of which can be analyzed independently. There are some basic steps to follow while using AHP, thses are as follows:

Establishment of a structural hierarchy

This step allows a complex decision to be structured into a hierarchy descending from an overall objective to various 'criteria', 'sub-criteria', and so on until the lowest level. The objective or the overall goal of the decision is represented at the top level of the hierarchy. The criteria and sub-criteria contributing to the decision are represented at the intermediate levels. Finally, the decision alternatives or selection choices are laid down at the last level of the hierarchy.

Establishment of comparative judgment matrices

Once the hierarchy is built, the decision makers systematically evaluate its various elements by comparing them to one another. In making the comparisons, the decision makers can use concrete data about the elements, or they can use their judgments about the elements' relative meaning and importance. The pair-wise comparisons are given in terms of how much more element A (one element) is important than element B (another element). As the AHP approach is a subjective methodology, information and the priority weights of elements may be obtained from a decision maker of the company using direct questioning or a questionnaire method.

Synthesis of priorities and the measurement of consistency

The pair-wise comparisons generate a matrix of relative rankings for each level of the hierarchy. After all matrices are developed and all pair-wise comparisons are obtained, eigenvectors or the relative weights (the degree of relative importance amongst the elements), global weights, and the maximum eigen value (λ_{max}) for each matrix are then calculated. λ_{max} is used as a reference index to screen information by calculating the consistency ratio *CR* of the estimated vector in order to validate whether the pair-wise comparison matrix provides a completely consistent evaluation. The consistency ratio is calculated as per the following steps:

1. Calculate eigenvector or the relative weights and λ_{max} for each matrix of order *n*.

2. Compute the consistency index for each matrix of order *n* by $CI = (\lambda_{max} - n) / (n - 1)$

3. The consistency ratio is then calculated using $CR = CI/RI$

where, RI is a known random consistency index obtained from a large number of simulation runs and varies depending upon the order of matrix. Table 3.1 shows the value of the random consistency index (RI) for matrices of order 1 to 10 obtained by approximating random indices using a sample size of 500.

Table 3.1

Average random index (RI) or random consisting index (RCI) based on matrix size (adapted from Saaty)

N	1	2	3	4	5	6	7	8	9	10
RCI	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

The acceptable CR range varies according to the size of matrix, *i.e.*, 0.05 for a 3 by 3 matrix, 0.08 for a 4 by 4 matrix and 0.1 for all larger matrices, $n \geq 5$. If the value of CR is equal to, or less than that value, it implies that the evaluation within the matrix is acceptable or indicates a good level of consistency in the comparative judgments represented in that matrix. In contrast, if CR is more than the acceptable value, inconsistency of judgments within that matrix has occurred and the evaluation process should therefore be reviewed, reconsidered, and improved.

Calculation of final priority weights

The AHP converts these evaluations to numerical values that can be processed and compared over the entire range of the problem. A numerical weight or priority is derived for each element of the hierarchy, allowing diverse and often incommensurable elements to be compared to one another in a rational and consistent way. In the final step of the process, numerical priorities are calculated for each of the decision alternatives. These numbers represent the alternatives' relative ability to achieve the decision goal, so they allow a straightforward consideration of the various courses of action.

4.5 Fuzzy-TOPSIS

In Fuzzy-TOPSIS (Total order preference by similarity to the ideal solution) method the ratings of various alternative suppliers under different subjective attributes and the importance weights of all attributes are assessed in linguistic values represented by fuzzy numbers. These linguistic ratings can be expressed in triangular fuzzy numbers. 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. And finally, aggregate the weights to calculate final weights of alternatives with respect to primary goal.A mathematical model of fuzzy-TOPSIS used for robot selection by Chu and Lin (2003) and its steps to solve problem is as follows:

Aggregate the importance weights

Let $W_{tj} = (a_{tj}, b_{tj}, c_{tj}), t = 1 \sim k$, j = 1 ~ n, be the linguistic weight assigned to criterion C_t by decision maker D_j. The aggregated linguistic weight, $W_t = (a_t, b_t, c_t)$, t = 1~ k, for criterion t from n decision makers opinions can be calculated by $W_t = (1/n) \otimes (W_{t1} \otimes W_{t2} \cdots \otimes W_{tn})$ where,

$$a_t = \frac{\sum_{j=1}^{n} a_{tj}}{n}, b_t = \frac{\sum_{j=1}^{n} b_{tj}}{n}, c_t = \frac{\sum_{j=1}^{n} c_{tj}}{n}$$

Determine the Positive ideal and Negative ideal solutions

Let R_{itj} denote the linguistic rating assigned to alternative A_i by decision maker D_j for subjective criterion C_t.

Construct the weighted decision matrix $S_{it} = W_t \otimes R_{it}$

To avoid a complicated calculation of irregular fuzzy numbers, all S_{it} terms are defuzzified into crips values S_{it} terms. Then, define the ideal (I^+) and (I^-) solution as:

$I^+ = (S_1^+, \ldots, S_t^+, \ldots, S_k^+)$

$I^- = (S_1^-, \ldots, S_t^-, \ldots, S_k^-)$

Where $S_1^+ = {}^{max}_{i}\{S_{it}\}$ and $S_t^- = {}^{min}_{i}S_{it}$.

Calculate the Distance of Each Alternative from I^+ and I^-.

$$d_i^+ = \left[\sum_{t=1}^{k}(S_{it} - S_t^+)^2\right]^{\frac{1}{2}} \ (i = 1 \sim m) \qquad d_i^- = \left[\sum_{t=1}^{k}(S_{it} - S_t^-)^2\right]^{\frac{1}{2}} \ (i = 1 \sim m)$$

Where d_i^+ denotes the distance between each alternative and the ideal solution, d_i^- denotes the distance between each alternative and the negative-ideal solution.

Calculate Closeness Coefficient:

The closeness coefficient of alternative A_i with respect to ideal solution A^+ can be defined as:

$$C_i = \frac{d_t^-}{d_t^+ + d_t^-}(0 < C_i < 1, i = 1 \sim m)$$

Clearly, an alternative A_i is closer to I^+ *than to* I^- *as* C_i approaches with C_i. The closeness coefficient C_i, can be regarded as the evaluation value of alternative A_t. Thus, the larger C_i, the higher priority the alternative A_i.

5. Future perspective in supplier selection problem

Literature review makes us believe that there is still several rooms for research in supplier selection that need to be addressed. The following are some of the points need more focus:

5.1 Global Supplier Issues:

Selection of suppliers at global level is somewhat critical issue rather than domestic suppliers. Globalization makes huge competition in the market and tries to break the boundaries of restriction by the countries, and fight to acquire worlds market. Researcher has scope to do comparative studies for domestic and global suppliers and find out selection criteria.

5.2 Adaptability to IT (Information Technology):

Recently, literature has started discussing the issue of 'e-Procurement' e-commerce involves the company's use of the internet for procuring materials, quality control, financial transactions, transportation, warehousing, customs clearing, and documentation. IT make the world closer and closer and it saves time and effort while supplier selection. It brings transparency at work result in selection of best and competent supplier.

5.3 Supplier selection risk Management:

Literature does not incorporate any issues of supplier selection risk. Supplier loyalty has not been considered yet. For big giant i5 the market has to think these issues and should include this as a selection criterion.

5.4 Green Supplier Selection:

Now a day's world's environmental department makes some plans for adapting green technology and making official order to the companies to follow environmental rules and regulations thus, effect of green policies on the supplier selection need to more focus.

5.5 Optimization Techniques:

Very few papers considering the optimization techniques like genetic algorithm integrated with any other existing approach.

6. Concluding remarks

This paper gives brief insights of the existing literature in last two decade (1991-2011). It provides breakdown of all published papers according to supplier selection criteria, solution methodology, case study approach. Methodologies like goal programming, linear programming, MAUT, Fuzzy-AHP, DSS, DEA *etc.* were discussed in other researchers point of view. This paper may helps to researchers for understanding the inadequacy in the supplier selection literature and to find the gaps for work to be done in future.

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