A

DISSERTATION REPORT

ON

Using Fuzzy AHP and DEAHP Methods for supplier selection in a manufacturing company

Submitted in partial fulfilment of the requirements for the award of degree of

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CERTIFICATE

This is to certify that the dissertation work entitled "Using fuzzy AHP and DEAHP methods for supplier selection in a manufacturing company" by Mr Pankaj Kumar Barman is a bonafide work completed under my supervision and guidance, and hence approved for submission to the Department of Mechanical Engineering, Malaviya National Institute of Technology in partial fulfilment of the requirements for the award of the degree of Master of Technology with specialization in Industrial Engineering. The matter embodied in this Seminar Report has not been submitted for the award of any other degree, or diploma.

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Candidate's Declaration

I hereby certify that the work which is being presented in the dissertation entitled " Using Fuzzy AHP and DEAHP method for Supplier Selection in Manufacturing Company", in partial fulfilment of the requirements for the award of the Degree of Master of Technology in Industrial Engineering, submitted in the Department of Mechanical Engineering, MNIT, Jaipur is an authentic record of my own work carried out for a period of one year under the supervision of Dr. M L Mittal of Mechanical Engineering Department, MNIT, Jaipur.

I have not submitted the matter embodied in this dissertation for the award of any other degree.

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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 aim of this research work is to determine the key factors of supplier selection and ranking of potential suppliers.

In Jaipur a manufacturing company has been considered for my dissertation work. The company was considering two criteria of suppliers selection i.e. quality rating and service rating. But I have considered five criteria instead of two for improving the supplier's selection process which are product quality, product cost, flexibility, delivery time and service rating.

In this dissertation work, first of all the key factors involved in supplier selection have been identified. A survey has been conducted for data collection from purchase department in the company. After that the criteria weights for the suppliers' selection are calculated using Fuzzy AHP method and DEAHP method the ranking of the suppliers are determined. The rating has been represented by linguistic variables and then parameterized by triangular fuzzy number. The contribution of this study is to give improved suppliers' selection process to the company.

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LIST OF ABBREVIATION

TOPSIS	Technique for Order Preference by Similarity to ideal Solution
AHP	Analytic Hierarchy Process
TQM	Total Quality Management
JIT	Just in time
MCDM	Multiple Criteria Decision Making
FAHP	Fuzzy Analytic Hierarchy Process
SR	Service Rating
CBR	Case base Reasoning
MAUT	Multi attribute utility theory
DEA	Data Envelopment Analysis
TCO	Total cost of analysis
TFN	Triangular Fuzzy Number
CI	Consistency Index
CR	Consistency Ratio

CHAPTER 1: INTRODUCTION

1.1 Background

In most industries, the cost of raw materials and component parts signifies the largest percentage of the total product cost. For example, in high technology firms, 80% of the total product cost goes to purchased material and service accounts. Therefore, in the organization in its supply chain to choose the best supplier for reducing the cost is a wide area to improve it. Choosing the right method for supplier selection effectively leads to a reduction in purchase risk and increases the number of just in time (JIT) suppliers and total quality management (TQM) production. Therefore choosing the best supplier is a major key to reduce its supply chain cost as well as risk related to the supply chain.

Buyer with the right quality products at the right price, at the right time and in the right quantities, is one of the most critical activities for establishing an effective supply chain. Both quantitative and qualitative factors are to be included in the supplier selection process because it is a multi criteria decision making problem. To choose the best supplier the most important thing is that there should be a balance between tangible and intangible factors because there is a chance that they may be conflict. The aim of this study is to develop a methodology to evaluate suppliers by two methods and find out which method is better.

Supplier selection, which includes multi criteria and multiple differing objectives, can be defined as the process of finding the right suppliers with the right quality at the right price, at the right time, and in the right quantities. It is noted that, manufacturers spend more than 60% of its total sale. In addition, their purchases of goods and services constitute up to 70% of product cost. Major advantage of choosing the best supplier is that it reduces purchasing costs, improves competitiveness in the market and enhances end user satisfaction. Since this selection process mainly involves the evaluation of different criteria and various supplier attributes, it can be considered as a multiple criteria decision making (MCDM) problem. Many decision making method have been developed which considered several criteria and alternatives various for decision making to provide a solution to this problem. Basically there are two types of supplier selection problems. In single sourcing type, one supplier can satisfy all the buyer’s needs. In the multiple sourcing types, no supplier can satisfy all the buyer's requirements. Hence the management wants to split order quantities among different suppliers (William, 2010).

On an average more than half of its revenue is spend to purchase goods and service by a manufacturer, the success of a company is mainly depend on that making a company's success reliant on their interaction with the supplier. The role of purchase Managers with in company has become particularly important. Supplier selection involves the congregation of decisions made by different organizational levels in the company. Each level or each department may have their own priorities based on their ease of manufacturing. Taking all these into study, one cannot have an optimal solution. So, in selecting an appropriate supplier, one has to consider all these requirements and should take a compromising decision. With much of company's money being spent and increasing dependency on the outsourcing of many critical and complex parts ,the role of buyer is not only critical but also challenging .Buyers must define and calculate what will be the best value means for the buying organization ,and undertake purchase action accordingly. To identify the best value, the purchase manager must have a common meeting with technical, operations and legal experts within the company, and should be a professional negotiator and director across many internal and external parties.

Supplier selection is the process by which the buyer identifies, estimates, and deals with suppliers. The challenges mentioned make supplier selection a rich topic for industrial operations and management disciplines.

To cope with the growing competition, it isn't enough only to select from the existing or known suppliers but the management should be able to identify new suppliers. New supplier advantage or low labour cost which ultimately impact the cost of the product and may be able to supply it for cheaper than any other or may be able to deliver with lesser lead time that might allow maintaining minimum inventory which reduces expenses for maintenance as well as money will be put to best use.

Therefore, supplier selection, evaluation and monitoring are crucial for an industry to survive in long term. Ranking of suppliers become complex when suppliers must be evaluated across multiple dimensions evaluation indices. For example , if the buyer wishes to evaluate supplier's bids on the extents of price and lead-time, the buyer must build a trade-off between these two dimensions to determine whether it favors, say, a bid with a high price and less lead time to a bid

with a low price and higher lead time. The real challenge of supplier evaluation lies in constructing this trade-off in a way that perfectly reflects the buyer's preferences (Belem, 2003).
Traditionally, suppliers were considered to be adversaries and cost of goods was the only factor considered for supplier selection. But, now it is realized both by academics and practicing managers that the supplier is not adversaries but the partners in the supply chain. It is also realized that the supplier selection should not be solely based on cost but on the factors such as quality, delivery, historical supplier performance, capacity, communication systems, service and geographic location, among others which can be qualitative and quantitative. The organizations attach different importance/preference to these factors.

Probable suppliers for single items, in practice, are many having their positives and negatives related to these factors. Under these circumstances the ranking of the suppliers giving due consideration to the above factors and their importance, requires some formal method. Several methods have been used for this purpose differing in their suitability to qualitative/ quantitative factors, the methodology used for ranking and complexity.
Decision or selection making is a vital part of daily life; of which the major concern is that almost all issues requiring decisions have multiple, often conflicting, criteria. In reality, there is no avoidance of the co-existing of qualitative and quantitative data, and the data are often full of fuzziness and uncertain .In order to mediate the conflicts and contradictions in the process and act in response to the lack of flexibility while adopting traditional multi-criteria method to solve fuzzy problem.

1.2 Supplier criteria

A criterion can be supposed of as any measure of performance for a particular supplier choice. An attribute is also sometimes used to refer to a measurable criterion. Criterion is a general term and includes both the concepts of attributes and objectives. An attribute is measurable quantity whose value reflects the degree to which a particular objective is achieved. An objective is a statement about the anticipated state of the system under consideration. It indicates the directions of improvements of one or more attributes. Objectives are functionally to, derived from a set of attributes. There might a formal relation shift between objective and attributes, but usually the relationship is informal. To assign an attributes to a given objectives, two properties which are comprehensive and measurability should be satisfied. An attributes is inclusive if its value sufficiently indicates the degree to which the objective is met. It is measurable if it is reasonable practical to assign a value in a relevant measurable scale. In this study the word criterion rather than attribute will be used.

1.3 Supplier selection methods

There are many methods of supplier selection which are as mathematical programming, multiple criteria decision making (MCDM), multivariate statistical analysis, artificial intelligence & expert systems and decision making tools. In this work we use the multiple criteria decision making method. In the MCDM we use fuzzy AHP method and DEAHP for ranking of supplier alternatives.

1.4 Objective of the Research

The major objectives of the current study are

- To identify the supplier evaluation criteria.
- The second objective is to identify and the ranking the potential supplier alternatives.
- The third objective is to develop a supplier selections procedure for a manufacturing company.

1.5 Thesis Outline

The dissertation report contains five chapters.

CHAPTER 1: The current chapter gives an introduction to supplier selection criteria and supplier selection methods. This chapter also gives the objective of the research.

CHAPTER 2: Literature review which describes types of supplier and supplier selection criteria and attributes and supplier selection methods.

CHAPTER 3: Explains the FAHP and DEAHP method used in supplier selection procedure.

CHAPTER 4: Case study of supplier selection in Sagar Techno hem Company Jaipur.

CHAPTER 5: Conclusion

CHAPTER 2: LITERATURE REVIEW

Supplier selection, which includes multi criteria and multiple conflicting objectives, can be defined as the process of finding the right suppliers with the right quality at the right price, at the right time, and in the right quantities.

Supplier selection or evaluation is common problem for acquiring the necessary material so support the outputs of organizations. The problem is to find and evaluate periodically the best or most suitable vendor's capabilities. This usually happens when the purchase is complex, high rupee value, and perhaps critical. There are two areas of research in supplier selection. One is the factors or criteria that are important and should be considered and the other is the process or methodology applied to rank the suppliers. Supplier selection is an important decision –making process in the supply chain management. Different suppliers have varied 'pros and cons' associated with them. Therefore, selecting an appropriate is always difficult task. Supplier selection has a major impact on proper functioning of supply chain as well as product quality. Selection of right supplier improves the efficiency of supply chain and significantly increases corporate competitiveness. Organizations must be very cautions not only about price and quality of raw material but also about the structure of the organization , production capabilities , reliability, company policies etc. for some cases, it is not only enough to look at supplier conditions but also supplier reliability and capacity. For the case of just in time (JIT) manufacturing, supplier selection is the most importance. 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, increase value added in supply and accelerated technological change. Purchasing involves buying the raw materials, supplies and components for the organization. The activities associated with it include selecting and qualifying suppliers, rating supplier performance, negotiating contracts, comparing price, quality and service, sourcing goods and service, timing purchases, selling terms of sale, evaluating the value received, predicting price, service and sometimes demand changes, specifying the form in which goods are to be received etc. A key and perhaps the most important process of the purchasing function is the efficient selection of suppliers because it brings significant saving for organization. The objective of the supplier selection process is to reduce risk and maximize the total value for the buyer and it involves considering a series of strategic variables. Among these variables is the frame of the relationship with the suppliers, the choice between domestic and international suppliers and the number of suppliers that is choosing between single or multiple sourcing and the type of the product. (Bhutta, 2003)

2.1 Types of suppliers

Suppliers are essential to any business and the process of identifying and selecting a supplier is both relevant and important .Sometimes supplier contacts with purchasing organization through their sales representatives, but more often, the buyer need to locate them either at trade shows, wholesale showrooms and conventions, or through buyer's directories, industry contacts and trade. Supplier can be divided into three general categories manufacturers, distributors and independent crafts people.

The first category of supplier is manufacturers, these are the companies that research, develop and actually produce the finish product ready for purchase. Manufacturers and vendors are the source of supply chain.

The second types of suppliers are the distributors who are also known as whole sellers, brokers or jobbers, distributors buy in quantity from several manufacturers and warehouse the goods for sale to retailers. Although their prices are higher than manufacturers, they can supply retailers with small orders from a variety of manufacturers. A lower freight bill and quick delivery time from a nearby distributor often compensates for the higher per –item cost. The third kind is the independent craftspeople that are exclusive distributers of unique creations frequently offered by this independent crafts people, those are representatives or at trade shows.

2.2 Supplier selection criteria

Supplier selection is complicated by the fact that various criteria must be considered in the decision making process. The analysis of criteria for selecting and measuring the performance of the suppliers has been the focus of many research papers. Some papers reviewed and examined the decision criteria used for supplier selection. Most papers attempted to identify and determine the relative importance of criteria for supplier selection in various industries. The decision criteria used for supplier selection and the weights assigned to them can be different due to a number of factors (Sonmez, 2006).

- The demographic characteristics of the purchasing managers.
- The size of the buyer organization.

- The existence of purchasing strategy.
- The type of products and /or services purchased.

On the basis of the literature reviewed 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. It indicates the directions of improvements of one or more attributes. Objectives are functionally to, derived from a set of attributes. There might a formal relation shift between objective and attributes, but usually the relationship is informal. To assign an attributes to a given objectives, two properties which are comprehensive and measurability should be satisfied. An attributes is comprehensive if its value sufficiently indicates the degree to which the objective is met. It is measurable if it is reasonable practical to assign a value in a relevant measurable scale. In this study the word criterion rather than attribute will be used.

The various important criteria for the supplier selection as observed from the literature reviewed are:

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

2.3 Supplier selection methods

There are many MCDM approaches that have been suggested in the literature; however, supplier selection problem may be classified into two broad categories: individual approaches and integrated ones (Ho et al., 2010). Agarwal et al. (2011) present a review of various MCDM methodologies reported in the literature for solving the supplier evaluation and selection process. The review is solely based on 68 research articles, including eight review articles in the academic literature from the year 2000 to 2011. According to it, the distribution of the articles under various classes of MCDM methods is as follows: DEA 30 percent, mathematical programming 17 percent, AHP 15 percent, case based reasoning 11 percent, fuzzy sets theory 10 percent, ANP 5 percent and rest are other methodologies. A close study of it reveals that 45 percent researches find it appropriate using DEA and AHP methodologies for supplier selection; hence a hybrid DEAHP would be a useful methodology for such problems, which are based on large number of criteria.

There is no specific method for every problem because each problem is unique. To work reasonably in the supplier selection, a large number of methods would be needed.
The large number of methods available also presents a weakness, as it is not clear which method should be used for which situation. A number of studies have been devoted to examining vendor selection methods. The common conclusion of these studies is that the supplier selection is a multi criteria decisions making problem (Nydick and hill, 1992; De Boer et. Al, 2001). Sonmez (2006) reviewed the decision making methods for supplier selection and clustered them into several broad categories.

The major supplier selection approaches are reported in Table 1.

Table 1Supplier selection methods

S.NO	Category	Method
1	Mathematical programming	Total cost based approaches Non-linear programming Mixed integer programming Linear programming Integer programming Goal programming Data envelopment analysis (DEA)
2	MCDM	AHP methods Outranking methods Multi-attribute utility theory (MAUT) Linear weighted point Judgmental modeling Interpretive structural modeling Categorical methods Fuzzy sets
3	Artificial intelligence & expert systems	Neural networks (NN) Case-base reasoning (CBR)
4	Multivariate statistical analysis	Structural equation modeling Principal component analysis Factor analysis Cluster analysis
5	Other decision making tools	Group decision making Multiple

2.3.1 Mathematical programming

Mathematical programming models make it possible to formulate a decision-making problem in terms of a mathematical objective function. An advantage of mathematical programming models is that they are more objective than rating and linear weighting models, because the decision-maker (DM) explicitly has to state objective functions.

Total Cost Approach

Companies wanting to implement a total cost-based supplier selection process often stumble over how to include non-monetary issues such as delivery and quality performance, lead time, services, and social policies (Jafar Rezaei, 2014). Unit Total Cost is the total cost to the purchaser per unit after inclusion of all relevant factors.

Harding (1998) provides a detailed application of this approach. - 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). Too may include, in addition to the price paid, elements such as order placement costs, research costs, transportation costs, receiving, inspecting, and holding or disposal costs and so on. In their book (Handfield et ah, 1999), explore the understanding of TCO using the product life-cycle approach. They note 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, 1995), Zero base pricing (Monckza, 1988), and cost-based supplier performance evaluation (Handheld et al.1999) among others. None of these approaches has received significant, widespread support in literature or in practice for a variety of reasons.

Data Envelopment Analysis

DEA is a mathematical programming method for assessing the comparative efficiencies of decision-making units (DMUs) where the presence of multiple inputs and outputs makes comparison difficult. Recent work by authors such as Weber (1996) has shown the efficacy of using Data Envelopment Analysis (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’.

Optimization Techniques- Several optimization techniques have been applied to SS.

Among the more commonly applied techniques are Dynamic programming (Masella, 2000), Linear programming (Ghodsypour et al., 2006) and Multi-Objective programming (Weber et al., 1993).

Goal Programming

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.

Integer linear programming

Talluri (2002) developed a binary integer linear programming model to evaluate alternative supplier bids based on ideal targets for bid attributes set by the buyer, and to select an optimal set of bids by matching demand and capacity constraints. Based on four variations of model, effective negotiation strategies were proposed for unselected bids.

Hong et al. (2005) presented a mixed-integer linear programming model for the supplier selection problem. The model was to determine the optimal number of suppliers, and the optimal order quantity so that the revenue could be maximized. The change in suppliers' supply capabilities and customer needs over a period of time were considered.

Integer non-linear programming

Ghodsypour and O'Brien (2001) formulated a mixed integer non-linear programming model to solve the multi-criteria sourcing problem. The model was to determine the optimal allocation of products to suppliers so that the total annual purchasing cost could be minimized. Three constraints were considered in the model.

2.3.2 Multiple criteria decision making (MCDM)

There are various methods in multiple criteria decision making such as AHP method, TOPSIS method, multi attribute utility theory, Fuzzy sets, judgmental modeling, linear weighted point, interpretive etc. The general methods are describes bellow as.

Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) provides a framework to cope with multiple criteria situations involving intuitive, rational, qualitative and quantitative aspects (Bhutta et al., 2003). The primary objectives affecting supplier selection criteria are grouped under three main categories: performance assessment, business structure capability assessment and quality system assessment. The AHP is used as a framework to formalize the evaluation of tradeoffs between the conflicting selections criteria associated with the various supplier offers. This is the main reason for selecting the AHP as the decision support model 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). Generally the hierarchy has three levels: the goal, the criteria and the alternatives. For the supplier selection problem, the goal is the best supplier, the criteria could be quality, on-time delivery, price, etc. and the alternatives are the suppliers or proposals of the suppliers.

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.

Multiple Attribute Utility Theory

Multiple Attribute Utility Theory (MAUT) 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 (Weber, 1991).

Multi-objective 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.

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

Outranking Method

Outranking methods are useful decision tool to solve multicriteria 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.

2.3.3 Artificial intelligence & expert systems

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:

Artificial Neural Network

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.

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.

2.3.4 Multivariate statistical analysis

There are various methods which are considered under these categories such as structural equation modeling, factor analysis, cluster analysis etc.

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. Obviously, CA can also be applied to a group of suppliers that are described by scores on some criteria. The result is a classification of suppliers in clusters of comparable suppliers (Bhutta, 2003).

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.

Table 2Technique and its proponents

Technique	Proponents	Methodology	Applications
Analytic hierarchy process(AHP)	Saaty, Belton, Dyer, Bard, Bhutta, Nydick, Hill	AHP provides a framework to cope with multiple criteria situations involving intuitive, rational, qualitative and quantitative aspects.	Prioritizing Alternatives
Unit Total Cost	Harding, Porter, Monckza.	Unit Total Cost is the total cost to the purchaser per unit after inclusion of all relevant factors	Cost of product is less significant than other costs

Total Cost of Ownership (TCO)	Ellram, Cart, Cavinto, Porter, Bhutta	TCO is a methodology and philosophy, 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	Cost of product is less significant than other costs
ABC costing Approach	Tyndall, Morris, Kaplan	Categorizing costs into ABC categories and then making a selection based on the criteria selected	When cost categories of parts is critical
Life Cycle Costing Approach	Jackson, Ostrom, Handfield, Pannesi	Looks at the cost of the product over its whole life	When periodic maintenance or replacement is needed and costs are high
Multi-Objective Programming	Weber, Ellram	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	Where multiple conflicting criteria have to be considered in a JIT environment.
Multi-Attribute Utility Theory (MAUT)	Weber, Nitszch	Use of MAUT, can help purchasing professionals to formulate viable sourcing strategies, as it is capable of handling multiple conflicting attributes	In situations of International supplier selection, where the environment is more complicated and risky.

		inherent in international supplier selection	
Dynamic Programming	Masella, Rangone	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.	Where output is a measured quantity And discretization of variables can be achieved
Data Envelopment Analysis (DEA)	Weber, Kleinsouza, Clarke, Kent	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.	Where there are multiple inputs and outputs that make comparisons difficult

3.1 Integrated approaches

3.1.1Integrated AHP approaches

Fourteen papers (17.95%) applied integrated AHP approaches to evaluate the performance of suppliers and select the best supplier

3.1.2. Integrated AHP and DEA

Ramanathan (2007) suggested that DEA could be used to evaluate the performance of suppliers using both quantitative and qualitative information obtained from the total cost of ownership and AHP. Specifically, costs based on the concept of total cost of ownership were regarded as inputs, whereas the AHP weights were considered as outputs in the DEA model. Saen (2007) proposed an integrated AHP–DEA approach to evaluate and select slightly non-homogeneous suppliers. The author stated that many suppliers do not comprehensively consume common inputs to comprehensively supply common outputs. In the approach, AHP was deployed to determine the relative weight of each supplier that had missing value (i.e., input or output). DEA was then applied to compute the relative efficiency of each supplier. Sevkli et al. (2007) applied an integrated AHP–DEA approach for supplier selection. In the approach, AHP was used to derive local weights from a given pairwise comparison matrix, and aggregate local weights to yield overall weights. Each row and column of the matrix was assumed as a decision making unit (DMU) and an output, respectively. A dummy input that had a value of one for all DMUs was deployed in DEA to calculate the efficiency scores of all suppliers. However, the authors pointed out that the approach was relatively more cumbersome to apply than the individual AHP. 3.1.3. Integrated AHP, DEA, and artificial neural network Ha and Krishnan (2008) applied an integrated approach in an auto parts manufacturing company for supplier selection. Twelve evaluating criteria were proposed for the selection problem. In the approach, AHP was used first to evaluate the performance of suppliers with respect to five qualitative factors. Then, the remaining seven quantitative criteria along with the scores for each supplier calculated by AHP were passed to DEA and artificial neural network (ANN) to measure the performance efficiency of each supplier. Both results were compiled into one efficiency index using a simple averaging method.

3.1.4. Integrated AHP and GP

Çebi and Bayraktar (2003) proposed AHP to evaluate the relative performance of suppliers for every raw material with respect to 14 evaluating criteria. The weightings of suppliers were then used as the input of a GP model to select the best set of suppliers for a particular type of raw materials, and determine the amount of raw materials to be purchased. Similar to Çebi and Bayraktar (2003), Wang et al. (2004, 2005) applied an integrated AHP–GP approach for supplier selection. The only difference between them is due to the evaluating criteria used in AHP. The AHP weightings were incorporated into one of the goal constraints of the GP model. Perçin (2006) applied an integrated AHP–GP approach for supplier selection. AHP was used first to measure the relative importance weightings of potential suppliers with respect to 20 evaluating factors. The weightings were then used as the coefficients of five objective functions in the GP model. The model was to determine the optimal order quantity from the most appropriate supplier while considering the capacities of potential suppliers. Kull and Talluri (2008) utilized an integrated AHP–GP approach to evaluate and select suppliers with respect to risk factors and product life cycle considerations. In the proposed model, AHP was used to assess suppliers along the risk criteria, and to derive risk scores. The GP model was then constructed to evaluate alternative suppliers based on multiple risk goals and various hard constraints.

Mendoza et al. (2008) presented an integrated AHP–GP approach to reduce a large number of potential suppliers to a manageable number, rank the alternative suppliers with respect to five evaluating criteria, and determine the optimal order quantity 3.1.7. Integrated AHP and multi-objective programming Xia and Wu (2007) incorporated AHP into the multi-objective mixed integer programming model for supplier selection. The model applied AHP to calculate the performance scores of potential suppliers first. The scores were then used as coefficients of one of the four objective functions. The model was to determine the optimal number of suppliers, select the best set of suppliers, and to determine the optimal order quantity.

3.2. Integrated fuzzy approaches

Nine papers (11.54%) proposed integrated fuzzy approaches to deal with the supplier evaluation and selection problem. Their applications and evaluating criteria used in the approaches.

3.2.1. Integrated fuzzy and AHP

Kahraman et al. (2003) applied a fuzzy AHP to select the best supplier in a Turkish white good manufacturing company. Decision makers could specify preferences about the importance of each evaluating criterion using linguistic variable. Chan and Kumar (2007) also used a fuzzy AHP for supplier selection as the case with Kahraman et al. (2003). In the approach, triangular fuzzy numbers and fuzzy synthetic extent analysis method were used to represent decision makers' comparison judgment and decide the final priority of different criteria.

3.2.3. Integrated fuzzy and GA

Jain et al. (2004) suggested a fuzzy based approach for supplier selection. The authors addressed that it might be difficult for an expert to define a complete rule set for evaluating the supplier Performance. GA was therefore integrated to generate a number of rules inside the rule set according to the nature and type of the priorities associated with the products and their supplier's attributes.

3.2.4. Integrated fuzzy and multi-objective programming

Amid et al. (2006) developed a fuzzy multi-objective linear programming model for supplier selection. The model could handle the vagueness and imprecision of input data, and help the decision makers to find out the optimal order quantity from each supplier. Three objective functions with different weights were included in the model. An algorithm was developed to solve the model. Amid et al. (in press) formulated a fuzzy multi-objective mixed integer linear programming model to solve the supplier selection problem. The approach is very similar to that in Amid et al. (2006), including the number of objective functions in the model, the criteria used to evaluate the suppliers, and the solution approach used to solve the model. The only difference is that quantity discount was considered in Amid et al. (in press). The price discount was directly proportional to the quantities ordered.

CHAPTER 3: THEORTICAL BACKGROUND

3.1 Fuzzy Set- theory

To deal with vagueness in human thought, Lotfi A. Zadeh(1965) first introduced the fuzzy set theory, which has the capability to represent manipulate data and information possessing based on non-statistical uncertainties. Fuzzy set theory has been designed to mathematically represent uncertainty and vagueness and to provide formalized tools for dealing with the imprecision inherent to decision making problems. Some basic definitions of fuzzy sets, fuzzy numbers and linguistic variables are reviewed from Zadeh (1975), Buckley (1985), Negi (1989), Kaufmann and Gupta (1991). The basic definitions and notations which are given below will be used throughout this thesis.

Fuzzy logic is a form of many-valued logic that deals with approximate, rather than fixed and exact reasoning. Compared to traditional binary logic (where variables may take on true or false values), fuzzy logic variables may have a truth value that ranges in degree between 0 and 1. Fuzzy logic has been extended to handle the concept of partial truth, where the truth value may range between completely true and completely false.

3.2 Definitions of Fuzzy Sets

Definition1. A fuzzy set A in a universe of discourse X is characterized by a membership function $\mu A(x)$ which associated with each element x in X a real number in the interval (0,1), the function value is the term of grade of membership of x in A (Kaufmann and Gupta, 1991).

Definition2**.** A fuzzy set A in a universe of discourse X is convex if and only if

$\mu A\ (\lambda + (1-\lambda)\ \min\ (\mu A(x1), A(x2))$

For all in X and all λ [0, 1], where min denotes the minimum operator (Klir and Yuan, 1995).

Definition3**.** The height of a fuzzy set is the largest membership grade attained by any element in that set. A fuzzy set A in the universe of discourse X is called normalized when the height of A is equal to 1(Klir and Yuan, 1995).

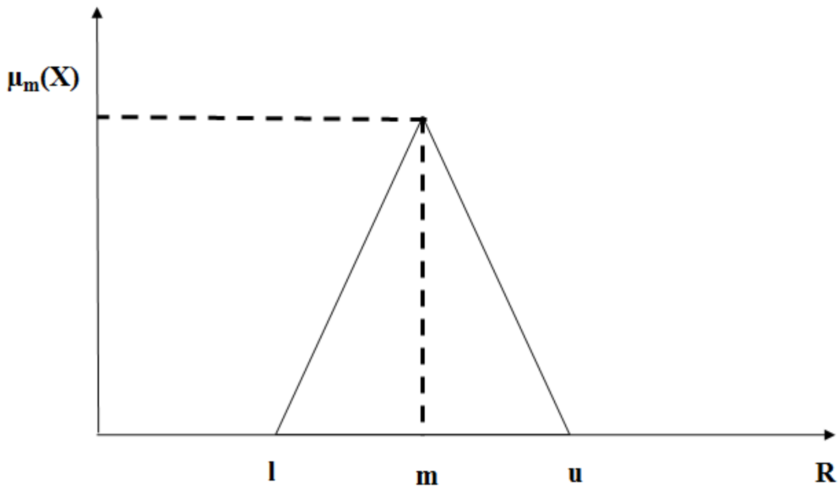

Figure 1Membership function of a TFN (Zadeh, Lotfi A, 1965)

3.3 Definitions of fuzzy numbers

Definition1. A fuzzy number is a fuzzy subset in the universe of discourse X that is both convex and normal. Fig. shows a fuzzy number ñ in the universe of discourse X that conforms to this definition (Kaufmann and Gupta, 1991).

Fuzzy set theory is a mathematical theory given by Zadeh. The key idea of fuzzy set theory is that an element has a degree of membership in a fuzzy set, ranging between 0 and 1. A triangular fuzzy number (TFN) is defined by a triplet (l, m, n). The membership function of this fuzzy number μ_A (X): R → [0, 1] given in equation 1.

$$\mu_A(X) = \begin{cases} 0 & x<1 \\ \frac{x-1}{m-1} & 1 \leq x \leq m \\ \frac{x-n}{m-n} & m \leq x \leq n \\ 0 & x>n \end{cases}$$

Let $\widetilde{\text{A}}$= $(l_{1,}m_{1,}n_1$) and $\widetilde{\text{B}}$= $(l_{1,}m_{2,}n_2$) are two TFNs then the operational laws of these TFNs are shown in table. Assuming that $\widetilde{\text{A}}$= $(l_{1,}m_{1,}n_1$) and $\widetilde{\text{B}}$ = $(l_{1,}m_{2,}n_2)$ are real numbers then the distance between Ã and is equal to the Euclidean distance.

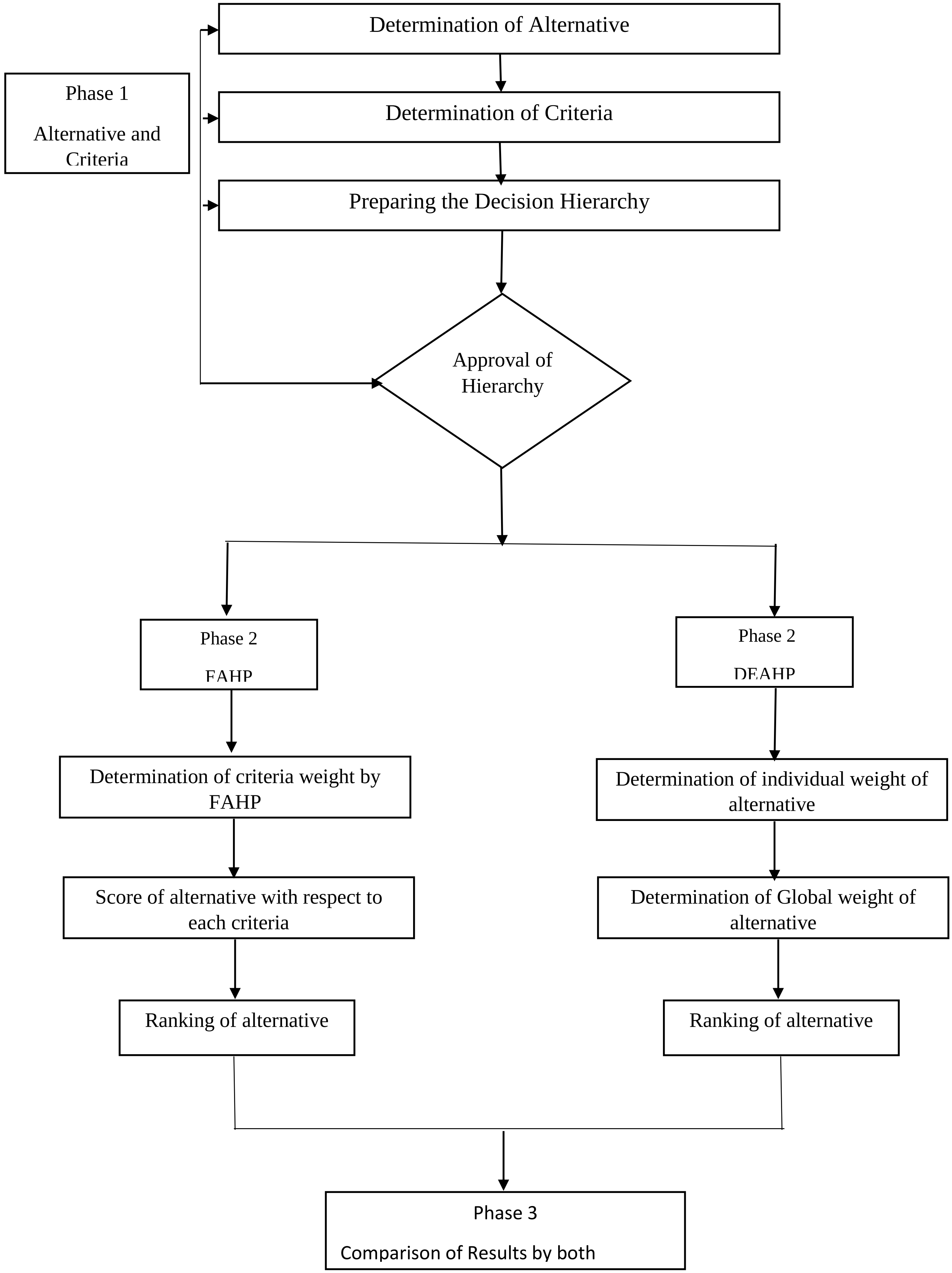

Figure 2 Flow Chart of Methodology

3.4 Fuzzy AHP

Fuzzy Analytic Hierarchy Process (F-AHP) embeds the fuzzy theory to basic Analytic Hierarchy Process (AHP), which was developed by Saaty. AHP is a widely used decision making tool in various multi-criteria decision making problems. It takes the pair-wise comparisons of different alternatives with respective to various criteria and provides a decision support tool for multi criteria decision problems. In a general AHP model, the objective is in the first level, the criteria and sub criteria are in the second and third levels respectively. Finally the alternatives are found in the fourth level.

Benefiting from fuzzy logic approach. in F-AHP, the pair wise comparisons of both criteria and the alternatives are performed through the linguistic variables, which are represented by triangular numbers. One of the first fuzzy AHP applications was performed by van Laarhoven and Pedrycz. They defined the triangular membership functions for the pair wise comparisons. Afterwards, Buckley has contributed to the subject by determining the fuzzy priorities of comparison ratios having triangular membership functions. Chang also introduced a new method related with the usage of triangular numbers in pair-wise comparisons. Although there are some more techniques embedded in F-AHP, within the scope of this study, Buckleys methods is implemented to determine the relative importance weights for both the criteria and the alternatives.

The procedure for determining the evaluation criteria weights by FAHP can be summarized in the following steps

Step-1 The hierarchy is constructed in such a way that the overall goal is at the top, criteria and sub criteria are in the middle and various alternatives at the bottom.

Step-2 The relative importance of each criteria with respect to the goal of the problem is determined by using a typical pair-wise comparison matrix in which all the attributes are compared with each other, and scores are given using a nine-point scale. For N criteria the size of the comparison matrix (C) will be N×N and the entry c_{ij} donates the relative importance of criterion i with respect to criterion j. if more than one decision maker, than average are taken.

$$c^k = \begin{bmatrix} {c_{11}}^k & \cdots & {c_{1n}}^k \\ \vdots & \ddots & \vdots \\ {c_{n1}}^k & \cdots & {c_{nn}}^k \end{bmatrix},$$

$\tilde{c}_{ij} = \frac{\sum_{k=1}^{k} {c_{ij}}^k}{k}$ where k is the no. of decision maker

Step-3 pairwise comparisons matrix updated according to average of decision matrix

$$\widetilde{C} = \begin{bmatrix} \widetilde{c_{11}} & \cdots & \widetilde{c_{1N}} \\ \vdots & \ddots & \vdots \\ \widetilde{c_{N1}} & \cdots & \widetilde{c_{NN}} \end{bmatrix}, \qquad \widetilde{c_{ij}} = 1, \widetilde{c_{ij}} = \frac{1}{\widetilde{c_{ij}}}, \widetilde{c_{ij}} \neq 1$$

Step-4 The geometric mean method is used for fuzzy weights evaluation. The fuzzy geometric mean;

$\widetilde{r_1} = [\widetilde{c_{i1}} \times \widetilde{c_{i2}} \times \ldots \ldots . \times \widetilde{c_{iN}}]^{1/N}$, i=1,2,3…………n

Step-5 fuzzy weights of each criterion is calculated.

Step-5a find the vector addition of each $\widetilde{r_1}$.

Step-5b calculate the inverse of addition vector. Replace the fuzzy triangular number, to make it in ascending order

Step-5c the fuzzy weight of the i^{th}criteria, indicated by a triangular fuzzy number

$$\widetilde{W_i} = \widetilde{r_1} \text{ x } [\widetilde{r_1} + \widetilde{r_2} \ldots \ldots \ldots \ldots \ldots \widetilde{r_N}]^{-1}$$

$$= (lw_i , mw_i , nw_i)$$

Step-6 Since $\widetilde{W_i}$ are still fuzzy triangular numbers, they need to de-fuzzified by Centre of area Method proposed by Chou and Chang

$$M_i = \frac{lw_i + mw_i + nw_i}{3}$$

Step-7 M_i is a non fuzzy number. But it needs to be normalized

$$N_i = \frac{M_i}{\sum_{i=1}^{N} M_i}$$

These 7 steps are performed to find the normalized weights of both criteria and the alternatives. Then by multiplying each alternative weight with related criteria, the scores for each alternative is Calculated. According to these results, the alternative with the highest score is suggested to the decision maker

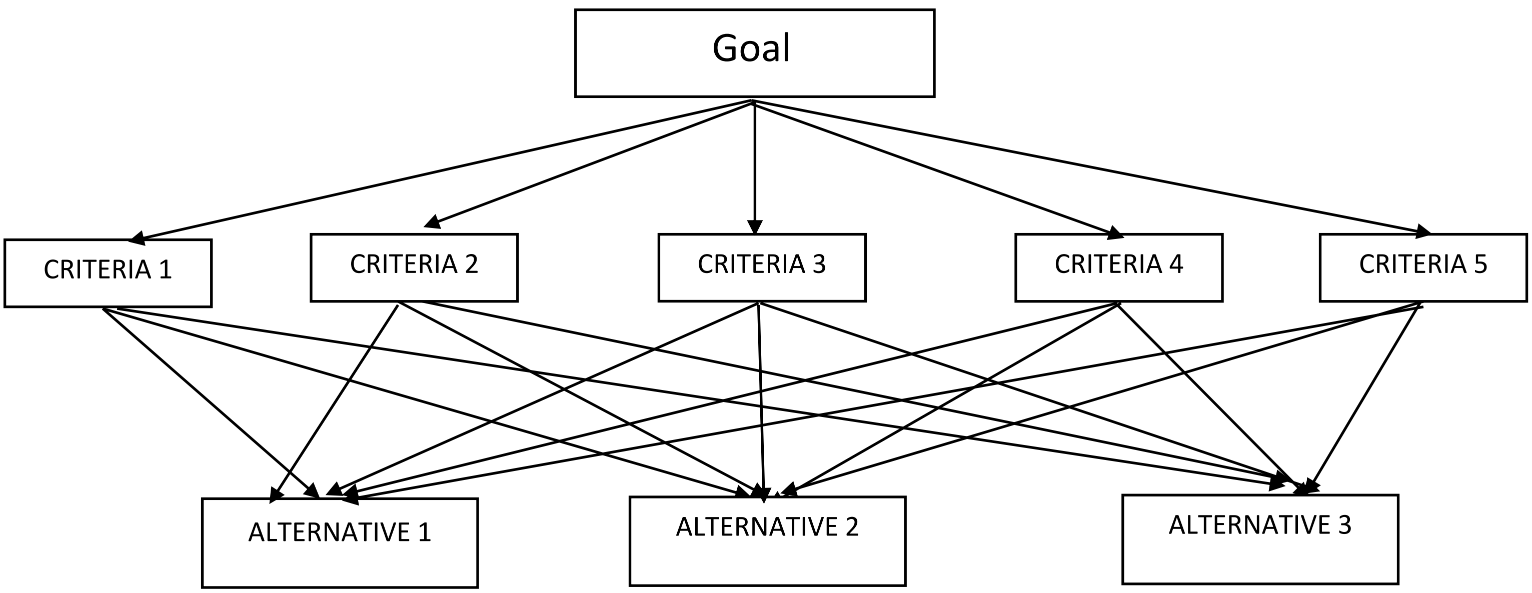

Figure 3 Hierarchy of Alternative and Criteria

3.2 DEA

DEA is data oriented approach for evaluating the performance of a set of peer entities called DMUs which convert multiple inputs into multiple outputs. Charnes et al. (1978) described DEA as a "mathematical programming model applied to observational data [that] provides a new way of obtaining empirical estimates of relations such as the production functions and/or efficient production possibility surfaces that are cornerstones of modern economics." The efficiency score in the presence of multiple input and output factors is defined as:

EFFICIENCY= $\frac{\text{weighted sum of output}}{\text{weighted sum of inputs}}$

Assuming that there are n DMUs, each with m inputs and s outputs, the relative efficiency score of a test DMU p is obtained by solving the following model:

max Z=$\frac{\sum_{k=1}^{s} W_k . y_{kp}}{\sum_{j=1}^{m} w_j . x_{jp}}$

Subjected to$\frac{\sum_{k=1}^{s} W_k . y_{kp}}{\sum_{j=1}^{m} w_j . x_{jp}}$≤1, $W_k, w_j \leq 0$

where k=1 to s; j=1 to m; i=1 to n; y_{ki} is the amount of output k produced by DMU i; x_{ji} is the amount of input j utilized by DMU i; W_k is the weight given to output k; w_j is the weight given to input j.

The fractional program can be converted to a linear program as shown

maxZ=$\sum_{k=1}^{s} W_k \, . \, y_{kp}$

subjected to$\sum_{j=1}^{m} w_j \, . \, x_{jp}$

$\sum_{k=1}^{s} W_k \, . \, y_{kp}$-$\sum_{j=1}^{m} w_j \, . \, x_{jp} \leq 0$

$W_{k,}w_j \geq 0$

The above problem is run n times in identifying the relative efficiency scores of all the DMUs. Each DMU selects input and output weights that maximize its efficiency score. In general, a DMU is considered to be efficient if it obtains a score of 1 and a score of < 1 implies that it is inefficient.

3.3 The DEAHP

Ramanathan (2006) first proposed the DEAHP methodology, in which DEA method is embedded into AHP method. The structure of DEAHP is same as AHP structure, i.e. the upper level of the hierarchy represents the overall goal, while the lower level consists of all possible alternatives. One or more intermediate levels embody the decision criteria and sub criteria.

In this methodology, each row of the pair wise matrix is assumed as DMU and each column is assumed as output. But according to DEA method, the efficiency scores of each DMU cannot be calculated entirely with outputs and requires at least one input.

So, dummy inputs for all the DMU's are employed which has a value of 1 as shown in Table II. In DEAHP methodology the efficiency scores are calculated using the DEA method for each pair-wise comparison matrix and could be interpreted as local weights of the DMUs. Once the local weights of DMUs are calculated, the next step is to aggregate the local weights to get overall weight. Again, the DEA method is used to derive the overall weights from the local weights. Ramanathan (2006) also approves that DEA method correctly derives the weights for consistent judgment matrix. Further, Sevkli et al. (2007) and Zhang et al. (2011) applied this approach for supplier selection problem. Hence, it is imperative to use an integrated DEAHP approach for the present study also.

CHAPTER 4: CASE STUDY

4.1 Introduction of the Company

- **Sagar Technochem** has been involved in providing perfect **water & waste water solutions** to various residential, commercial and industrial applications.
- As an **ISO 9001: 2008 certified Manufacturer, Supplier and Service Provider**, the organization work with set industrial norms and ever-rising technological trends as well.
- Also, it have specialization in **Water Treatment Solutions** allow them to do the very best towards the total customer satisfaction. It covers **R.O. Plant, Water Softener Plant, Effluent Treatment Plant, Sewage Treatment Plant, Water Treatment Chemicals** and more.
- Besides the products, it also provide **Installation and Repair Services.** The plants they offer have some certain features such as ***low power consumption, easy to operate, automatic facilities and flawless output***.
- It have every modern-day facilities at our infrastructural setup that combines core technologies, high-grade material, components and other inputs and sound methods. All such facilities enable them develop the finest Water Treatment Solutions that feature cost-effectiveness and high efficiency and environmental friendliness.
- Also, the team of ingenious professionals helps them run effective working by using right techniques and following current industrial trends. They keep up with specific details of clients and incorporating the same come up with satisfactory solutions.
- For that reason, it have been effectively catering the needs of **Food & Beverages, Commercial Application, Automobiles, Petrochemicals Industry, Hospitality** and other industries.

4.2 Current supplier selection method

The present procedure of the supplier selection in Sagar Technochem Company is based on the quality rating and service rating factor but there are more than two factors important like product price, flexibility, delivery time etc. Therefore in this thesis we consider the five factors such as product price, service rating, flexibility, products quality and delivery time. In this thesis, five criteria and three potential suppliers are determined as a result of negotiations held with decision markers.

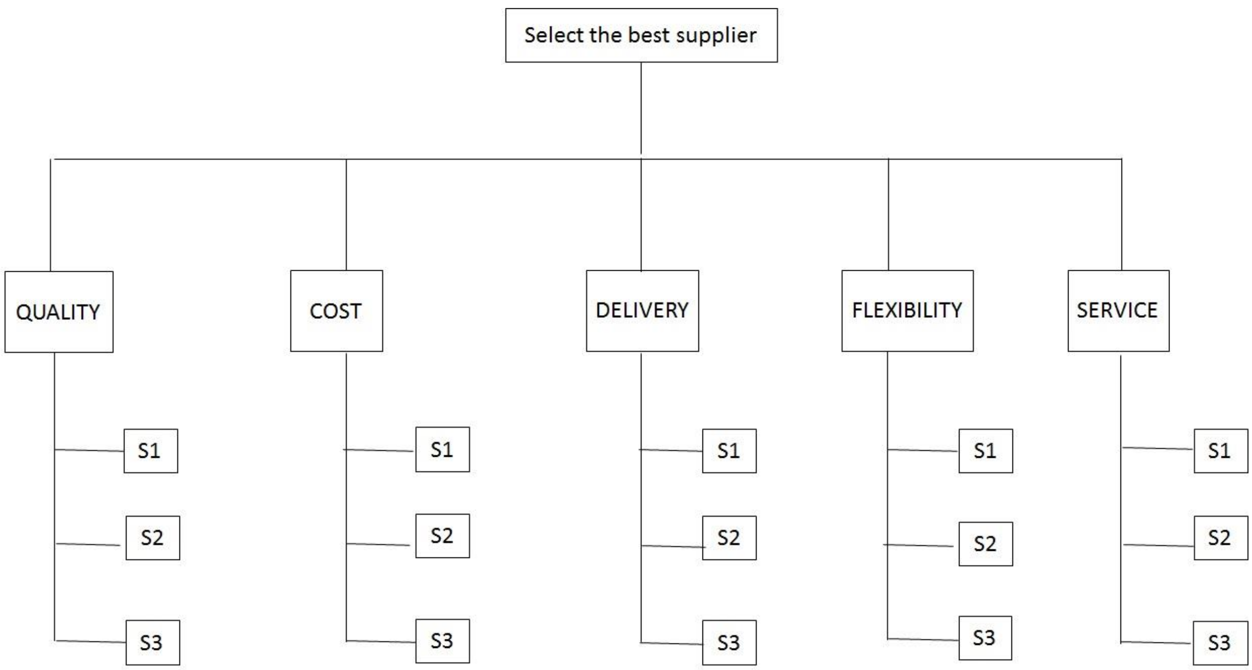

Figure 4 Criteria and Alternatives

4.3 Supplier selection criteria description

There are a number of supplier selection criteria. In this thesis work six criteria are considered which are cost, product quality, location, price, information system and service rating. These six criteria are explained below.

4.3.1 Cost / price

In the competitive environment, every purchasing manager is looking for the economical products. Therefore, the cost of the product is also a very important decision criterion for supplier selection. Cost / price are an obvious consideration for any purchase, many researchers and mentioned cost as an important factor in selecting suppliers. In ordinary usage, price is the quantity of payment for something. In business, the cost may be one of acquisition, in which case the amount of money expended to acquire it is counted as cost. In this case, money is the input that is gone in order to acquire (Wikipedia, 2007). The cost/ price factor has been measured on the basis of the importance of the following cost/ price dimensions in the buying organizations supplier selection :total cost (evaluating a supplier is cost structure involves providing detailed cost data by the supplier), payment procedures understanding, offering the supplier to competitive pricing, quantity , discount (suitability of discount scheme implemented on payment of invoices within time frame) and payment terms (suitability of terms and conditions regarding payment of invoices, open accounts, sight drafts, credit letter and payment schedule) (HS Keska, 2004).

4.3.2 Quality

Quality is closely related to the end use of the product. A good quality product must meet the minimum standards and the requirements of the customer and it should perform efficiently, consistently and satisfactorily. The supplier's quality systems and processes that maintain and improve quality and delivery performance are key factors. Selection criteria may consider the supplier's quality assurance and control procedures, complaint handling procedures, quality manuals, ISO 9000 standard registration status, and internal rating and reporting systems. Just as the role of price has reduced as a criterion in supplier selection in many sectors, so quality has become a more important factor. The supplier's capability to reduce his price in the future and to further optimize his quality potential comes into play as well. In addition, the understanding of the concept quality has been transformed. Quality no longer simply applies to the product itself but also applies to the service and other received aspects of the supplier-manufacturer relationship (HS Keskar, 2004).A good relationship is a prerequisite to good problem solving and co-operation in product modification. Supplier quality has been established as a primary concern in the supplier selection process for decades (De Boer et al., 1998).

quality factor was measured in terms of suppliers ability to provide inputs that are reliable and durable (measure of useful life of the product), possessing the supplier to quality system, adherence to quality tools, percent rejection and supplier reputation and position.

4.3.3 Delivery time

In general, time when actual delivery takes place. If a supplier submits the lowest price, it doesn't mean much to the firm if the vendor is also late two or three weeks on all contracts (De Boer and Der Wegan, 2003). The delivery factor has been measured on the basis of the importance of the following delivery dimensions in the buying firm is supplier selection process: ability and willingness to expedite an order, how quickly a supplier can deliver, the amount of time that it takes a supplier to deliver the supplies, upcoming delivery commitments, safety and security components during the transportation and modes of transportation facility.

4.3.4 Service rating

Service rating is the flexibility in the implementing changes in delivery, design etc. Service rating is a very important factor in supplier selection criteria. Service rating includes following parameters:

- Cooperativeness and readiness to help in emergencies.
- Response on quality complaints including replacement of rejected materials.
- Flexibility in implementing changes in delivery, design etc.
- Promptness in reply.
- Compatibility to bill payment terms.

Service rating (SR) on overall basis is to be assigned by a committee consisting of representatives from purchase department and planning department. The final service rating for a given vendor will be the average of rating assigned by all members of the committee.

The service rating shall be once a year for a given vendor and shall be completed well before the tendering action for the next year's requirement, based on the experiment from the supplier for the previous year.

4.3.5 Flexibility

Flexibility is defined as the ability of a system to adapt to external changes, while maintaining satisfactory system performance. System performance is characterized by parameters such as capacity, level of service, maintainability and profitability. External changes are uncontrolled conditions that affect the system, including changes in level of demand or use, shifts in spatial traffic patterns, infrastructure loss and degradation, and changes in the price and availability of important resources such as fuel, etc. Indeed flexibility is vital to the success of supply chain, since the supply chains generally operate in uncertain business environment. It has a variety of dimensions attached with it (Singh and Sharma, 2014). Flexibility measures are broadly divided under the four headings:

(1) Volume flexibility: the ability to respond to change in demand.

(2) Mix flexibility: the ability to change the variety of products produced.

(3) Delivery flexibility: the ability to respond quickly to tight delivery requests.

(4) New product flexibility: the ability to introduce and produce new products (also includes modification of the existing system).

Therefore, the flexibility of the supplier can be evaluated under four attributes: ability to quick change program, short new product line time, Short lead time and solve conflict.

4.4 Solution of Supplier Selection Problem Using FUZZY AHP and DEAHP Method

In this section we follow the evaluation methodology which is describes in previous section. We select the three supplier alternatives and five criteria which is shown in Table.

Table 3Supplier Selection Criteria

Sr. No.	Criteria
1	Quality
2	Cost
3	Delivery Time
4	Service Rating
5	Flexibility

We give the supplier alternative rating according to the supplier criteria in terms of linguistic values. The selection criteria of supplier and alternatives of supplier are transformed into linguistic variables which are given in following table. This table gives the linguistic values in terms of fuzz

Table 4 Linguistic values and fuzzy numbers

Linguistic values	Fuzzy numbers
Very low (VL)	(0, 0.10, 0.25)
Low (L)	(0.15, 0.30, 0.45)
Medium (M)	(0.35,0.50,0.65)
High (H)	(0.55, 0.70, 0.85)
Very high (VH)	(0.75, 0.90, 1)

We adopt the fundamental relational scale for pair-wise comparisons in which intensity of importance on an absolute scale in between 1 to 9 scales. If absolute scale is 1 then its meaning equal importance which means two activities contributes equally to the objective. If absolute scale is 2 then its meaning weak importance which means experience and judgment slightly favor one activity over another and it represented in the scale of fuzzy number as (1,2,3). The fundamental relational scale which is follow in this work is shown in Table

Table 5 The fundamental relational scale for pair-wise comparisons

Intensity of importance on absolute scale	**Definition**	**Explanation**	**Scale of Fuzzy numbers**
1	Equal importance	Two activities contribute equally to the objective	(1,1,1)
3	Weak importance	Experience and judgment moderately favor one activity over another	(2,3,4)
5	Fairly importance	Experience and judgment strongly favor one activity over another	(4,5,6)
7	Strongly importance	An activity is very strongly favored and its dominance is demonstrated in practice	(6,7,8)
9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation	(9,9,9)

We use the above Table 6 in the pair wise comparison. From the survey in purchase department and brainstorming we made the comparison matrix.

Table 6Pair wise comparison matrix

	Quality	Cost	Delivery	Service	Flexibility
Quality	(1,1,1)	(4,5,6)	(4,5,6)	(6,7,8)	(6,7,8)
Cost	(1/6,1/5,1/4)	(1,1,1)	(6,7,8)	(4,5,6)	(6,7,8)
Delivery	(1/6,1/5,1/4)	(1/8,1/7,1/6)	(1,1,1)	(1/4,1/3,1/2)	(2,3,4)
Service	(1/8,1/7,1/6)	(1/6,1/5,1/4)	(2,3,4)	(1,1,1)	(1,1,1)
Flexibility	(1/8,1/7,1/6)	(1/8,1/7,1/6)	(1/4,1/3,1/2)	(1,1,1)	(1,1,1)

In the pair-wise comparison matrix decision makers decided the importance of one criterion to other criteria. After the making of pair-wise matrix we find the consistency index (CI) value by the use of software CGI .CGI software gives the following results:

Max. Eigen value =5.381

C.I. = 0.09525

Weights (Eigen vector)

Product quality = .522834

Product Price = 0.278801

Delivery time = 0.0660271

Service Rating = 0.8547

Flexibility System = 0.0468

Where consistency index value is measure the consistency of the pair wise comparison. The CI value is defined as

$$CI=\frac{\lambda_{max}-n}{n-1}$$

Consistency Ratio (CR) $=\frac{CI}{RI}$

Where RI is Random Index

For n=5, RI= 1.12

So CR= $\frac{0.09525}{1.12}$=.085

Where n is the size of matrix and $\lambda_{max}$is principle Eigen value of the matrix. It is well known that $\lambda_{max} \geq n$holds for a pairwise comparison matrix and that λ_{max} = n if and only if the corresponding comparison matrix is completely consistent. Hence, in general the more CR value is, the less consistent a pair wise comparison matrix is, and Saaty indicates that a comparison matrix can be thought to be consistent if its CR value is less than 0.10.

Table 7 Geometric means of fuzzy comparison values for criteria

Criteria	$\tilde{r}_i$		
Quality	3.565	4.145	4.70
Cost	1.89	2.178	2.49
Delivery	.40	.49	.61
Service	.529	.611	.699
Flexibility	.329	.367	.425

Table 8 Relative Fuzzy weight of each criteria

	$\widetilde{w_i}$		
Quality	.399	.531	.696
Cost	.213	.278	.368
Delivery	.0448	.063	.090
Service	.0592	.078	.103
Flexibility	.0368	.0469	.063

Table 9 Averaged and normalized relative weights of each criteria

Criteria	M_i	N_i
Quality	.542	.484
Cost	.286	.255
Delivery	.0659	.0588
Service	.08	.071
Flexibility	.147	.131

Table 10 Comparison of alternative with respect to Quality

	A1	A2	A3
A1	(1,1,1)	(6,7,8)	(4,5,6)
A2	(1/8,1/7,1/6)	(1,1,1)	(1/4,1/3,1/2)
A3	(1/6,1/5,1/4)	(2,3,4)	(1,1,1)

Table 11 Geometric means of fuzzy comparison values for Quality

Alternative	$\bar{r}_i$		
A1	2.854	3.23	3.587
A2	.318	.365	.441
A3	.693	.844	1

Table 12 Relative Fuzzy weight

Alternative	w		
A1	.642	.836	2.14
A2	.071	.094	.263
A3	.156	.218	.597

Table 13 Averaged and normalized relative weights of Quality criteria

Alternative	M_i	N_i
A1	1.206	.72
A2	.143	.085
A3	.324	.194

Table 14 Comparison of alternative with respect to Cost Criteria

	A1	A2	A3
A1	(1,1,1)	(1,1,1)	(1/6,1/5,1/4)
A2	(1,1,1)	(1,1,1)	(1/4,1/3,1/2)
A3	(4,5,6)	(2,3,4)	(1,1,1)

Table 15 Geometric means of fuzzy comparison values for Cost

Alternative	$\bar{r}_i$		
A1	.553	.588	.633
A2	.633	.694	.795
A3	1.986	2.44	2.85

Table 16 Relative Fuzzy weight

Alternative	w		
A1	.129	.157	.199
A2	.148	.186	.25
A3	.465	.653	.898

Table 17 Averaged and normalized relative weights of Cost criteria

Alternative	M_i	N_i
A1	.162	.157
A2	.195	.189
A3	.672	.653

Table 18 Comparison of alternative with Respect to Delivery criteria

	A1	A2	A3
A1	(1,1,1)	(4,5,6)	(4,5,6)
A2	(1/6,1/5,1/4)	(1,1,1)	(2,3,4)
A3	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1,1,1)

Table 19 Geometric means of fuzzy comparison values for Delivery

Alternative	$\bar{r}_i$		
A1	2.49	2.89	3.26
A2	.696	.845	1
A3	.351	.41	.503

Table 20 Relative Fuzzy weight

Alternative	w		
A1	.523	.696	.922
A2	.146	.203	.283
A3	.074	.098	.142

Table 21 Averaged and normalized relative weights for Delivery

Alternative	M_i	N_i
A1	.714	.693
A2	.211	.205
A3	.105	.102

Table 22 Comparison of alternative with respect to service criteria

	A1	A2	A3
A1	(1,1,1)	(2,3,4)	(1/6,1/5,1/4)
A2	(1/4,1/3,1/2)	(1,1,1)	(1/4,1/3,1/2)
A3	(4,5,6)	(2,3,4)	(1,1,1)

Table 23 Geometric means of fuzzy comparison values for Service

Alternative	$\bar{r}_i$		
A1	.696	.845	1
A2	.0625	.484	.633
A3	1.986	2.44	2.85

Table 24 Relative Fuzzy weight

Alternative	w		
A1	.155	.224	.364
A2	.014	.128	.23
A3	.443	.647	1.04

Table 25 Averaged and normalized relative weights for Service

Alternative	M_i	N_i
A1	.247	.228
A2	.124	.115
A3	.71	.657

Table 26 Comparison of alternative with respect to flexibility criteria

	A1	A2	A3
A1	(1,1,1)	(1,1,1)	(1/4,1/3,1/2)
A2	(1,1,1)	(1,1,1)	(1/4,1/3,1/2)
A3	(2,3,4)	(1,1,1)	(1,1,1)

Table 27 Geometric means of fuzzy comparison values for Flexibility

Alternative	$\bar{r}_i$		
A1	.638	.694	.795
A2	.638	.695	.795
A3	1.26	1.44	1.58

Table 28 Relative Fuzzy weight

Alternative	w		
A1	.201	.245	.313
A2	.201	.245	.313
A3	.397	.508	.622

Table 29 Averaged and normalized relative weights for flexibility

Alternative	M_i	N_i
A1	.253	.249
A2	.253	.249
A3	.509	.501

Table 30 Aggregated results for each alternative according to each criteria

Criteria	Score of Alternative with respect to related Criteria			
	Weight	A1	A2	A3
Quality	.484	.72	.085	.194
Cost	.255	.157	.189	.653
Delivery	.058	.693	.205	.102
Service	.071	.228	.115	.657
Flexibility	.131	.249	.249	.501
Total		.477	.150	.380
Rank		1st	3rd	2nd

4.5 Solution by DEAHP Method

Table 31 Evaluation of alternatives with respect to Quality

DMU	Output1	Output2	Output3	Input	DEAHP
A1	1	7	5	1	1
A2	1/7	1	1/3	1	.14
A3	1/5	3	1	1	.43

Objective function

Maximization Z = x11+7x12+5x13

Subjected to

y11=1

x11+7x12+5x13-y11<=0

.143x11+x12+.33x13-y11<=0

.2x11+3x12+x13-y11<=0

End

Similarly to obtain the local weight of other alternative, similar model is used by changing the objective function, i.e.

Maximization Z = .143x11+x12+.33x13

Maximization Z = .2x11+3x12+x13

Table 32 Evaluation of alternatives with respect to Cost

DMU	Output1	Output2	Output3	Input	DEAHP
A1	1	1	1/5	1	.33
A2	1	1	1/3	1	.33
A3	5	3	1	1	1

Objective function

Maximization Z = x11+x12+.2x13

Subjected to

y11=1

x11+x12+.2x13-y11<=0

x11+x12+.33x13-y11<=0

5x11+3x12+x13-y11<=0

End

Similarly to obtain the local weight of other alternative, similar model is used by changing the objective function, i.e.

Maximization Z = x11+x12+.33x13

Maximization Z = 5x11+3x12+x13

Table 33 Evaluation of alternatives with respect to Delivery

DMU	Output1	Output2	Output3	Input	DEAHP
A1	1	5	5	1	1
A2	1/5	1	3	1	.60
A3	1/5	1/3	1	1	.20

Objective function

Maximization Z = x11+5x12+5x13

Subjected to

y11=1

x11+5x12+5x13-y11<=0

.2x11+x12+3x13-y11<=0

.2x11+.33x12+x13-y11<=0

End

Similarly to obtain the local weight of other alternative, similar model is used by changing the objective function, i.e.

Maximization Z = .2x11+x12+3x13

Maximization Z = .2x11+.33x12+x13

Table 34 Evaluation of alternatives with respect to Service

DMU	Output1	Output2	Output3	Input	DEAHP
A1	1	3	1/5	1	1
A2	1/3	1	1/3	1	.33
A3	5	3	1	1	1

Objective function

Maximization Z = x11+3x12+.2x13

Subjected to

y11=1

x11+3x12+.2x13-y11<=0

.33x11+x12+.33x13-y11<=0

5x11+3x12+x13-y11<=0

End

Similarly to obtain the local weight of other alternative, similar model is used by changing the objective function, i.e.

Maximization Z = .33x11+x12+.33x13

Maximization Z = 5x11+3x12+x13

Table 35 Evaluation of alternatives with respect to Flexibility

DMU	Output1	Output2	Output3	Input	DEAHP
A1	1	1	1/3	1	.50
A2	1	1	1/3	1	.50
A3	3	2	1	1	1

Objective function

Maximization Z = x11+x12+.33x13

Subjected to

$y_{11}=1$
$x_{11}+x_{12}+.33x_{13}-y11<=0$

$x_{11}+x_{12}+.33x_{13}-y11<=0$

$3x_{11}+2x_{12}+x_{13}-y11<=0$

End

Similarly to obtain the local weight of other alternative, similar model is used by changing the objective function, i.e.

Maximization Z = x11+x12+.33x13

Maximization Z = 3x11+2x12+x13

Table 36 Computing the overall score of suppliers

DMU	Output1	Output2	Output3	Output4	Output5	Input	DEAHP
A1	1	.33	1	1	.5	1	1
A2	.14	.33	.6	.33	.5	1	.52

A3	.43	1	.2	1	1	1	.67

Objective function

Maximization Z = x11+.33x12+x13+x14+.5x14

Subjected to

y11=1

x11+.33x12+x13+x14+.5x15-y11<=0

.14x11+.33x12+.6x13+.33x14+.5x15-y11<=0

.43x11+x12+.2x13+x14+x15-y11<=0

End

Similarly to obtain the local weight of other alternative, similar model is used by changing the objective function, i.e.

Maximization Z = .14x11+.33x12+.6x13+.33x14+.5x15

Maximization Z = .43x11+x12+.2x13+x14+x1

Table 37 Weight of supplier by both method

Sr.NO.	Alternative	FAHP	DEAHP
1	A1	.477	1
2	A2	.150	.52
3	A3	.380	.67

Above table shows the final result of both methods. Alternative 1 have maximum weight by both methods. So supplier 1 have rank 1.While supplier 2 supplier 3 have rank 3 and rank 2 respectively. The results obtained by both methodologies are same. Therefore this analysis suggest that supplier 1 should be recommended as most eligible supplier to supply the material.

FAHP vs. DEAHP

In FAHP method, normalized weight is calculated with the help of geometric mean. The ranking we calculated by FAHP can be changed if we added or remove any alternative because of the sum of alternative weight should be 1. For example, the ranking of alternative in above table will be changed if any alternative added or delete.

In DEAHP method the efficiency score of each alternative is calculated separately using a linear programming model. In DEAHP method if we add or delete any alternative there will be no change on other alternatives. The weight of alternative is calculated with relative to the best alternative or that have highest rank.

CHAPTER 5: CONCLUSION

The companies who followed the best practice they lead and remain their status in the market, considering the performance indicators identified by Bititci *et al.* (2011), they known as leading companies in their respective field in India as well as in the world. Supplier selection is an important task in the whole purchasing process. It has a great impact over the expenditure and organization objective. Generally, there are many suppliers for single items with varying capabilities. Organization generally faces a problem of selection of a supplier for an item fulfilling the organizational objectives. This requires a systematic approach. The literature related to this is reviewed in this dissertation which falls into two categories: the criteria to be used and the methodology for the ranking of the suppliers based on the company requirements and the supplier capabilities. The most important criteria include price, quality, service rating, delivery time and flexibility system. A large variety of MADM techniques have been used for the supplier selection problem such as AHP, DEA, TOPSIS etc.

A case study is presented in this dissertation in which a private sector company, Sagar Technochem, is considered as the case company. Existing supplier selection process in the company is first reviewed and the weaknesses are identified. In order to overcome these weaknesses a supplier selection process is proposed. Three factors which have not been used by the company earlier are suggested for use. In this research work we have used fuzzy AHP and DEAHP approach for ranking of supplier alternative and compare their results. Supplier selection is a broad comparison of suppliers using a common set of criteria and measures to identify suppliers with the highest potential for meeting a firm's needs consistently and at an acceptable cost. Selecting the right suppliers significantly reduces the purchasing costs and improves corporate competitiveness therefore supplier selection one of the most important decision making problems.

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APPENDIX

Linguistic terms and the corresponding triangular fuzzy numbers

Saaty scale	Definition	Fuzzy Triangular Scale
1	Equally important (Eq. Imp.)	(1,1,1)
3	Weakly important (W. Imp.)	(2,3,4)
5	Fairly important (F. Imp.)	(4,5,6)
7	Strongly important (S. Imp.)	(6,7,8)
9	Absolutely important (A. Imp.)	(9,9,9)
2 4 6 8	The intermittent values between two adjacent scales	(1,2,3) (3,4,5) (5,6,7) (7,8,9)

The leanness level of each perspective (alternative) is assessed by the number of questions (q) that are answered on a range of 1–5, where 1 being the worst and 5 being the best

FUZZY AHP QUESTIONNAIRE

With respect to the overall goal "selection of the best route for lean implementation"

Q1. How important is Quality (Q) when it is compared with cost(C)?

Q2. How important is Quality (Q) when it is compared with Delivery time (DT)?

Q3. How important is Quality (Q) when it is compared with Service (S)?

Q4. How important is Quality (Q) when it is compared with Flexibility (F)?

Q5. How important is Cost (C) when it is compared with Delivery time (DT)?

Q6. How important is Cost (C) when it is compared with Service (S)?

Q7. How important is Cost (C) when it is compared with (Flexibility)?

Q8. How important is Delivery time (DT) when it is compared with Service (S)?

Q9. How important is Delivery time (DT) when it is compared with flexibility (F)?

Q10. How important is Service (S) when it is compared Flexibility (F)?

With respect to the overall goal "Best supplier selection"

QUESTION	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Attribute	**Q**	**Q**	**Q**	**Q**	**C**	**C**	**C**	**DT**	**DT**	**S**
(9,9,9) Absolute (6,7,8) Very strong (4,5,6) Fairly strong (2,3,4) Weak (1 ,1,1) Equal (2,3,4) Weak (4,5,6) Fairly strong (6,7,8) Very strong (9,9,9) Absolute										
Attribute	**C**	**DT**	**S**	**F**	**DT**	**S**	**F**	**S**	**F**	**F**

With respect to the main attribute

Q1. How important is Alternative (A1) when it is compared with Alternative (A2)?

Q2. How important is Alternative (A1) when it is compared with Alternative (A2)?

Q3. How important is Alternative (A2) when it is compared with Alternative (A3)?

With respect to the main attribute "Quality"

Q#	**(9,9,9) Absolute**	**(6,7,8) Very strong**	**(4,5,6) Fairly strong**	**(2,3,4) Weak**	**Alternatives**	**(1 ,1,1) Equal**	**Alternatives**	**(2,3,4,) Weak**	**(4,5,6) Fairly strong**	**(6,7,8) Very strong**	**(9,9,9) Absolute**
1					A1		A2				
2					A1		A3				
3					A2		A3				

With respect to the main attribute "Cost(C)"

Q#	**(9,9,9) Absolute**	**(6,7,8) Very strong**	**(4,5,6) Fairly strong**	**(2,3,4) Weak**	**Alternatives**	**(1 ,1,1) Equal**	**Alternatives**	**(2,3,4,) Weak**	**(4,5,6) Fairly strong**	**(6,7,8) Very strong**	**(9,9,9) Absolute**
1					A1		A2				
2					A1		A3				
3					A2		A3				

With respect to the main attribute "Delivery time (DT)"

Q#	(9,9,9) Absolute	(6,7,8) Very strong	(4,5,6) Fairly strong	(2,3,4) Weak	Alternatives	(1 ,1,1) Equal	Alternatives	(2,3,4,) Weak	(4,5,6) Fairly strong	(6,7,8) Very strong	(9,9,9) Absolute
1					A1		A2				
2					A1		A2				
3					A2		A3				

With respect to the main attribute "Service"

Q#	(9,9,9) Absolute	(6,7,8) Very strong	(4,5,6) Fairly strong	(2,3,4) Weak	Alternatives	(1 ,1,1) Equal	Alternatives	(2,3,4,) Weak	(4,5,6) Fairly strong	(6,7,8) Very strong	(9,9,9) Absolute
1					A1		A2				
2					A1		A3				
3					A2		A3				

With respect to the main attribute "Flexibility (F)"

Q#	(9,9,9) Absolute	(6,7,8) Very strong	(4,5,6) Fairly strong	(2,3,4) Weak	Alternatives	(1 ,1,1) Equal	Alternatives	(2,3,4,) Weak	(4,5,6) Fairly strong	(6,7,8) Very strong	(9,9,9) Absolute
1					A1		A2				
2					A1		A3				
3					A2		A3				