STUDY OF SUPPLIER SELECTION PROCESS UNDER STRATEGIC OUTSOURCING CONDITIONS

A thesis submitted to Goa University for the award degree of

Doctor of Philosophy

in

Management

By

MAHESH HARIBHAU DANI

Goa University

Taleigao, Goa

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Research Guide

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2017

DECLARATION

I, Mahesh Haribhau Dani, do hereby declare that this dissertation entitled **"Study of Supplier Selection Process under Strategic Outsourcing conditions"** a bonafide record of research work done by me under the supervision of Dr. Dayanand M.S., Associate Professor, Department of Management Studies, Goa University.

I also declare that this dissertation or part of thereof, has not been submitted by me for the award of any Degree, Diploma, Title or Recognition before.

Mahesh Haribhau Dani

CERTIFICATE

This is to certify that the Ph.D thesis titled **"Study of Supplier Selection Process under Strategic Outsourcing conditions"** is the original work carried out by Mr. Mahesh Haribhau Dani under my guidance, at Department of Management studied, Goa University.

This dissertation or part thereof has not formed the basis for the award of any Degree, Diploma, Title or Recognition before.

Dr. Dayanand M. S.

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Mahesh Haribhau Dani

ABSTRACT

STUDY OF SUPPLIER SELECTION PROCESS UNDER STRATEGIC OUTSOURCING CONDITIONS

By

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In the competitive environment organizations struggle to survive and grow. The activities having potential for competitive advantage are protected and controlled and other non core activities are outsourced, so that resources can be concentrated on core activities to get competitive edge in the market. By outsourcing, organization's capacities and capabilities are supplemented by the supplier's skill, knowledge, expertise and resources. So it is essential to have association of the buyer and supplier in the long run with proper coordination, collaboration and integration with appropriate strategy (low cost strategy, response strategy or differentiation strategy) in the market. Hence supplier selection is crucial for the organisation. Supplier selection methods suggested in the literature are at the choice phase with a mostly focus on operational criteria.

In today's context, supplier selection phase starts at outsourcing stage. Supplier selection decision depends on the outsourcing decision, buyer-supplier relationship and supplier selection criteria. The outsourcing decision has advantages like access to technology, access supplier resources, improves flexibility, cost reduction, enhancing buyer capacity and capability. The risks in outsourcing are loss of key skills, developing wrong skills, losing the control over supplier. This has effect on competitive advantage of the buying firm. Hence the outsourcing decision and supplier selection decisions are to be carefully taken. The outsourcing decision encompasses the supplier selection. A systematic method is required to guide the decision maker to decide on the outsourcing. Here the heuristic approach is proposed using decision theory to guide the organization during outsourcing decision,

whether to in source or outsources the activities. The supplier performance has impact on the competitive advantage, customer satisfaction, market share, profitability and competitive position of the buyer in the market. The selection of right supplier is a crucial decision for the decision maker. A wrong supplier decision will have long term effect on the organization functioning. The organisation functions in uncertain environment. The uncertainties are demand uncertainty, customer uncertainty, technological uncertainty. The complexity increases due to multiple criteria, multiple suppliers, functioning environment and boundaries of the organisation. The difficulty level of supplier selection decision is reduced by proposing two methods for supplier selection. The two methods proposed for supplier selection are 1.Hybrid fuzzy-QFD method 2.Hybrid QFD-Entropy method.

The first, Hybrid fuzzy-QFD method is an combination of analytical hierarchy process, quality function deployment and linear weighted method. A QFD process is proposed with two house of quality phases performed sequentially to get the final score of the supplier. Relationship matrix is developed between buyer requirement and supplier evaluating factor. AHP assist in maintaining the consistency in the decision maker's judgment. The fuzzy set theory is applied to get realistic results in fuzzy environment. The linguistic assessment of decisions maker in the fuzzy environment is represented by TFN to reduce the fuzziness in the supplier selection process. Quantitative evaluation of supplier is done by linear weighted method to obtain quantitative supplier score. The results of qualitative and quantitative evaluation are aggregated to rank the suppliers. The method proposed is tested in the three different organizations under three different conditions: 1.Group decision and multiple suppliers, 2 Group decision and two suppliers, 3 Single decision maker and multiple suppliers.

The Second, Hybrid QFD-Entropy method proposed uses entropy (dispersion) to incorporate uncertainty and variations in the selection process. The entropy is the measure for amount of information required represented by probability distribution. The competitive priority and improvement ratio for the supplier are calculated. This assists the buyer to judge each of the supplier based on the goal and improvement ratio. The buyer also assesses the supplier on technical criteria influencing the buyer requirements. The QFD matrix is built for assessing supplier on evaluating criteria. The improvement ratio is obtained to rank the

suppliers and assess the difficulty of strategy implementation. The method proposed is tested under group decision making and multiple suppliers.

The results obtained by both the methods under condition of group decision and multiple supplier are compared. The hybrid FQFD method ranks the supplier on score obtained, however and QFD-entropy method depicts the level of difficulty in strategy implementation faced by each supplier and rank the suppliers. One can use any method as per the suitability of the organization.

The proposed methods can be used by single decision maker or for group decision making to solve supplier selection problem with multiple criteria, vagueness, imprecise data, human judgment and decision maker's intuition, insight, experience, skill, knowledge with linguistic assessment. The proposed hybrid fuzzy QFD method can incorporate qualitative and quantitative data; however QFD-Entropy method is suitable only for the qualitative criteria. The criteria can be changed by the decision maker as per organisation requirement. The methods have criteria flexibility. The experts from different functional areas are involved in the decision making process as supplier selection is multi criteria decision making problem. The proposed methods are generic, suitable for any type of organisation, multiple criteria, multiple suppliers, and group decision making. The QFD entropy method assist decision makers to evaluate the improvement strength of each supplier, asses the level of difficulty in strategy implementation based on the competitive priority of evaluating criteria and rank the suppliers.Both methods proposed are simple, effective, efficient and easy to use. The methods can be used by the management personnel, senior managers, or purchase mangers involved in supplier selection decision making process. The algorithms are proposed for outsourcing and supplier selection with risk test.

A diversified range for future work of research is available for the presented methodology. Future research is to compare the outcome of proposed methods with other group decision methods for supplier selection. The relationship matrix developed can be further improvised by increasing the number experts used for development The methods can be applied to other areas for problem solving like, material selection, human resource selection, selection of site for industry, marketing, manufacturing, construction industry etc. The future work is encouraged for developing user friendly application programs based on proposed algorithms.

CHAPTER 1
INTRODUCTION

1. 1. Introduction

In the competitive global market, goods, services, financial capital and knowledge flow across the boundaries of a nation and lead to economic interdependence between countries, their industries and organizations. Financial capital in global markets move from one national market to another national market e.g. financial capital of one market is used to purchase raw material, manufacturing machinery from other markets. Goods/products produced using these machines are sold in different national markets. Thus a range of opportunities are generated for companies in the competitive environment leading to different levels of globalization e.g.economic, social, political, cultural, religious and legal, all interlinked in a complex fashion. Consequently the processes of an organisation like design, manufacturing, distribution and service get affected leading to changes in the competitive structure of the organization. Economic interlinking due to globalization results in organizations across the globe getting into networks for enhanced performance. These networks help in adapting and innovating processes, products, technologies and services amongst the network members. H.Schiele et al. (2011) mention that "firm's competitive position is significantly influenced by its ability to engage in a network approach to innovation." Innovation in technology and technological opportunities exert pressure on organizations to remain strategically competitive to have a competitive advantage in the market. Innovative products/service, end user expectations, market responses set a new focus and agility for the organization to remain competitive and challenge-worthy.

Porter (1980) suggests that, "differentiation, cost leadership and focus are the strategies that provide firms with the ability to attain a competitive advantage and outperform rivals in an industry. He claims that organizations that follow one of these three generic strategies can show above average performances in the long-term, while firms that are stuck in the middle perform less well. He defines stuck in the middle as a firm's unwillingness to make strategic choices and its attempts to compete by every means." Hence organizations strive to reduce their total cost and also expect cost reductions from their suppliers to whom they would have outsourced the supplies leading to an impact on the entire Supply Chain. Sameer Kumar et al. (2011) mention that, "Global sourcing is helping companies stay competitive by sourcing lower cost raw materials. More important than lower cost, global sourcing offers companies an avenue to quickly enter new markets and

offer new products. These two reasons cost and quick turnaround, are only a few of the reasons why companies turn to global sourcing." Tan (2001) stresses that, "Genuinely integrated supply chain management requires a massive commitment by all members of the value chain."

An organization faced with challenges in the competitive environment, such as, product customization, variable customer expectations, rapid advancement in technology, capital investments, environmental issues, rules and regulations, taxes, resource constraints, geographical location etc. addresses them using the support of a strong integrated supply chain management system in a strategic outsourcing scenario enabling competence building/ competitive advantage. According to Tan (2001), "Manufacturing and distribution systems in today's competitive markets face a myriad of dynamic challenges that require not only exceptional planning capacity, but also robust supply chain networks with communication and coordination mechanisms that allow the parties involved in such networks to address changes in a short notice." Organizations have to overcome challenges by performing all operations on their own or take the support from the market place for the operations/activities which are uneconomical to be performed internally or require special knowledge and skill of supplier/s to manage firm's processes and functions.

Quinn (1999) states that, "Core competency with outsourcing strategies enable companies to: focus and flatten their organization by concentrating their limited resources on a relatively few knowledge based core competencies where they can develop best in world capabilities, leverage their internal innovation capabilities by hundreds or thousands of time through effective personal, IT, and motivational links to outside knowledge sources, eliminate inflexibilities of fixed overhead, bureaucracy, and physical plant by conscientiously tapping the more nimble resources of both their customer chain downstream and their technology and supply chain upstream, expand their own knowledge and physical investment capabilities by orders of magnitude through exploiting the facilities and program investments of outside source." According to Tomas Espiano (2005) "If the firm opts for externalize, it could lose the skills and capabilities, and the corresponding experience, which are necessary to undertake such services internally. So a firm which outsources should always maintain the responsibility for the strategic management of its business." Organizations need to evaluate the benefits and risks while deciding and implementing outsourcing decisions. Quinn and Hillmer (1994) mention that, "Outsourcing complete or partial activities creates great opportunities but also new type of risks. Management's main strategic concern is (1) loss of critical skills or developing the wrong skills, (2) loss of cross

functional skills, and (3) loss of control over a supplier." Along with the risk of losing skills, knowledge and control, organizations reduce resource capacity, flexibility, capability and face difficulty to internalize outsourced activities in the future.

Nowadays organizations are interested to build long-term relationships with suppliers in order to overcome these risks. Gustin C.M. et al. (1997) state that, "Traditional adversarial, short-term relationships are replaced with longer-term partnership." A closer relationship between the buyer-supplier will help each other to mitigate risks and solve problems for better performance. Kotabe M. et al. (2003) suggest that, "strong performance potential exists in very long lived relationship," Sheth and Sharma (1997) suggests that, "developing relationship with suppliers will be critical for the functioning of the firms. There are four underlying reasons for supplier relationships. These are increased cost efficiency, increased effectiveness, enabling technologies, and increased competitiveness. Supplier relationships will reduce some of the transaction costs. They further mention that, organizational buying behavior shifts from a transactional oriented to relational oriented philosophy and will shift from buying process to supplier relationship process. Organisational strategies shift towards developing relationship with suppliers."

In such relationship scenario, organizations need to reengineer their processes, restructure their systems, develop strategic blocks for rivals, benchmark the figures of merit and control buyer-seller relationships for effective implementation of the strategic outsourcing. Such organizations are able, flexible and agile to deliver better performance. According to Insinga and Werle (2000), "Organizations have been, or are being, restructured, downsized, and reengineered in a relentless attempt to achieve a state of efficiency, effectiveness, and agility expected to deliver increased productivity. In order to do more with less, a company must focus its limited resources on those activities that are essential to its survival and must leverage activities that are peripheral. The result is a greater use of partnerships, collaborations, and simple buying to substitute for in-house capabilities."

Organisations follow outsourcing processes to supplement the internal resources. As per Wadhwa V. et al. (2007), "companies are outsourcing portions of their business processes—from IT to raw material to after sales service to logistics and transportation." Outsourcing processes are a part of purchase processes. Sheth J.N. (1973) states that, "The decision to buy is usually initiated by a continued need of supply or is the outcome of long range planning." The broad dimensions of purchasing decision process are technical, commercial and social Sam Dzever et al. (2001).The main purchasing function in the buying

process is supplier selection. Earlier in adversarial relationship, price/cost was preeminent determinant for the evaluation and selection of supplier Gustin (1997). The strategic approach to purchasing incorporates new criteria for supplier selection Ellram (1990).

This study presents a framework in Table 2.1and Table 2.2, showing the supplier selection criteria used by the authors from 2002 to 2015. The initial work of Dickson (1966) listed 23 criteria for selecting the suppliers in order of importance based on empirical study. Since then the professionals, researchers and academicians focused on multi criteria for supplier selection. Based on literature review, S.Sen et al. (2010) mentioned 49 criteria for supplier selection and other authors added new criteria as per their requirement, which indicate that supplier is to be evaluated and selected on multi-criteria. Based on the literature review from 2000 to 2008, William Ho (2010) proves that, "the traditional single criteria approach based on the lowest cost is not supportive and robust enough in contemporary supply chain management. Instead the most popular criteria used for evaluating the performance of the suppliers are quality, followed by delivery, price or cost, and so on."

As number of criteria are increased the supplier selection problem becomes complex and is termed as multiple criteria decision making problem. It is a challenge to the decision makers to select the right suppliers by relative evaluation of suppliers based on these criteria. According to Chen and Paulraj (2004), organization operates in uncertain environment like supplier uncertainty, manufacturing uncertainty, and demand/customer uncertainty. Criteria associated with environmental, social and economic uncertainties make the supplier selection process still more complex. An organisation's need of a product /service activates search operation for the supplier in the local market, domestic market, and/or foreign market.

Mehtap Dursun et al. (2012) say that, "Supplier selection is a popular area of research in purchasing with methodologies ranging from conceptual to empirical and modelling streams." In the literature many techniques/approaches are suggested by the academicians/researchers for solving supplier selection problems. According to the study by William Ho (2010), the approaches are either individual approaches like Data Envelopment Analysis (DEA), Linear Programming (LP), Goal Programming (GP), Analytical Hierarchy Process (AHP), Analytical Network Process(ANP), Artificial Neural Network(ANN) etc. or integrated approaches like AHP-GP, AHP-DEA etc. applied for supplier selection. The supplier selection decisions are taken in dynamic environment using uncertain, imprecise and vague data. Limited evidence, of usage of operational criteria and strategic criteria together with relationship in the supplier selection approach, is available in the academic literature. Based on the literature survey and open discussions with the industry

professionals/academicians, it is inferred that, strong relationship exists between operational and strategic criteria, and it needs to be addressed properly to obtain optimal solutions for supplier selection.

This study reviewed the supplier selection literature on existing models and methods supporting the supplier selection process to identify some important opportunities to present new and efficient model for decision making. The research intent is to explore alternatives for selection of the right supplier under strategic outsourcing conditions. Further to assist purchasing managers for selecting most effective suppliers under multi criteria decision making in varied purchasing situations. This research study proposes decision tree method for supplier base and two methods a. Hybrid fuzzy QFD-AHP method and Hybrid Entropy QFD method for supplier selection under strategic outsourcing condition.

1.2 Supply Chain Management

1.2.1 Supply chain

In today's business world, organizations come close to form network and perform their business functions. As per kathawala Y. et. al.(2002), "the effective and efficient organization of a company's supply chain is essential to its success and survival. Supply chain includes activities necessary for satisfying customer demands and requests. These activities are associated with material, information and fund flow. Effective and efficient management of flow is key requirement in supply chain." Chen and Paulraj (2004) say that, "Increasing global cooperation, vertical disintegration and a focus on core activities had led to the notion that firms are links in the networked supply chain (SC). This strategic view point has created the challenge of coordinating effectively the entire supply chain." As mentioned by Lin C. et al. (2005), "traditionally, focus of supply chain was on specific functionalities such as purchasing, manufacturing, and shipping to support logistic operations. The competitive environment of the 21st century requires delivery of the cost, efficiency; high service levels, rapid response, and high quality of products and services. The effective management of technology and quality is the key to increased quality and enhanced competitive position in today's global environment."

As per Hokey Min et al.(2002)) "A supply chain is referred to as an integrated system which synchronizes a series of inter-related business processes in order to: (1) acquire raw material and parts;(2) transform these raw materials and parts into finished products; (3) add value to these products; (4)distribute and promote these products to either

retailers or customers;(5) facilitate information exchange among various business entities (e.g. suppliers, manufacturers, distributors, third-party logistics providers, and retailers).” In simple words it can be said that “Supply chain is a coordinated network of suppliers, manufacturers, distributors and customers with systematically managed flow of materials, money and information for effective performance of the business activities of all network partners.” The supply chain of Ling Li et al.(2007) is simplified and is shown in Figure. 1.1

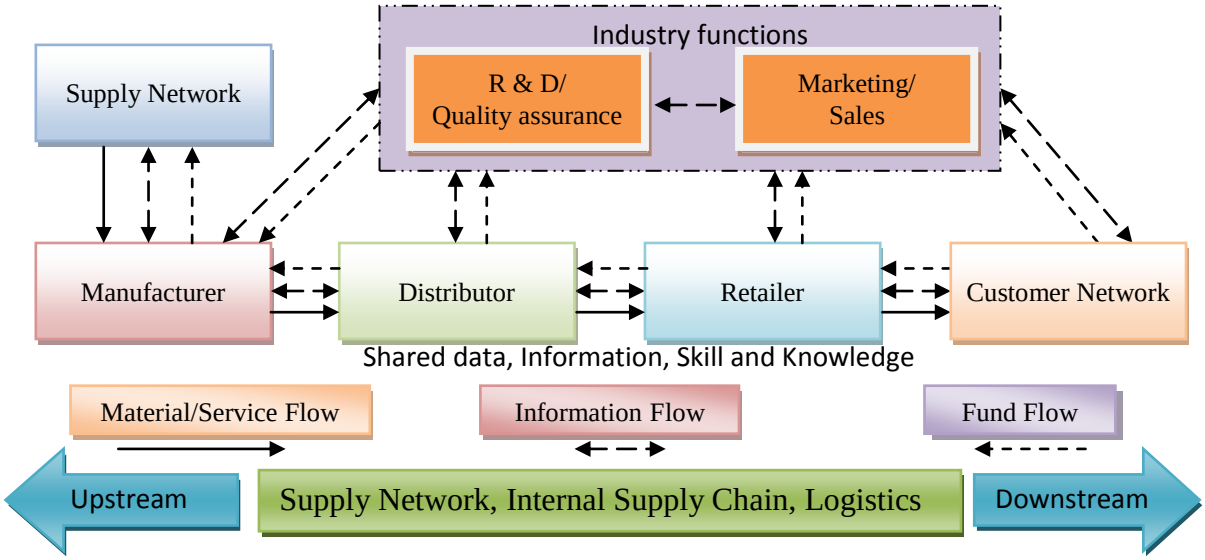


Figure.1.1 Material, Service, Information and Fund flow in supply chain. Ling Li et al. (2007)

The flow within the supply chain network is monitored and controlled by use of information and communication technology (ICT). According to Chopra S.et al (2007), “the four major drivers in a supply chain are: inventory, transportation, facilities, and information.” Burke Jr. (2005) mentions that, “Information technologies are a key driver of modern operational efficiency, and efficient operational execution is a driver of effective SCM.” A reliable information system is necessary for optimal management and coordination of a supply chain. As stated by Ravindran and Warsing (2013), “High inventory levels increase the responsiveness of the supply chain but decrease its cost efficiency because of holding costs. Inventory is recognized as one of the major drivers of a supply chain.” Determining and controlling the appropriate levels of inventory at the various stages is crucial in supply chain. This can be possible only if, the suppliers in supply chain are flexible, agile, and responsive, so that the efficiency and performance of the supply chain members is improved.

1.2.2. Supply chain management

The development in SCM field aims to leverage strategic positioning over competitors mainly through operational efficiency. Tan (2001) state that, “Supply chain

management creates a virtual organization composed of several independent entities with the common goal of efficiently and effectively managing all its entities and operations, including the integration of purchasing, demand management, new product design and development, and manufacturing planning and control. This perspective on supply chain management focuses on the manufacturing industry and has little to do with the wholesaling or retailing industry. Its short-term objective is primarily to increase productivity and reduce inventory and cycle time, while the long-term strategic goal is to increase customer satisfaction, market share and profits for all members of the virtual organization. To realize these objectives, all strategic partners must recognize that the purchasing function is the crucial link between the sources of supply and the organization itself, with support coming from overlapping activities to enhance manufacturability for both the customer and supplier." Ling Li et al.(2007) mention that, "the objective of supply chain management is to maximize the overall value generated rather than profit generated in a particular supply chain." According to Chen and Paulraj (2004), "the management of business and relationships with other members of the supply chain (i.e. buyer-supplier relationship) is increasingly referred to as SCM." The cooperative relationship with transparent business transactions is essential within the network members for enhancing the performance. The supply chain performance depends on the performance of the supply chain member. Kathawala Y. et al. (2002) state that, "Benchmarking as an essential requirement to supply chain success. The objective is to adapt superior practices of one organisation to another to produce improved performance."

1.2.2.1 Supply chain management and supplier

As per Benton,W.C.et al.(2005), "Individual firms are links in the supply chain, but a supply chain is only as strong as its weakest link. Thus, a manufacturer cannot be responsive without satisfied suppliers, and the benefits of such a relationship cannot be transferred to the end customer unless the distributors align with this manufacturer's strategy as well. At the same time, a manufacturer cannot produce quality products without pushing quality responsibility upstream to its suppliers." In short quality supplier can deliver quality product/service to the end user and hence supplier selection is to be done cautiously. As referred by Chen and Paulraj(2004), "supplier have a profound and direct impact on cost, quality, time and responsiveness of the buying firm." The suppliers are required to improve performance at all stages of its operations to improve performance of buying firm. Supply chain member is either supplier or buyer or both in the supply chain. Biswas S. et al.(2004)

mentions that, " performance measures are categorized into two: qualitative measures (such as customer satisfaction and product quality) and quantitative measures (such as order-to-delivery lead time, supply chain response time, flexibility, resource utilization, delivery performance, etc.).

As per Demeter K.et al. (2004), "The goals for successful SCM are increasing strategic role, increasing strategic orientation of operations, increase the competitiveness of firms and make operations to be able to contribute to the execution of firms' strategies."Efficient integration of supply chain members for sustainable competitive advantage is primary intent of supply chain management. Mutual trust, faith, respect, clear communication and transparent business transaction is essential requirement in supply chain to build a relationship among the supply chain members. Supply chain members exchange among themselves their resources to build, develop and maintain their long term strategic relationship

1.2.2.2 Supply chain management definition, process and customer

. As per Amin Amid et al. (2009), "SCM is now distinguished as a governing element in strategy and as an effective way of creating value to customer". Benton W.C et al.(2005) state that, "Supply chain management involves the strategic process of coordination of firms within the supply chain to competitively deliver a product or service to the ultimate customer."According to Ling Li. et al.(2007), "The supply chain management is a set of synchronized decisions and activities utilized to efficiently integrate suppliers, manufacturers, warehouses, retailers, and customers so that the right product or service is distributed at the right quantities, to the right location, and at the right time, in order to minimize system wide costs while satisfying customer service level requirements. The objective of supply chain management is to achieve sustainable competitive advantage." Boron F.E. et al.(2009) state that, "The major aims of SCM are to reduce supply chain risk, reduce production cost, maximize revenue, improve customer service, optimize inventory levels, business process and cycle times, and resulting in increased competitiveness, customer satisfaction and profitability." Ling Li et al.(2007) state that, "The main intent of supply chain management is to enhance the overall performance and generate value rather than profit in supply chain. Members of supply chain require strategic goal and direction to move forward while competing. Competition is based on overall cost, quality standards adopted, delivery time, flexibility and new products. Harland C.M. (1996) describes supply

chain management as "managing business activities and relationships (1) internally within an organization, (2) with immediate suppliers, (3) with first and second-tier suppliers and customers along the supply chain, and (4) with the entire supply chain." As per Tan (2001) "A key facilitating mechanism in the evolution of supply chain management is a customer-focus corporate vision, which drives change throughout firm's internal and external linkages."

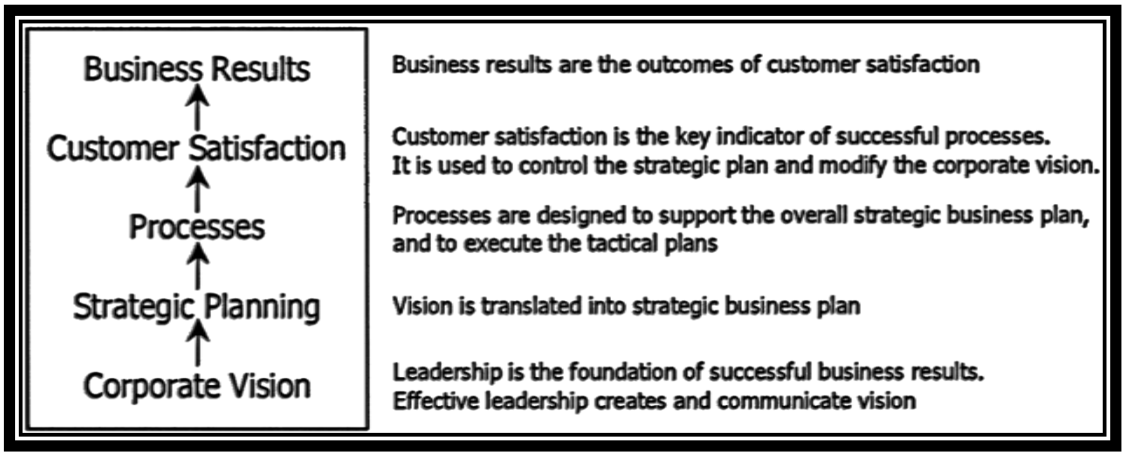


Fig 1.2 Strategic vision of supply chain management source: Tan (2001)

According to Houshang Taghizadeh et al.(2013), "As customer expectation are increasing and customer want to see an increase in product variety, lower cost, better quality and most fast access to product. Hence, organizations emphasis more on supply chain management to, support their manufacturing goals such as flexibility, cost, quality and delivery." According to Amin Amid et al.(2009),"SCM is now distinguished as a governing element in strategy and as an effective way of creating value to customer." As per Tan (2001), "Supply chain management appears to treat all organizations within the value chain as a unified and virtual business' entity. It includes activities such as planning, product design and development, sourcing, manufacturing, fabrication, assembly, transportation, warehousing, distribution, and post delivery customer support." Ling Li et al. (2007) mention that,

"1. The role of supply chain management is to produce products that conform to customer requirements.

2. The objective of supply chain management is to be efficient and cost-effective through collaborative efforts across the entire system.

3. The scope of supply chain management encompasses the firm's activities from the strategic level through the tactical and operational levels since it takes into account the efficient integration of suppliers, manufacturers, wholesalers, retailers, and end users." SCM stress on supplier certification to control source quality, minimize inventory, improve

conformance, eliminate communication errors, avoid rework, remove incoming inspection, in time delivery to end user, reduce cycle time, and shift focus from process input to output for customer satisfaction.

1.2.3 Supply chain management and supplier relationship

Chen and Paulraj (2004) mention that, "supplier have a profound and direct impact on cost, quality, time, responsiveness of the buying firm, the management of business and relationships with other members of the supply chain (i.e. buyer-supplier relationship) is increasingly referred to as SCM." Carol Prahinski (2004) state that, "The buying firm can influence the supplier's commitments through enhanced communication and relationship development. Relationship development includes enhancing cooperation, problem solving and expressing their commitments, loyalty and desire to continue the relationship for many years into the future." Ling Li et al.(2007) state that, "In the integrated supply chain, mutual trust, respect to supply chain member, just in time production philosophy, transparent and informal two way communication play important role. Supply chain management provides greater visibility and more strategic capability for companies to improve profitability and competitiveness." Organisations have to strive to overcome the barriers which impede its effectiveness, operations and processes. The barriers to effective supply chain management mentioned by Benton,W.C et al.(2005) are, "failure to share information, fear of loss of control, lack of self awareness, lack of partner awareness, enormity of supply chain, lack of supply chain satisfaction, lack of customer understanding, lack of understanding of supply chain, myopic strategies, deficiency of mutuality." The supplier should effectively perform the activities with extending trust and faith to its buyer.

However due to advancement in technology, information and globalisation the boundaries between the supply chain members (suppliers, manufacturers, distributors, retailers and end users) are bleak and unclear. The relationship between the buyer and supplier at all stages in the supply chain play important role in satisfying customer needs. The customer needs are satisfied on answering questions when, where and how they want it. The probability of high or low inventory level and demand uncertainty in supply chain is minimised by reducing the lead time of supply. As per Ling Li et al.(2007), "A firm's position on competitive priorities is determined by its four long term structural decisions: facility, capacity, technology and vertical integration, as well as its four infrastructural decisions: workforce, quality, production planning and control, and organization. In the

business today the supply chain member need to have quick reaction time, development speed, fast delivery times, customization, volume flexibility, high capacity cushions, low inventory levels and short cycle times. There should be proper coordination on material flow and service to minimize inventories and maximize the efficiency of the manufacturers and service providers in the chain." Geographical location decides logistic mode, logistic cost, and delivery lead time. Supply chain management coordinates manufacturing, logistics, and material management functions within an organization Lee and Billington(1992).

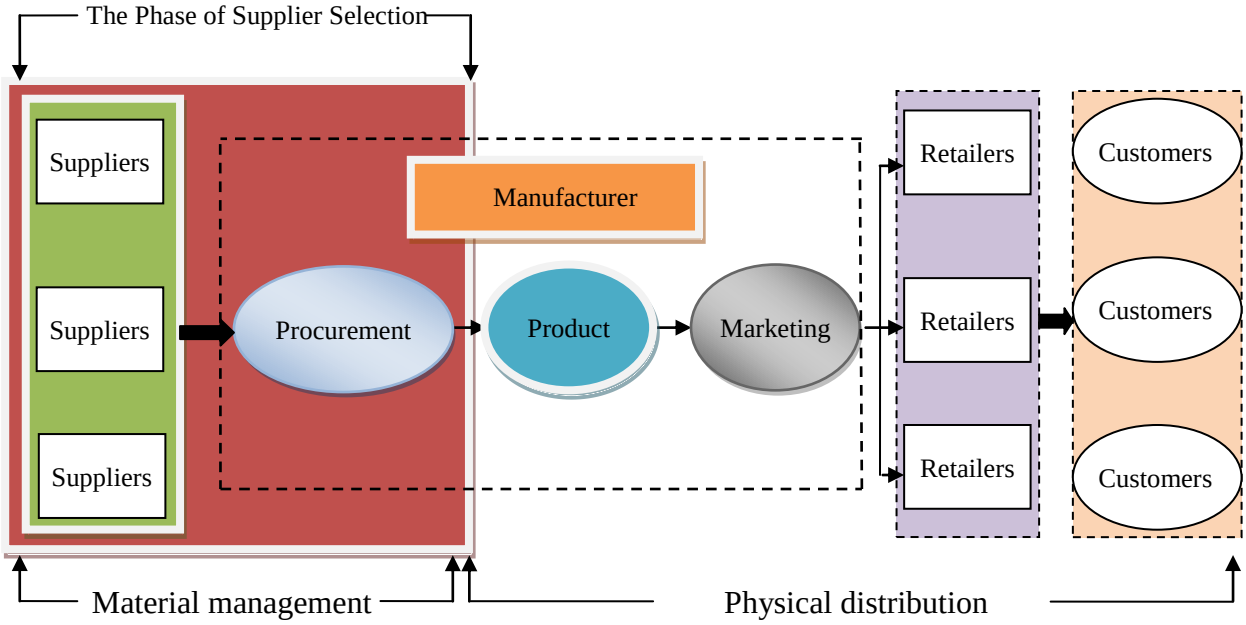


Fig 1.3 supply chain flow process, Liao and Kao (2011); Min et al.(2002)

According to Farley (1997), "supply chain management focuses on how firms utilize their suppliers' processes, technology, and capability to enhance competitive advantage. Hence supplier plays a crucial role in supply chain to meet the objectives of buyer organisation.

1.3 Strategic Outsourcing and Supplier Selection

1.3.1 Strategic Outsourcing

In competitive business environment organizations are forced to concentrate, capture and adopt the cost saving approaches to improve their efficiencies in all the business functions to improve the overall performance of the organization. The pressure mounts on the organization due to competitiveness in the global market. To overcome this pressure organization follows "do more with less". According to Insinga and Werle (2000), "the goal of companies that aggressively outsource most functions is to enhance competitiveness by

achieving a higher return on assets through less capital commitment and increasing the ability to adjust quickly to a changing environment through less commitment to in-house resources."

According to Ling Li et al.(2007), "in the supply chain the material requirement planning (MRP) process influence the effectiveness of all other succeeding operations of the organization. The decisions for material requirements planning focus and originate search process for cost reduction, improvement in production quality and reducing process time and creating value for the end user." The search process will be effective if the right source is available in the supplier market with expertise, resources and capability to support the buyer organization. Kahraman,C**.** et al.(2010) state that, "One of the most popular strategies in contemporary business life is outsourcing." The decision to outsource the activities to the external source is of strategic importance to the buying firm to meet the short- term and long-term objectives of the organisatiion. Holcomb and Hitt (2007) define, "strategic outsourcing as organizing arrangement that emerges when firms rely on intermediate markets to provide specialized capabilities that supplement existing capabilities deployed along a firms' value chain."

The sourcing option may be single sourcing dual sourcing, multiple sourcing or mixed sourcing as per suitability of the organization. Salpek Jennifer J (1998) mention other terms like, "in-sourcing, co-sourcing, share-sourcing and strategic sourcing depend on mutual beneficial relationship like, partnership or alliance rather than contractual agreement." According to Gonzalez R. et al (2008), reasons for outsourcing are, "focusing on strategic issues(focus on their core competences),increasing flexibility, improve the quality, getting rid of routine tasks-which are very time consuming, facilitating to access to technology, reducing the risk of obsolescence, saving staff costs, have alternative to internal staff, save technology costs and following the fashion." According to Salopek Jennifer J (1998), "Outsourcing provides new opportunity for in-house trainers: selecting, supervising, and evaluating vendors. With this shift in focus, it's important to maintain competencies to make sure vendors are performing as expected." As per Holcomb and Hitt (2007), "The decision to outsource existing production represents the simplest form of strategic outsourcing" The suppliers are heterogeneous in terms of resources and capabilities. The suppliers are to be examined and compared for cost differential and/or resource differential before taking outsourcing decisions. Hence outsourcing decision is associated with monitoring of supplier regularly for performance and improving the efficiency of the organisation.

1.3.2 Strategic Outsourcing risks

Desheng Wu et. al. (2008) mentions that, "A common occurrence in 21st century is outsourcing product manufacturing. This usually motivated by lower product costs. There are increased risks expected from differences in product quality, as well as differences in the probabilities of late delivery, as many times lower cost manufacturers are located in developing economies and have transportation risk, risk of shipping (piracy risk, ship still sinks(if only occasionally)). Further mentions risks sighted by Sounderpandian (2008) i.e. risk of extra lead time variability and higher possibility of material losses in transit. The risk reducing strategy is to rely upon long-term commitments." The activities outsourced by the organization are sometimes difficult for the supplier to perform and generate various types of risks. According to Mosher R. et al.(2011), " although these arrangements have the potential to deliver significant value, the organization typically has little or no control over the service provider's internal processes. Consequently, any organization that decides to outsource part of its operations puts its reputation, along with any data processed or customer interactions performed on its behalf, in the hands of third party." Quinn and Hillmer (1994) mention that, "Outsourcing complete or partial activities creates great opportunities but also new type of risks. Management's main strategic concern is (1) loss of critical skills or developing the wrong skills, (2) loss of cross functional skills, and (3) loss of control over a supplier." Along with the risk of losing skills, knowledge and control, organizations reduce resource capacity, flexibility, capability and face difficulty to internalize outsourced activities in the future. As per Kotabe et al. (2007) and Lei and Hitt(1995), "outsourcing refers to the reliance on external sources for manufacturing components and other value-adding activities (often capital intensive). Therefore, outsourcing involves reliance on external skills and capabilities. Unfortunately, outsourcing can erode the firm's potential for organizational learning and development of new technologies, particularly those skills necessary for the development of new business and core capabilities." Gonzalez R. et al. (2008) list various risks like, "loss of qualified staff, lack of compliance, dependence, loss of technical knowledge, inability to adopt new technology, unclear cost-benefit relationship, security" Deshang Wu et al.(2008) mention " supply chain risks are external and internal, as well as has level of controllability and refer Li (2007) for supplier risk attitude with respect to risk aversion." Anil Arya (2008) states that, "sourcing decisions can be influenced by fears of supplier hold-up, concerns about leakage of proprietary information, the need to ensure

timely and reliable supply of high-quality inputs, and prospective gains from cultivating long-term alliances with suppliers."

Traditionally, strategic sourcing decisions are based on a cost differential. However, this cost-based approach is too narrow for strategic sourcing decisions. According to Pouder R.W. et al.(2011), " by outsourcing noncore activities, firms can dedicate greater attention to their core activities and increase value for shareholders. The decision to outsource has traditionally been based on cost reduction rather than on any type of strategic motives. This kind of outsourcing (based on costs) has led to what Rueda (1995) has called tactical or traditional outsourcing. Nevertheless, the reasons why firms opt to outsource have changed, moving from the tactical towards the strategic." According to Ling Li et. al.(2007), "The trend of mass-customisation forces many companies to focus on their core competencies. Non-core activities and functions are outsourced e,g. functions like design, manufacturing, distribution etc."

1.3.3 Strategic Outsourcing benefits and purchasing

According to Mehltretter Steven (1996), "strategic sourcing- a disciplined, analytical and systematic approach to purchasing- is saving companies the world over hundreds of millions of dollars." As per Anonymous(2003), "procurement organisatins at most benchmark companies are responsible for the following 'key' procurement activities: drafting policies, strategic sourcing, e-procurement, real estate negations and corporate travels." As per Kathawala Y. et. al. (2002) sourcing in supply chain are two types systematic sourcing and spot sourcing. Further Kathawala Y. et. al. (2002) mentions that, "whenever a business engages in systematic sourcing, it seeks to build close relationship with its buyers and negotiates its purchasing terms to establish long- term buyer-seller contracts. Products involved usually include those that are mission critical, specific, and essential to a company's business. A company practicing spot sourcing, on the other hand, seeks to fulfil its immediate needs at the lowest possible cost. Often buyers and sellers do not even know their transaction partners identity. This type of sourcing ideally practiced for non-mission-critical commodity goods, since even in the event of a supplier default, the buyer will be able to purchase from a substitute supplier." As per Kakabadse and Kakabadse (2005), "outsourcing achieves cost benefits, access to resources and firms may attempt to reduce risk."

A strategy is an integrated and coordinated commitment of the decision maker to initiate actions designed to exploit core competencies and gain a competitive advantage for the organization. Strategic competitiveness is achieved when a firm successfully formulates and implements a value creating strategy. Holcomb and Hitt (2007) state that, "Competitor should find difficult and costly to duplicate and imitate the strategy implemented by organization to gain competitive advantage." Organizations adapting strategic outsourcing as a strategy concentrate on core business needs by reducing cost and improve speed of delivery. The important drivers for strategic outsourcing are focus on core competencies, access to special expertise, processes, skills, knowledge, operations and new technology of the supplier. As per Holcomb and Hitt (2007, "a more complete understanding of economic activities require a greater sensitivity to the interdependence of capabilities, production activity, inter-firm relations that emerge from boundary decisions. As per Craumer M. (2002), "relative to strategic motives, outsourcing motivated by cost reduction signals shorter-term benefits. On the other hand, strategic outsourcing signals long range opportunities that drive key external results such as repositioning in the marketplace, adapting to changing business environments, building better product quality, and improving speed to market." As per the study of Pouder R.W.(2011), "cost cutting and strategic advantage motives influence a firm's decision to outsource. 27.5% of the outsourcing announcements in their study sample explicitly cite both motives for outsourcing. Dual motives in an outsourcing contract would signal to the market a firm's intention to improve short term financial performance and strengthen long term strategic advantage." Mosher R. et al.(2011) state that, " successful outsourcing involve balancing the risks and benefits of obtaining external expertise in support of a set of tasks that are beyond the capabilities of internal staff or cannot be performed cost effectively in-house." Organisations develop flexibility by strategic outsourcing through improved capabilities to meet uncertain demand and tap opportunities in competitive environment.

1.3.4 Strategic outsourcing process and caution

As per Prahalad C.K et al.(1990), "a core competence is an activity in which a firm excels and that contributes substantially to competitive advantage." A challenge to the organization is to segregate core activities which give competitive advantage in the long run to the organization. As per Barney J.B. (1991), "a firm develops core competencies by exploiting valuable, rare, and inimitable resources and capabilities within the firm." As per

Cui and Loch (2011), "The three fundamental decisions organization must take on strategic contribution, source and structure and process when outsourcing innovation activities. A key feature of the strategic outsourcing portfolio is the mix-and match mindset." Outsourcing quality not only depends on product quality but also include effective customer service and satisfaction, in time product delivery. The critical assessment of outsourcing is essential for implementing the decision.

According to Paul Juras (2007), "common reasons outsourcing arrangements fail are: 1.Outsource activities that should not be outsourced, 2.Select the wrong vendor, 3.Write a poor contract, 4.Overlook personnel issues, 5.Lose control over the outsourced activity, 6. Overlook the hidden costs of outsourcing, 7. Fail to plan an exit strategy." Mosher R. et al. (2011) suggest that, "If risk associated with performing a process in-house do not match the objectives set for the organization, and the degree of risk involved in outsourcing the process is acceptable, then external options may be an appropriate path to pursue." Organisation has to decide and follow systematic sequential steps to mitigate the risk associated with for strategic outsourcing. As per Velma Robert, six steps in evaluating strategic outsourcing are

Six Steps in Evaluating Strategic Outsourcing

Steps	Actions
1. Evaluate whether outsourcing is a viable strategy for the organization given its current strategic goals and objectives.	1. Develop a clear understanding of the strategy for the function being outsourced. Consider the impact on achievement of organizational mission and strategy, including cost, quality, flexibility, and timeliness. Consider changes in the environment that require a change in strategy.
2. Analyze and assess information on services outsourced and service deliverables.	2. Identify services to be outsourced and the expected level of performance. Ensure a clear definition of services to be outsourced and their value. Protect and retain core services and capabilities. Be clear about the scale of costs and potential savings by including all costs.
3. Select the appropriate vendor.	3. Identify the number of viable vendors, and document vendor's technical and managerial capabilities, culture, and fit. Explicitly state and agree on expected service levels.
4. Secure a contract that protects the organization yet flexible enough to accommodate unplanned events.	4. Negotiate an agreement that is fair and equitable. Specify expected performance from each partner and how it will be measured and compensated and how disputes will be settled. Specify contingency clause and how subcontractors will be managed.
5. Develop a transition plan for transferring outsourced activities to vendor.	5. Establish a temporary transition team to organize and supervise the transition. Involve employees that may be affected, and make sure that key executives and managers from the outsourced function or department are involved.
6. Develop guidelines for reappointment of vendor	6. Review service provisions in the contract, and measure actual outcomes against expected outcomes to decide if vendor's performance warrants reappointment.

Adapted from Jennings, D. 1997. "Strategic Guidelines for Outsourcing Decisions." *Strategic Change* 6: 85–96.

Fig 1.4 Six steps of evaluating strategic outsourcing (Velma Robert)

Insinga and Werle(2000), suggested outsourcing methodology with two dimensional matrix to assess activities and to suggest appropriate actions. The author considers relational view and resource based view theory to develop the method. "The resource-based view argues that a firm's survival depends on the accumulation of resources that are rare, valuable, non substitutable, or difficult to imitate. Thus, the firm achieves an advantage over its competitors. The relational view adds another dimension—the network of firms. The relational view recognizes that sources of competitive advantage can exist outside the enterprise, in its relationships with other firms." The planning guide enables decision maker to conduct a thorough and systematic review of its functions and operations in order to take outsourcing decision strategically.

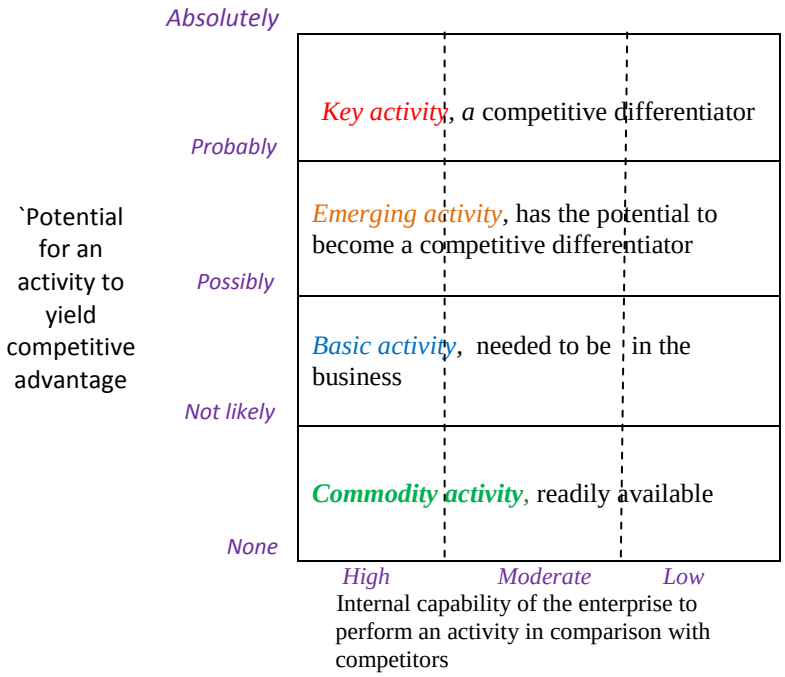


Fig 1.5 Planning Matrix Source: Insinga and Werle (2000)

Wadhwa and Ravindran (2007) suggested five step outsourcing process for ease of decision maker. The major actions involved in this process are 1. draft preparation 2. identification 3.negotiations 4. monitoring and control 5 evaluate periodically .

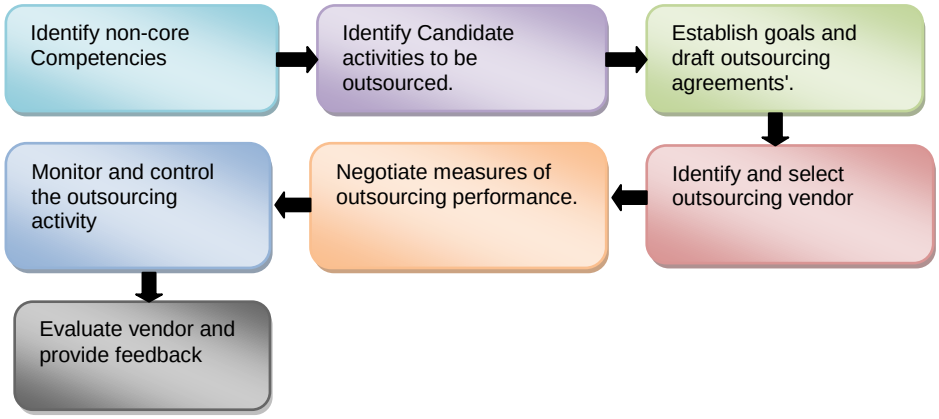


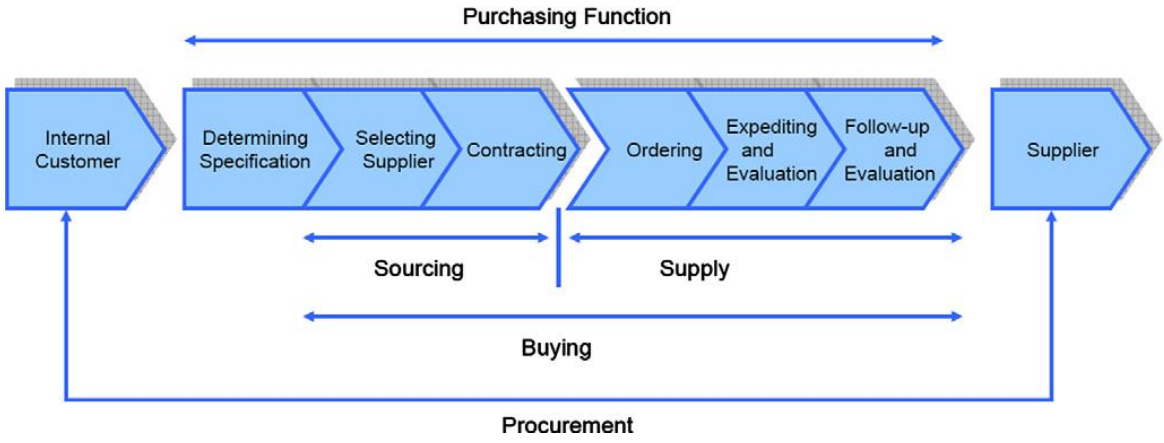
Fig 1.6 Overview of Outsourcing Process source: Wadhwa and Ravindran (2007)

Mosher R. (2011) state that, "understanding key areas of exposure associated with outsourced processes and developing steps to mitigate those exposures are critical to the outsourcing process." Competition in the market is based on overall cost, quality standard, delivery time, flexibility, new product/s, service rendered etc. by the organization.

1.3.5 Strategic outsourcing, suppliers and purchasing

More emphasis on SCM is increasing significance of purchasing function and purchasing decision. Purchasing function activities in organization has strong relation with

buying process. These activities are: determining the need, selecting supplier, appropriate price, terms and conditions of supply, issuing the contract or order, and ensuring proper delivery. Major function in SCM is purchasing. Ghodspour S.H.et al. (2001) state that, "the purchasing department can play a key role in an organization's efficiency and effectiveness because it has a direct effect on cost reduction, profitability and flexibility of a company." According to Mehltretter Steven (1996), "The purchasing department must understand how its action affects the overall business. It must ensure that its efforts are in alignment with the company's business strategy. Clearly, when purchasing is guided by a comprehensive procurement strategy, it not only directly supports but enhances the delivery of goods, services and overall value to the customers." The suppliers selected should aim at customer satisfaction by providing services as per customer needs. Kathawala Y.(2002) quote Chase et al.(2001) that, " core services provided by the company are correctly made products that are customised to the customer's needs, delivered in time, and priced competitively. Value-added services are those that make the external customer's life easier, in the case of internal customer, aid them in carrying out their particular function." The purchasing managers of the organisation in the supply chain buy different types of products and services, and procedure involved in purchasing generally varies according to purchase type. Weele Van (1994) divide the procurement process into five stages: the determination of purchase order specification, supplier selection, the purchasing contract, ordering, and expediting. The selection of capable supplier is key to desired level of quality, on time delivery, price, and technical support. Choi et al.(2008) say that, "procurement is capital intensive decision that account for a large portion of the total operation cost. Therefore it is very important to reduce purchase cost and time by selecting appropriate suppliers, which will result in improvement of corporate competitiveness."



"Fig. 1.7 Purchasing process activities (A.Van Weele (1994))

According to Jill Bossi and Tobias Schoenherr (2015), "The best manufacturers leverage supply management to deliver benefits such as lower priced goods and services while gaining early access to innovative new products and technologies that will improve their products and increase shareholder value. In those companies, supply management—a term we use interchangeably with the terms sourcing, purchasing, and procurement—is no longer focused just on getting the right product at the right price at the right time; instead, these manufacturers nurture their supply base to become their suppliers' customer of choice and an indispensable business partner, one who can help them deliver a sustainable competitive advantage." Out of five forces acting on the industry to remain competitive suggested by Porter, the two identified are buyer and supplier. Benyoucef L. et al.(2003) refer text contents of different authors as, "In one of the initial book on purchasing, Howard (1943) mentioned that, "It is probable that of all the responsibilities which may properly be said to belong to the purchasing officers, there is none more important than the selection of supplier. Indeed, it is in some respects the most important single factor in purchasing." Later, England and Leenders(1975) said that, "supplier selection is purchasing most important responsibility." Further Doble et al.(1984) reiterate the words, "selecting capable suppliers is one of a purchasing manager' most important responsibility."" As per Thompson(1990), "the industrial purchasing function is among the most critical activities for ensuring the long term viability of a firm." K.C. Tan (2001) mentions that, "Purchasing function activities in organization has strong relation with buying process. These activities are: determining the need, selecting supplier, appropriate price, terms and conditions of supply, issuing the contracts or orders, and ensuring proper delivery of products. Ellram et al. (1994) mention the views of Freeman and Cavinato that, "Purchasing's role, capabilities and resulting organization must be congruent with the evaluation of the firm itself. If not, purchasing can become extremely vulnerable during the period of downsizing and reorganization, since only those functions that are perceived to contribute significantly to the welfare of the firm stand to remain intact." Hence, supplier selection decision is directly proportional to firms' competitive advantage for retaining the position in the market. As per Kathawala Y. et al. (2002), "company's purchases can be classified into manufacturing inputs and operating inputs. Manufacturing inputs are raw materials that go directly into a product or process and purchased from industry specific suppliers. Operating goods are maintenance, repair and operating goods, usually not industry specific, but are needed in all companies and purchased from horizontal buyers." Pagell M et al. (2010) give the reference of Kraljic(1983), "the purchase inputs are categorized into four types i.e. strategic, leverage,

bottleneck and noncritical with strategic importance on profitability and supply risk. Strategic items should be purchased from small number of suppliers (often one) with whom the buyer has a close, trusting and long term relationship. Supplier selection should be based on total cost, rather than price. Leverage items are generally commodities for which there are multiple homogeneous potential suppliers, any of which can provide identical quality and performance. These inputs should be purchased based mainly on price, and perhaps availability, from multiple suppliers with whom the buyer does not invest in relationship. Noncritical items should be sourced from multiple vendors and purchased in transaction based manner based on price. Bottleneck items, or items that are not strategic but are available from only one supplier, should drive organization to mitigate risks and limit transaction costs through contracting and focused inventories strategies." Purchasing activity is of strategic importance as it assists in cost reduction and improves quality of input material. Purchasing function is responsible and bound to select reliable supplier to supply the material as per the required specification in right quantity at right time. According to Gonzalez M. et al.(2004), "with increasing importance of purchasing function, supplier management decisions have become more strategic." Purchasing strategies should guard the core competencies by providing strategic block to competitors and it should also have potential for competitive advantage to the organization in the market. Supply chain management focus is to fit the sourcing and purchase strategies in supply chain objective to support firm's long term strategy and competitive positioning. Global market and thought of strategic purchasing lead the firms to practice and manage good relationship with their suppliers. As per Sheth and Sharma(1997), "The importance of individual supplier is expected to increase because of emergence of sourcing on a global and relational basis with a few key suppliers." According to Tiaojun Xiao et.al (2007), "Outsourcing may increase the consumer's positive perception about the product if manufacturers choose reputable suppliers with better brand or quality." Gonzalez M. et al. (2004) mentions that, "supplier decisions are one of the most important aspects that firms must incorporate into their strategic processes. As the organisation become more dependent on suppliers, the direct and indirect consequences of poor decision making become critical." Effective purchasing policy can bring in the cost saving. In most industries the cost of raw materials, component parts and service represents major share in the total cost of a product Shuo-Yan Chou et al.(2008). As per Weber et al. (1991), "purchased material and services account for 80% of the total product cost." A.Mendoza et al.(2012)mention that, "apart from mere cost reduction, to

remain competitive, companies are continually working with suppliers to, for instance, reduce product development time, improve product quality, and reduce lead-times."

According to Sheth and Sharma (1997), "industry restructuring through merger, acquisition, and alliances on a global basis has reorganized the procurement function from a decentralized administrative function to a centralized strategic function. This is further intensified by outsourcing (buy versus make) many support functions such as data processing and human resources." Strategic purchasing has a proactive, long term focus with integration of internal and external exchange functions. The organizations adopt total quality management(TQM),5s, quality circle and Just-in-Time(JIT) to improve the performance , response time and to remain competitive in the market. Barbarosoglu G. et al.(1997) mention that, "all companies are faced with quality assurance issues in design, manufacturing, purchasing and delivery. JIT purchasing requires the supplier to produce and deliver to the manufacturer precisely the necessary quantity at the required time with objective of continuous and consistent conformance to performance specification. Thus, the performance of suppliers has become a key element in company's quality success or failure and clearly influences the quick response ability of the company." According to Jone Konig et al.(2011), "international outsourcing is the acquisition of production parts from an independent foreign supplier. Outsourcing has become an important managerial tool in reorganizing a firm's production process and depends on the bargaining power of the labor union in relation to wages and profit sharing." The comparison between the lowest price offered by the suppler and the internal cost of manufacturing product give a guideline for decision to make –or-buy product/service from least costly supplier. A critical evaluation of supplier is required when purchasing product/service from the monopoly supplier. Such suppliers may be suppliers to the competitors of the firm in the market. The product design, processes, operations and the key core competencies are to be protected. In such situation maintaining confidentiality is a challenge before the organization. As per Quinn (1999), "Core competencies are not products or 'those things we do relatively well', they are those activities—usually intellectually based service activities or systems--- that the company performs better than any other enterprise. They are the sets of skills and systems that the company does at 'best in world' levels and through which company creates uniquely high value for customers." It is essential to protect the knowledge and skill; otherwise it may happen that the competitors may develop its manufacturing facility for its inputs as a strategy. Understanding the dependence of the organization on supplier, supplier may dictate price to the organization. Anil Arya et al.(2008) studied the strategic benefit from purchasing

an input from a common external supplier which can induce a firm, to outsource production of the essential input even when the supplier's quoted price exceeds the firm's cost of in-house production." Organizations can overcome this by building blocks for competitors and invest in developing the core skills and resources to have competitive edge in the market. Organisation need to prioritize the activities to be outsourced and reengineer the organization structure for taking outsourcing decision to reduce the investments.

Lie and Hitt (1995) state that, "continued reliance on outsourcing, in turn, can potentially "lock out" the firm from participating in future technologies and new industries." Outsourcing based on price/cost gives short term benefit to the organization. Pauder R.W.(2011) suggest that, "some opportunities in long run due to strategic outsourcing are repositioning in the market place, adapting to changing business environments, building better product quality, and improving speed to market." Kahraman, C. et al. (2010) mention that, "In outsourcing, the most critical factor is selecting the best vendors. A right vendor should meet and complement the organisation's needs from its corporate culture to long term future needs." Sameer Kumar et al.(2011) developed a generic strategic outsourcing model and a closed loop multi-steps strategic and tactical supplier selection process for packaging material that streamlines and standardizes the process and creates efficiencies for everyone involved. Selection of a right supplier reduce operational cost, product design and development time, improve product quality, increase flexibility and competiveness in the market.

1.4. Motivation for this research

The product manufactured by the company depends on the raw material, parts/components, machinery/ equipments, human resources used in the final assembly of the product. The product quality and product performance influence the customer satisfaction and company performance. The organizations focus on their resource utilization and take support from the supplier market to strengthen their resources and processes to remain competitive in the market. The cost reduction at all stages is essential for the organisation. The organisation attempts to achieve the cost reduction by segregating its activities into core and no core activities. The activities which bring in the value and necessary for maintaining the competitive position in the market are retained and performed by the organisation itself and all other are outsourced to the suppliers. Supplier firms are the extension of buyer facilities for processes/operations without any liability or risk. The

organisation performance depends on the supplier performance. Suppliers play key role in the functioning of the organisation. Hence selection of right supplier is important for the organisation. Suppliers are evaluated on multiple criteria. The multiple criteria and uncertain environment make the supplier selection problem complex.. The extant literature available on supplier selection methods, the still global competition and changing environmental conditions is a challenge for the company to maintain the position in the market and select the right supplier for the organisation. This was the driver for the thoughts for researching alternative supplier selection method for group decision making problem. The method should be simple, easy and suitabile in dynamic conditions. This motivated to take this topic for research.

1. 5. Organization of this research

The chapter 2 deals with the literature review on supplier selection process, supplier selection criteria and supplier selection methods. Chapter 3 is on the research methodology used for research. The literature available on the supply selection process, supplier criteria, supplier selection methods is referred and exploratory study is done by visiting organizations and open ended discussion with the industry officials to understand the outsourcing, supply selection process followed, supplier selection criteria and methods adopted across the companies. The chapter 4 deals with data collection and data analysis. The data is collected by visiting organizations. Heuristic method proposed using decision tree for outsourcing decision and supplier base. The two methods are proposed for supplier selection. 1. hybrid fuzzy QFD method and 2.hybrid QFD-Entropy method. The hybrid fuzzy QFD method proposed is applied in three organizations for supplier selection and discussed under conditions, 1.group decision making and multiple suppliers 2.group decision making and two suppliers, 3.single decision maker and multiple suppliers. QFD-entropy method is applied in the organisation with multiple suppliers and group decision making. A comparative analysis is performed for hybrid fuzzy QFD and hybrid QFD-Entropy method. The algorithms for supplier selection and outsourcing are proposed as a guideline for the decision makers. Entropy is used as a measure for amount of information represented by probability distribution to find the competitive priority of the supplier based on the criteria. The hybrid QFD-Entropy method also assesses the difficulty of strategy implementation by the suppliers. The chapter 5 is on the discussions and conclusions. The advantages and limitations of the proposed supplier selection methods are discussed and the directions for

future work are highlighted in chapter 5. The methods proposed are of academic interest and can be used by professionals in the medium scale and large scale companies with limited application in small scale firms.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

Vendre in French language implies, to sell. This is the source of the word vendor. The word vendor or supplier is used in the literature. The organisations depend on the supply for the functioning of operations. This need initiates the search operation for the right source of the supply for efficiently performing all activities in the functional departments of the organisation for customer satisfaction. Supplier selection is challenging task for the organisation due to globalisation and dynamically changing market conditions. Supplier selection decision is critical as it has direct effect on operational and financial performance of the organisation. Liao Chin-Nung et al. (2012) mentions that, "Selecting the right supplier significantly decrease purchasing cost, improves competitive advantage and enhances customer satisfaction."

In the global competition no boundaries exists for business. Firms strive hard for improving market share and performance by focusing on core competencies and utilizing own internal resources to the maximum extent. Non-core activities are performed by outsourcing or subcontracting Holger Gorg et. al.(2004),Quinn and Hilmer(1994), Kotabe,M.et.al.(2007). Non core activities having indirect impact on the organization operations are performed internally to avoid access to the competitors. The competitors are distinguished based on the unique skill and knowledge possessed by them. It is essential to monitor, control and protect core activities of the organization to mitigate market risks. According to Quinn and Hillmer(1994), "Companies assess potential of competitive edge and the risk of outsourcing the activities with the level of control essential for protecting the confidentiality and secrecy of the operations performed by the organisation." As per Ronan McIvor(2000), "fundamental of outsourcing strategy is to gain strategic advantage by outsourcing non value adding activities." Organisation outsourcing its functions/activities should decide about the relationship it requires with the outsourced firm. As per Velma Robert, Ph.D thesis, S. Sen et al.(2008), relationship are : "Arms-length relationship or strategic relationship. Sourcing decisions are either "make" or "buy" or "acquire" or "ally" decisions."

The organizations insist suppliers to reduce cost, improve response and reliability of supply chain. As per Mendoza A. et. al. (2012); Weber CA et al.(1991); Chin-Nung Liao et al.(2012), "The cost of raw material, components and parts purchased from outside is more

than 50% of sales." Organisation purchasing from the right source gets benefits like, cost reduction, risk mitigation, competitive advantage in market place, efficient resource utilization and customer satisfaction. Hence selecting right supplier is a crucial and strategic task for the organization functioning in the today's global competitive market. Sameer Kumar et al. (2011) mention that, "company must determine the appropriate criteria for selecting suppliers to source raw materials so that the supply chain remains steady and robust."

Kahraman et al.(2003) state that, "selection criteria conventionally fall into one of the four following categories: supplier criteria, product performance criteria, service performance criteria, and cost criteria." As per Luo X.X. et al.(2009) supplier selection is multi objective problem with minimization and maximization objective functions subject to constraints, in which some criteria are minimized and other are maximized to obtain trade-off between criteria. Suppliers are evaluated based on more than one criterion like cost, delivery time, service, production facility, management culture etc. and the problem becomes complex as number of criteria increases. Hence supplier selection is a multi criteria decision making (MCDM)/multi attribute decision making (MADM) problem Bhattacharya,A.et.al.(2010). Supplier are selected considering type of criteria, purchasing situation, sourcing strategy, business strategy of the firm, number of decision makers and type of supply chain in which firm operates. According to Luitzen de Boer et al.(1998), "Multiple alternatives-due to fierce competition and internal and external constraints imposed on the buying process makes the supplier selection decision making problem difficult and/or complicated." Complexity of the problem motivated researchers and practitioners to develop models, methods and techniques to assist decision maker to take accurate sustainable decision to select supplier. There is extant literature available on the supplier selection criteria and methods (Weber C.A et al, 1991; L. de Boer et al, 2001; William Ho et al, 2010; Setak, Mostafa, 2012).

2.2 Supplier Selection Process

Supplier selection has become a crucial issue for the success of a company in a supply chain. Supplier selection is a multi criteria problem, which include both qualitative and quantitative factors Ghodsypour and O'Brien(1998). According to Bouchard, Veronique, (1997), "As supplier/client relations evolve towards partnerships, which mean fewer and better suppliers and a higher degree of mutual dependence, supplier evaluation is becoming a

truly critical business process." It is of strategic importance for a company to select the strategic supplier that can best meet long-term expectations, as well as short term requirements of the company. Barbarosoglu G. et al.(1997) state that, " in order to attain the goals of low cost, consistent high quality, flexibility and quick response, the process of reengineering the company activities must also include the supplier selection process." According to Sheth and Sharma (1997), " As supply function becomes more a strategic differentiator and a core competency, it will encourage treating suppliers less as vendors and more like partners." Selection of right supplier enhances the performance and competitive position in the market of the firm. As per Zang Ju-liang et al.(2011), "one way of supplier selection is to select single supplier as the supply partner and to place all the orders to this single supplier. Single sourcing can foster better collaboration and partnership and reduce cost. However, relying on single supplier will increase the risk of supply disruption and weaken the supply chain robustness. In order to overcome the shortcomings of the single sourcing many firms have adopted multiple sourcing, that is, they select multiple suppliers as partners and allocate their ordering quantities among these suppliers. This will cost a little more because selecting a potential supplier as a real one will incur a fixed cost (e.g. administrative, negotiation etc.) and the buyer firm should place at least a minimum order quantity to this supplier if one supplier selected as partner." "With the recent trend on just-in-time (JIT) manufacturing philosophy, there is an emphasis on strategic sourcing that establishes long-term mutually beneficial relationship with fewer but better suppliers. Hence, supplier selection problem characteristics include strategic decision, (Vokurka et al., 1996; Talluri and Narasimhan, 2004; Prahinski and Benton, 2004)." Purchasing function encompasses the outsourcing process which involves supplier selection process. As per literature, "The supplier selection process problem is characterized by: First, strategic decision for long term benefit, effective coordination of operational functions and firms' competitive position in market. Second, multiple criteria for satisfying needs of customer and subjective criteria require experts from different functional area for quantification. Third, the multiple suppliers for uninterrupted flow of material due to constraints like capacity, quality, delivery time and uncontrollable factors (war, strikes, climatic conditions etc.)." As per Bouchard, Veronique, (1997), "The results of the supplier selection process are very much dependent on the adequacy and soundness of its underlying methodology and the best practices addresses the following key methodological issues :

- What should be the main steps of the selection process?
- What dimensions should be evaluated? What selection criteria should be used?

- What measurement techniques and selection method should be adopted?
- Who should participate to the selection process? In what phases and according to what modalities?"

L.de Boer et al. (2001) divide the supplier selection process into five phases:

"1. Need assessment of new supplier

2. Establishing selection parameters

3. Initial screening and short list the suppliers

4. Pruning and final supplier base selection

5. Evaluation and monitoring of supplier. " Decision in the selection process depends on the diversity of purchasing situation. Masella,C. et al.(1995), S.Sen et al.(2008) consider importance of strategy supporting the firm's strategy i.e. Low cost strategy, response strategy, differentiation strategy and regarding the outsourcing strategy with or without supplier integration for competitive advantage. Selection criteria in the supplier selection process are prioritized and placed in hierarchical order of importance. The integration level between buyer and supplier is important in the selection process. It is essential to decide the criteria for selection and use appropriate method to select the right supplier. The supplier selection process should be easy and efficient for the decision maker to take effective decision to achieve long term gain for the organization.The supplier selection process flow shows the sequence of steps and guides the decision maker to select a supplier.

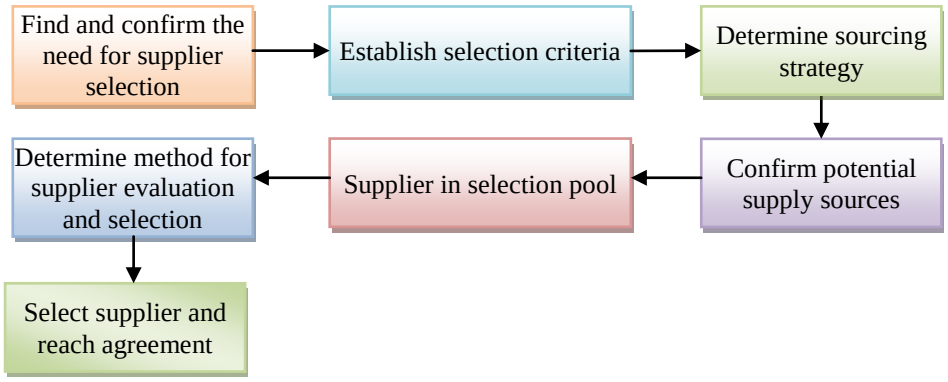


Figure 2.1 Supplier selection process

(Source: Purchasing and Supply Chain Management 3e Monczka el.at. Thomson Learning, 2005)

Braglia & Petroni (2000) suggest that, "supplier selection decision has two major tasks: 1.Process of evaluation and assessment 2.Aggregation of outcome to make the decision." The outcome of the selection process relies on the criteria selected in the supplier selection process. Ellram L.M.(1990) reviewed prescriptive model and descriptive model used in the supplier selection and suggested criteria necessary for buyer-supplier strategic

partnership. The suppliers with partnership potential will give long term benefits to the buyer.

Eric Sucky,(2007) mentions that, "typical characteristics for strategic vendor selection are: (i) the existence of only a few potential vendors, (ii) long-term contracts, and (iii) significant investment and switching costs." Biswas S. et al.(2004) mentions that, " supply chain performance measures are categorized into two: qualitative measures (customer satisfaction and product quality) and quantitative measures(order-to- delivery lead time, supply chain response time, flexibility, resource utilization, delivery performance, etc.)." The buyer and suppliers are the part of supply chain and the buyer has to satisfy its customers, maintain product quality etc. in long run for competitive position in the market. The supplier performance measure should be aligned with buyer's strategy. The organization should relatively list the supplier selection criteria required in the supplier selection process. As per Demeter K. (2004), "operational efficiency is directly affected by uncertainties originated from (1) the uncertain demand that materials management faces and (2) material flow that take place in the chain when satisfying the demand." As per Anderson et al.(1989), "operations strategy is a long-range vision for the operations function. The plan must be integrated with business strategy and implemented throughout the operating decision areas. They suggest that the resulting strategy based on a firm's mission, objectives, policies and distinctive competence should guide tactical operating decisions," In supplier selection process according to Verma, R.et al. (1998), "the relative importance of different supplier attributes in actual choice of suppliers is not the same as the perceived importance of the attributes. For example, it appears that managers perceive quality to be the most important attribute but they assign more weight to delivery performance and/or cost when actually choosing a supplier." Hence human judgment has effect on the supplier selection decison. As per Sameer Kumar et al.(2011), in supplier selection process multiple criteria are required to be analyzed to understand the suppliers capability to meet the buyers' requirement.

2.3 Supplier selection criteria

The supplier selection decisions are complicated as variety of criteria must be considered in decision making process. Muralidharan et. al. (2002) are of the opinion that, "suppliers have been acknowledged as the best intangible assets of any business organization." Chen and Paulraj(2004) mention that, "organisations are buying supplier's

capabilities." Quinn(1992) state that, "outsourcing provides substantial intangible benefits, such as increased ability to adapt to varying business conditions, improved quality and productivity, increased speed to market, improved access to outside experience and expertise etc.".Purchasing manager select the right qualified source based on the predetermined/identified criteria. Evaluation criteria for the supplier selection, may be tangible (measurable)(quantitative) or intangible (immeasurable)(qualitative). Palanisamy,A (2011) classified criteria into four types : "**Benefit**(response, product reliability, environmental control), **Opportunity**(supplier collaboration, supplier development, increase in manufacture capacity, **Cost**(product cost, logistic cost, after sales cost) and **Risk**(order delay, field return, financial strength, change in demand, labor strike, customer complaints, machine breakdown)." S.Sen et al.(2008) mention that, "Criteria are either supplier based: net price, the cost of operating, defects or product based: delivery lead time, supplier reputation, quality of supplier services." Verma, R.et al.(1998) considered quality, cost, delivery and flexibility in their study of supplier selection process. Chin-Nung Liao et al.(2012) opine that, selecting the right supplier significantly decrease purchasing cost, improves competitive advantage and enhance customer satisfaction. Type and size of business organization influence the supplier selection criteria and supplier selection methods/techniques in the supplier selection process. S. Kumar et al.(2009) mention that, "Large organization use different set of criteria and a formal approach when selecting supplier compared to small and medium size enterprises." Luitzen de Boer et al.(1998) refer in their paper that, "Criteria selection for supplier selection and performance measurement attracted attention of decision makers since 1960." Based on the empirical study conducted in United States and Canada, Dickson (1966) contributed 23 supplier selection criteria and it was the trigger to researchers and practitioners, which is a reference for most of the literature published on supplier selection problem. Almost all researchers have considered these criteria in fully or partially for selection and evaluation of supplier. However there is addition of more criteria due to change in the business environment. Among the 23 criteria listed by Dickson (1966), top three criteria in order of importance are; quality of product, on-time-delivery and performance history of the supplier and the warranty policy used by the supplier. Ing-Hwang et al.(2005) investigated factors affecting the choice of suppliers "(Foreign: value creation, product and operation capability Domestic: reputation, technical capacity, customer capability and Local: operation capability, technical capability, customer capability." Vendor selection decisions is complicated as various criteria must be considered in the decision making process. Weber C.A. et. al.(1991) reviewed 74 related articles which

have appeared since 1966-1990. Each annotation list three subentries: criteria used, purchasing environment, technique or analytical method used. They noticed that, price, delivery, quality and production capacity and location are often considered in the literature. It is concluded that the quality at top followed by delivery and cost respectively. Further Weber et.al.(1991) are of the opinion that, geographical location of supplier is important in Just-in-Time(JIT) environment alongwith criteria like, communication system, desire of business and management and organisation suggested by Dickson(1966).

Beil D.(2009) mentions criteria as per its usage, "**frequently appearing dimensions** include production capacity and flexibility, technical capabilities and support, information and communication systems, financial status, and innovation and R&D. Dimensions that appear with **moderate frequency** in the literature include quality systems, management and organization, personnel training and development, performance history, geological location, reputation and references, packaging and handling ability, amount of past business, warranties and claim policies, procedural compliance, attitude and strategic fit, labour relations record, and desire for business. Of course, buyers often employ new dimensions in response to prevailing business issues and challenges. Dimensions that have emerged recently include environmental and social responsibility, safety awareness, domestic political stability, cultural congruence with the buyer organization, and terrorism risk."

In reality close coordination and cooperation required among supply chain members for effective functioning.. Such closeliness leads to partnership, long-term relationship and develops previledged supplier in the supply chain. The traditional management of buyer-supplier relationship influence competition among suppliers with cooperation between buyer and supplier from product design stage. Such relationship require selection criteria like capacity of cooperation, communication system, control and coordination instead of criteria such as cost,quality,delivery etc. Paulo Avila(2012) Li, Wu (2008). William Ho et al.(2010) reviewed the papers till 2008. It is mentioned in their paper that criteria like, "quality, delivery, price, manufacturing capability, service, management, technology, research and development, finance, flexibility, reputation, relationship, risk, safety and environment are used by decision maker in supplier selection process." Since 1990 development in computer, information technology, quality management system, JIT, TQM philosophy, 5S etc. changed the focus of organization and new criteria emerged for supplier selection. A close long term relationship between supplier and buyer is desired in the global competitive scenario due to advancement in technology. This can be achieved by cooperation and integrating the

business processes. The supplier evaluation for long term relationship requires strategic and operational criteria.

Barbarosoglu G. et al.(1997) suggest criteria such as, "supplier performance (shipment quality, delivery and cost analysis), supplier business structure/manufacturing capability(technical cooperation, employee profile, financial status, equipment, manufacturing) and quality system(management commitment, product development, process improvement, quality planning, quality assurance in supply, quality assurance in production, inspection and experimentation, quality staff)." Lean philosophy stress on minimizing waste, inventory levels etc. for cost reduction in all operation. As per Bhutta,K.S et al.(2002), Shuo-Yan Chou et al.(2008), Arash S. M. et al.(2013), due to cost reduction efforts by the organizations net price criteria is replaced by cost criteria.

TABLE 1: Legend for Figure 1

PERFORMANCE ASSESSMENT

A1: Rejection Rate
A11: Rejection in Incoming Quality Control
A12: Rejection in the Production Line
A13: Rejection from Customer
A2: Lot Certification
A3: Sorting Effort
A4: Defective Acceptance
B1: Compliance with Quantity
B2: Compliance with Due Date
B3: Compliance with Packaging Standards
C1: Compliance with Cost Analysis System
C2: Cost Reduction Activities
C3: Compliance with Sectoral Price Behavior

BUSINESS STRUCTURE/MANUFACTURING CAPABILITY ASSESSMENT

D1: Response to Quality Problems
D2: Design Capability
D3: Level of Cooperation and Information Exchange
E1: Organizational Structure
E2: Number of Employees
E3: Number of Technical Staff
E4: Education
F1: Total Revenue
F2: Profitability
F3: Company Share within the Work Volume
G1: Production Machinery
G2: Technological Compatibility
G3: Computer Hardware
H1: Production Planning System
H2: Lead Time
H3: Maintenance Activities
H4: Plant Layout and Material Handling
H5: Transportation, Storage and Packaging

QUALITY SYSTEM ASSESSMENT

I1: Quality Assurance System Documents
I2: Role of the Quality Function in the Firm
I3: Internal Audit
I4: Workforce Participation in Quality Improvement
J1: Assessment of Design Development Activities
J2: Design Functionality and Reliability Experiment
J3: Quality Techniques in Design
K1: Process Improvement Activities
K2: Process and Machine Capability Indices
K3: Quality Techniques in Process Improvement
L1: Compliance with Company Specifications
L2: Prototype Controls
L3: Traceability
L4: Assessment of Quality Improvement Activities
L5: Quality Costs
L6: Quality Database
M1: Purchasing Procedures and Supplier Evaluation
M2: Quality Certified Shipment
M3: Approval of Changes
M4: Incoming Quality Control Procedures
N1: Part/Product Definition and Sorting
N2: Rework
N3: Process Control and Interference
N4: Statistical Applications
N5: Application of Advanced Quality Techniques
N6: Corrective Action Response
O1: In-Process Inspection and Reliability Tests
O2: Final Inspection and Reliability Tests
O3: Product Audits
O4: Measurement and Testing Equipment
O5: Calibration Activities
P1: Number of Quality Staff
P2: Education of Quality Staff

Fig 2.2 Criteria for supplier selection source: Barbarosoglu G. et al.(1997)

According to Sameer K et. al.(2011), "Total cost of ownership is defined as a philosophy for understanding all relevant supply chain costs of doing business with a particular supplier of a particular good/service, or the cost of the process, or particular supply chain design." Bhutta,K.S et al.(2002) say that, "Total cost of ownership looks beyond the price of a purchase to include many other purchase-related costs." According to Lee, M. S.et.al.(2003),meaning of quality is extended to quality system eg.ISO9001 system,

inspection, experimentation and quality staff. Choy, K. L.et al.(2002), Choy, K. L.et al.(2003) term delivery as lead time and in JIT environment referred as delivery capability.

The organisation boundaries are shifting due to competition and most focus is given on product design and development, flexibility, and close relationship with suppliers to improve supply chain profit. According to Ali Naseri et al. (2011), "the factors identified for strategic partnership are financial issues, long term outlook for the supplier firm. Organizational culture and strategy, deals with the way that the buying and supplying organizations fit together in terms of management style, future direction/strategy and overall compatibility. The third is technology, requires an assessment of the supplying firm's future technological directions and capabilities and the other factors include safety record of the supplier, business references, suppliers customers base." These criteria are similar to the criteria investigated by Ellram LM(1990) for supplier selection decision in strategic partnership. As per Liang-Hsuan Chen et.al.(2010) evaluating criteria are "financial consideration, quality, service performance, compliance and culture." S. Sen et al. (2008), Ellram, L.M. (1990) noticed that, the organizations believe in long term relationship and strategic partnership with the supplier. So emphasize on strategic criteria like quality system, manufacturing capability, financial strength etc. is essential for the proper selection of supplier. Enyinda C.I. et al.(2010) consider strategic supplier selection criteria like, "regulatory compliance, quality, cost, service, supplier profile and risk." Quality is generally considered for product or service but, it is required to in all functions of organization to establish position in market and hence organisation should have quality system to improve its performance. Lin C. et.al.(2005) mention that, "quality management practices are imperative in supplier selection strategies." "Gonzalez ME et al.(2004)found that, "quality is the most significant attribute in supplier selection."

Klassen RD et al.(2007) state that, "the managers need to mitigate the impact of uncertainties in the supply networks. They proposed the uncertainty coping strategies: increase inventory, increase spare capacity and reduce the variability of production capability. They divided the production variability into predictable components and that due to random factors, recommending just–in-time (JIT) practices for the former and total quality management (TQM) for the later." Hence quality as strategic criteria is to be considered during supplier selection. Sameer Kumar et al.(2011) discuss on evaluation of criteria needed to form a successful relationship between manufacturer and material supplier. As per Gholipour R. el at.(2014) criteria are: technical, capability and skill, financial, managerial, facilities and support services, performance history. Sezhiyan DM et al.(2011)

mention criteria like: "quality, price, delivery, production facility and capacity, technical capacity, financial position, management and organisation. Further they say that, supplier selection is positively associated to supply chain management strategy and firms performance."

Amoribieta et al., (2001) state that, "Manufacturing industries discovered that delivery and quality are among the crucial underlying constructs for consistency in the context of supplier selection, making them the most significant factors in selection of the supplier. Potential suppliers are to be assessed on competency, availability and prompt service." As per Hoetker, G. (2005), "technological capabilities of the supplier can supply the innovative parts and components." Business ethics guidelines should be followed to avoid moral hazard by the supplier. Buyer and supplier are required to pursue sustainable purchasing view. It includes environment, finance and social sector. "Leonidou (2004) identified advantages that are strategically beneficial for firms that are involved in long-term relationships. such as ,sellers can retrieve repeat buys from their customers enabling them new business." Technology and financial strength are crucial supplier selection in industry. Consistencies in delivery schedule and acceptance level planned by the buyer are important criteria. Supplier should comply for ensure reliable supply at purchasers premises for uninterrupted production. Supplier should follow suitable quality standard practices and procedures in its operations/production. "S.Sen et al.(2008) suggests heuristic method for assessing the integration level essential between buyer and supplier and deciding the corresponding supplier evaluation criteria. The weight assigned to supplier selection criteria may vary due to factors like: decision makers, organization size, sourcing strategy, supply chain strategy (competitive strategy) and product and/or services purchased."

Mandal and Deshmukh(1994) classified the criteria into four types: Autonomous, dependent, linkage, driver/independent based on the driver power and dependence. They developed interpretive structural model(ISM) frame work to identify the criteria level for supplier selection, Supplier selection criteria listed by Dickson(1966) are considered in supplier selection problems by many researchers/professionals in their studies, cited in most of the literature and used in industry for supplier selection. Patil et al.(2014) listed 48 criteria from literature referred between 1966-2012. Levary(2007) considers supply risk of foreign supplier and suggest criteria like, technological base, skilled labor, quality standard, technical support, acceptable price, IT facility, volume flexibility, product flexibility, proprietary information protection, supplier reliability, reliable transportation, country risk(political risk, natural risk, man-made risk, currency convertibility risk).

Literature with Focus on Criteria	Bibliographic Reference
Quality	1,2,4,5,7,23,24,29,30,33,42,43,47,50,55,67,69,72,81,93,96,103,104,109,115,117 ,125,126,135,136,138,139,146,148,149,151,155,160,162,165,173,182,190,193, 197,199,202,209,214,215,223,227, 228
Price/ Cost	1,2,4,5,17,23,24,29,30,43,47,55,67,71,72,80,86,91,93,96,104,109,115,117,128, 135,137,138,139,144,146,148,149,151,153,160,162,164,173,182,190,193,197, 199,202,209,215,221, 223,227.
Delivery	2,4,5,6,7,17,23,24,29,43,47,55,71,72,81,86,93,103,115,117,125,126,128,135, 139,144,146,148,149,150,155,160,162,165,173,182,190,199,202,214,215,223, 227, 228.
Service	1,4,6,7,13,23,29,30,42,43,47,67,69,81,96,104,115,125,128,136,138,151,160,165 ,173,209,214,228.
Production Facility	2,4,17,30,55,69,72,86,93,125,146,149,151,162,164,173,215,223,227.
Financial Strength	4,6,13,17,42,62,69,125,144,148,149,151,162,164,209,223,227,228.
Management	6,23,30,42,47,55,62,69,86,126,144,160,162,164,193,199,223,227.
Experience	23,67,69,96,109,125,126,135,148,149,162,221,228.
Technology	7,23,62,71,86,93,173,193,197,223,227.
Inspection	2,.7,23,71,86,128,135,149,221,228.
QMS	6,7,55,117,149,151,164,193.
Reputation	6, 86,125, 135,155, 221,227, 228.
Risk Management	6, 67, 96, 151, 164,197, 228.
Innovation	4, 6, 55, 69, 96,199, 228.
Support Service	6,7, 29, 96, 126, 228.
Expertise Support	7,69, 128, 135,149
Product Range	5,6,24,221
Human Resource	69,86,149
Communication	6, 69,128
Security	7

Table 2.1: Supplier selection criteria from 2002 to 2015

Literature with focus on supplier requirements	Bibliographic Reference
Quality	1,2,4,5,7,23,24,29,30,33,42,43,47,50,55,67,69,72,81,93,96,103,104,109,115,117, 125,126,135,136,138,139,146,148,149,151,155,160,162,165,173,182,190,193, 197,199,202,209,214,215,223,227, 228
Capability	1,4,6,7,13,17,23,29,30,50,55,62,69,71,72,86,93,125,126,128,146,149, 151,162,173,182, 197,199,215,223,227,228
Reliability	4,6,7,13,17,23,43,47,50,55,62,67,81,93,103,104,115,117,135,144,149, 151,160,162,164, 190,199,202,215,223,227.
Availability & sustainability	1,6,7,13,23,30,43,47,50,67,69,93,104,125,126,128,135,136,138,160,164, 209,214,227, 228
Stability	4,6,13,50,62,67,69,125,126,144,149,151,162, 164,209,223, 227,228.
Flexibility	4,7,24,29,50,55,71,103,115,128,136,162, 164,165,173,223, 227

Table 2.2 Literature with focus on buyer perception on supplier requirement

S.Sen et al. (2008), Masella, C. et al. (1995) study say that, "It is essential to know the firm's strategy (i.e. Low cost strategy, response strategy, and differentiation strategy), competitive position and buyer-supplier integration level before implementing the outsourcing strategy. The supplier selection criteria depend on the buyer-supplier integration level." All these factors of outsourcing should be considered in supplier selection process. The papers selected in this study focus on fuzzy, dynamic, stochastic or uncertain environment. It is observed in the study that, either operational criteria and/or strategic criteria are used depending on the need of the organization.

This study presents a framework in Table 2.1 and Table 2.2, showing the supplier selection criteria used by the authors from 2002 to 2015. It is found that, operational criteria like quality, price, delivery and service are considered in all the papers. Strategic criteria are the system parameters of the organization like quality system, production system, environment systems etc are also considered in some papers. Hence the supplier selection is

multi criteria decision making problem. It is essential to use both type criteria in supplier selection process for competitive advantage.

2.4 Supplier selection methods

Supplier selection and evaluation problem has been studied extensively by the researchers, professional and academicians and extant literature available in literature. As per A. Mardani et al.(2015), "choosing a problem solution approach and a model is dependent upon the actors that are involved in the process of decision making, desired goals, available information, time, and so on." The supplier selection problem is characterized by: First, strategic decision for long term benefit, effective coordination of operational functions, and firms' competitive position in market. Second, multi criteria for satisfying needs of customer and subjective criteria require experts from different functional area for quantification. Third, multiple suppliers are for uninterrupted flow of material due to constraints like capacity, quality, delivery time and uncontrollable factors (war, strikes, climatic conditions etc.) The supplier selection problem can be divided based on sourcing strategy: 1.single sourcing 2.multiple sourcing. If single supplier does not fulfills all requirement of the buyer than buyer has to search for multiple suppliers to satisfy the demand. However buyer demand fulfillment depends on the constraints of supplier (capacity, geographical location, etc.). Suppliers satisfy the requirement of the buyer at different levels as per supplier's strength and weakness. Organisation boundaries are transcending due to competition and global sourcing S. kumar(2011). Use of multiple criteria gives reliable results in supplier performance evaluation in supply chain. It is advantageous to avoid single parameter in supplier evaluation either qualitative or quantitative. Traditionally price was considered to select the supplier and the lowest price supplier was selected, but it is not true in contemporary supply chain. The contemporary supply management is to maintain long term partnership with suppliers and use fewer but reliable suppliers William Ho et al.(2010). Suppliers are selected keeping in mind the buyer-supplier integration level, purchasing situation, competitive position of the organization and the corporate strategy S.Sen et al.(2008). This makes the supplier selection decision process complicated due to multiple criteria, conflicting objectives of the criteria, multiple supplier due to competition, constraints into buying process de Boer L.et. al.(1998). Hence appropriate methods are to be used to solve supplier selection problem as per suitability of the decision environment.. As per Li et al.(1997), "supplier selection methods are models or approaches to conduct

selection process." The researchers Ha et al. (2008) ,William Ho et al. (2010), Onder et al. (2013) ,Ware et al. (2014) etc. classifies the supplier selection methods into two types: 1.Single or Independent approach and 2. Hybrid or integrated approach Figure 3 show the overview of the methods in tree form. The framework of methods and criteria from 2002 to 2015 is shown in the annexure. The methods using quality function development (QFD) from 2010 to 2015 are shown in Table 6 below.

The type of criteria and its need for evaluation classify the supplier selection methods. According to Ware et al. (2014) methods are two types: quantitative methods and qualitative methods. Quantitative methods use mathematical programming like linear programming (LP), mixed-integer linear programming (MILP), mixed integer non linear program(MINLP), dynamic programming(DP), multi objective programming(MOP), genetic algorithm(GA), data envelopment analysis(DEA) to analyse quantitative criteria.. Similarly for qualitative criteria the methods include analytical hierarchy process(AHP), fuzzy AHP, Analytical Network process(ANP), technique for order preference by similarity to ideal solution(TOPSIS), Fuzzy TOPSIS, case based reasoning(CBR), AHP and linear programming(LP). William Ho et al. (2010) reviewed 78 international journal articles on multi criteria supplier evaluation and selection approaches from 2000 to 2008 and divided supplier selection methods into two types: individual approach and integrated approach. Their study focused on the examined for methods mostly used, influential criteria in decision making and inadequacy of the approach. They mention that, "It is found that all methods are capable of handling multiple qualitative and quantitative criteria. The most prevalent approach is data envelopment analysis (DEA) and most popular integrated approach is AHP-GP (goal programming). The most popular criteria used for evaluating the performance of supplier is quality followed by delivery, price or cost." According to S.Sen et.al.(2008) procurement situation influence the decision of supplier selection. The procurement situation and the phases in the supplier selection process are considered by Ha et al. (2008) during classification of supplier selection methods. As per Ha et.al.(2008), "pre qualification phase includes supplier selection methods like, data envelopment analysis(DEA), cluster analysis (CA) and case based reasoning (CBR). The final phase generally called as choice phase considers methods like linear weighted (LWM), total cost of ownership (TCO) and mathematical programming (MP), statistical and artificial intelligence (AI)." The supplier selection method is dependent on the number of suppliers and the sourcing decision. Sourcing strategy decides a single or multiple suppliers to be hired during outsourcing.

Supplier selection requires strategic thinking and clear decision-making which is quite often time consuming.

Traditional supplier selection and evaluation methods are all too often based on quoted price, which ignore the significant costs associated with ordering, expediting,

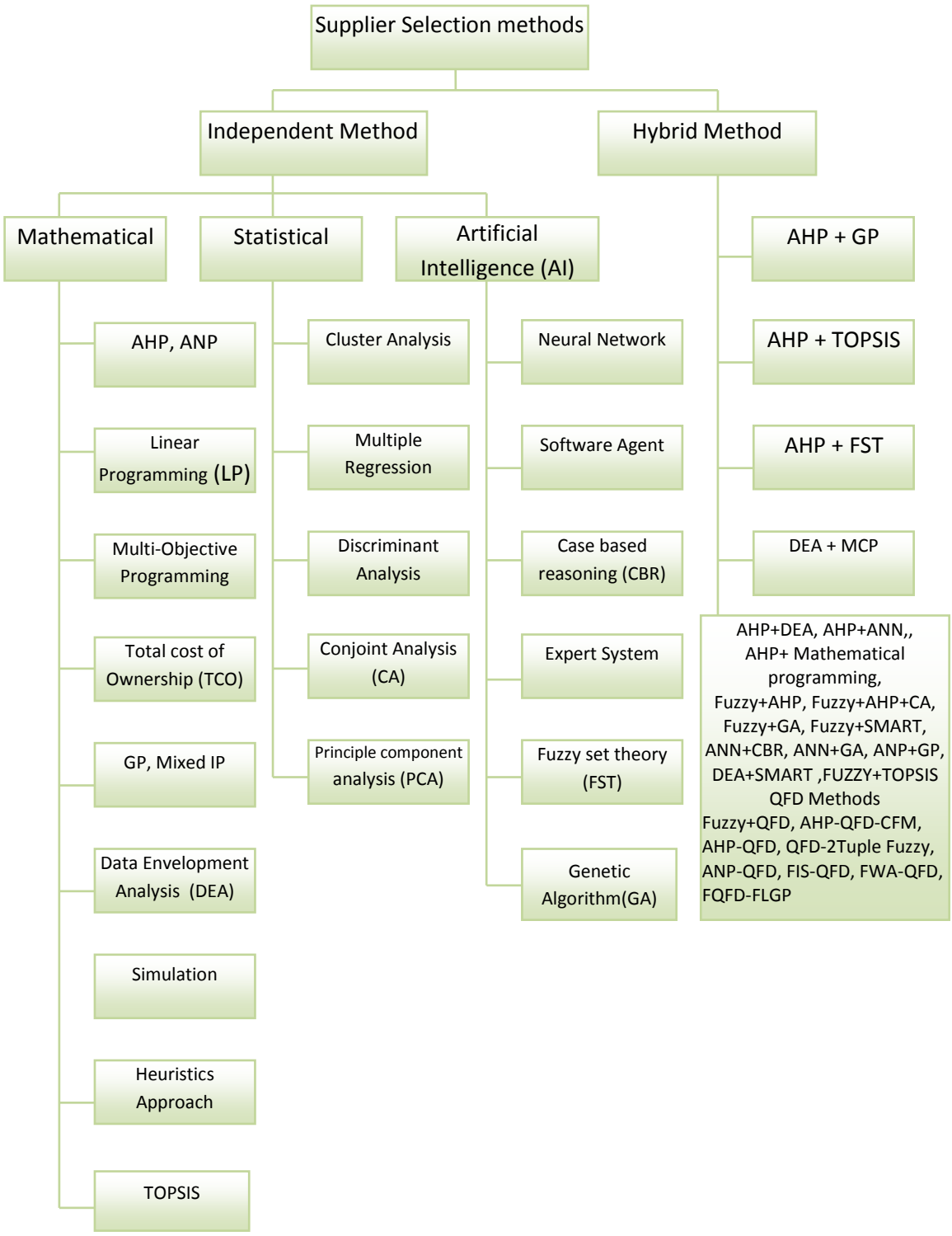


Figure 2.3: Classification of supplier selection methods

(Source: 8, 21, 31, 59, 61, 84, 92, 141, 161,178,216,220) (2002-2015)

receiving, inspecting, and using purchased parts and materials. In single sourcing strategy, the task is to select best flexible supplier satisfying the firm's needs with uninterrupted supply and in multiple sourcing, decision making methods should be capable of selecting and ranking best alternative suppliers from supplier base followed by subsequent decision for order allocation to each supplier. The conventional methods for supplier evaluation and selection are (1) categorical methods, (2) weighted point methods, (3) cost based methods, Timmerman (1986). These method are heavily depends on the experience and human judgment. The methods focus on criteria like quality, delivery, service and price.

In the Categorical Method decision maker assigns either good (+), neutral (0), or unsatisfactory (-) to each defined criteria for all suppliers, then a total rate for each supplier is calculated. The primary advantage of the categorical approach is that it helps to structure the evaluation process in a clear and systematic manner. This method is quite simple; it is not supported by objective criteria, and rarely leads to performance improvements. This method is inexpensive and requires minimum performance data. The main drawback of this method is that the identified criteria are weighted equally subjective and imprecise.

Linear weighting models proposed rate the suppliers for each criteria and combine these rating to obtain the single score for each supplier. The supplier with highest score is selected by the decision maker. The widely used approach is Weighted Point Plan. This is a simple scoring method. In the weighted point method criteria are weighted by importance in purchasing situation by the buyer. The weight for each criterion is then multiplied by the performance score of the supplier assigned by the buyer. Finally, summation of the product determines the score of each supplier. This score is used to rate the supplier. Buyer can take number of criteria as per the requirement and assign them weight as per the organisation's needs. This method is suitable quantitative analysis.

As per Timmerman (1986), "In the cost ratio method the purchasing costs are identified and compared with the monitory value of the components and parts received from the supplier." The suppliers with lower ratio are rated high. In the cost ratio method a benchmark of supplier service is established to evaluate supplier below or above the bench mark in relation to price. This method has reduction in subjectivity compared to other methods. "The cost ratio method is based on cost analysis that considers cost ratios for product quality, delivery, customer service and price. The cost ratio measures the cost of each factor as a percentage of total purchase for the supplier. Due the flexibility of this method, any company in any market can adopt it. The drawback of the method is its

complexity and requirement for a developed cost accounting system." As per Degraeve and Roodhooft (1999), "The total cost of ownership method attempts to quantify all of the costs related to the purchase of a given quantity of products or services from a given supplier." According to Ellram (1995), "Optimum use of all discounts available can lead to substantial savings. In addition to the price component, other cost factors also play an important role, including the costs associated with quality shortcomings, a supplier's unreliable delivery service, transport costs, ordering costs, reception costs, and inspection costs. This method uses activity- based costing which is a management accounting technique that attempts to assign costs to cost generating activities within a business. This technique uses activity analysis, which defines the various activities performed by an organization. The first step of the total cost of ownership method is to define all the activities related to external purchasing. These are specific to every enterprise and should be expressed through the activity analysis. Subsequently, costs must be assigned to the different activities. The next step is to define factors which raise the cost of a given activity (cost drivers). Finally, identify which activities are generated in the purchasing organization by each individual supplier. This approach enables cost savings to be achieved, compare various purchasing policies and assist decision maker to select right supplier."

Petroni and Braglia(2000) proposed principle component analysis(PCA) method for supplier selection. The criteria considered are price, delivery reliability and quality for evaluation. The advantage is considering the input and output without initially assigning the weights. The eigen values are calculated and skree plot is drawn to get the values. The decision maker should have thorough statistical knowledge beforehand for applying this technique. The simple method is the linear scoring method/model with continuum of 1 to 5 with unsatisfactory and outstanding as two extremes. The weights/scores are arbitrarily assigned to the supplier, for example, 1 for 'unsatisfactory' and 5 for 'outstanding' based on implicit and incorrect assumptions: e.g. 'outstanding' is five times better than 'unsatisfactory. This method solely depends on perception and human judgment towards the supplier of decision maker. This problem is avoided in the AHP or ANP model by converting the priorities into the ratings with regard to each criterion using pair wise comparisons and the consistency ratio (Satty 1980). Therefore, the typical priority scaling model of AHP/ ANP models are better than the linear scoring model Ghodsypour el at.(1998). . The major problem in mathematical programming model is to use qualitative criteria. As per S. Sen et al.(2008); Ghodsypour S.H.et al.(1998); Mandal and Deshmukh((1994),in buyer-supplier relationship qualitative criteria are important. This

problem can be overcome by using AHP/ANP to treat the qualitative criteria. In our problem multi criteria are present, we use priority scaling method specifically AHP for supplier selection.

Nydick and Hill(1992) suggested the advantages of the AHP method introduced by Saaty(1980) for supplier selection. The advantages are ease of application and capability of involving uncertain and subjective information, and including experience, insight, and intuition of purchasing managers. "Ghodsypour and O'Brien(1998) proposed an integrated model of AHP and linear programming which considered both tangible and intangible factors in choosing the best suppliers and placing the optimal order quantities among suppliers in order to maximize the total value of purchasing. Paper highlights quality, cost and delivery performance measures in the supplier selection process."

The study on strategic partnership by Ellram(1990) suggests criteria like "financial issues, organizational culture and strategies, technology ,other factors include safety etc. are of importance for supplier selection." According to Mehmet Sevkli et al. (2007), "hybrid AHP-FLP method proposed for supplier selection considers criteria performance assessment, human resources, quality system assessment, manufacturing, business, and information technology. Further suggests that, its application will be more appropriate for high-value components where stringent purchasing criteria are required. In contrast, AHP remains an appropriate approach for relatively lower value components (C class). The findings of this study indicate that the weights of supplier selection criteria calculated by the AHP-FLP model are in line with the actual supplier selection decision of purchasing managers." Babak et al.(2014) reviewed 170 articles on supplier selection published during 2000 to 2010 and classified supplier selection methods into three types: qualitative factor approach, quantitative factor approach, and integrated factor approach. Their study shows that 40% of the articles used hybrid/integrated method to solve supplier selection problem. Choi et. al.(2008) proposed e-procurement decision model using multi criteria and use optimization using rule based reasoning for supplier selection in B2B marketplaces considering supply conditions and order allocation.

Most of the recent methods developed use fuzzy set theory to tackle the uncertainty and imprecise data. Two kinds of justification can be provided for increasing popularity of the application of fuzzy set theory into supply chain management. First, fuzziness must be introduced so as to obtain a reasonable model to solve the complex problems of supplier selection. Second, there is a need to formulate human knowledge and judgment in a systematic manner and put it into mathematical models. Rezaei J. et al.(2013) proposed

method for fuzzy preference relation with AHP. "The method uses segmentation dimension: supplier capability and supplier willingness along with the criteria used in supplier selection." Feyzan Arikan (2013) applied fuzzy solution approach for multi objective functions. The multiple objective includes two maximization (quality and on time delivery) and one minimization (cost) function. Here opportunity is given to the decision maker to obtain her/his own preference achievement levels for the objective. The model proposed has reduced level of complexity for computation. In reality the information is associated with uncertainty which requires the fuzzy approach to solve the problem. There exists interdependence between the selection criteria. Rong-Ho Lin(2012) study proposes FANP (ANP +fuzzy preference programming(FPP)) to prioritize the supplier and integrates with fuzzy multiple objective linear programming(FMOLP) to decide about order allocation to each supplier selected. The integrated approach effectively manages the interdependence and feedback effects under uncertainty. Their model consists of, "four objective functions including minimum purchase cost of the product, minimum delay in delivery by quantity, minimum quantity of defective product, and maximum overall value of order quantity and three set of constraints, based on buyer's demand, supplier capacity, and quality." The suggested method incorporates aspiration levels of decision maker for allocating optimal order quantity to each selected supplier. The model helps firms to monitor suppliers so as to avoid subjective human judgment in the future and to improve the buyer-supplier relationship. Facho Li et al.(2012) proposed model based on fuzzy sets and comparison using synthesis effect. The method uses evaluation index system, weights for 3PL supplier and considers the degree of satisfaction. K. Shaw et al.(2012) use Fuzzy AHP and Fuzzy MOLP for supplier selection. FAHP is used to find the weights of factors. The considered factors are cost, quality rejection percentage, late delivery percentage, green house gas emission and demand. The method is applied and case study is presented. Y.H. Chen el at.(2012) presents a simple and efficient procedure for rating suppliers. The proposed methodology employs the AHP hierarchy for criteria and utilizes consistent fuzzy preference relation (CFPR) for supplier selection to reduce the pair wise comparisons for grouped criteria. Using additive transitivity the CFPR method guarantees the consistency in constructing the decision matrix. Min-Chun Yu (2012) consider multi objective supplier selection program under lean purchasing with cost , delivery schedule violation and quality level of purchased quantity as objective functions and used fuzzy .AHP in proposed algorithm. The paper considers uncertainty in manufacturing capacity in the proposed model

to decide the supplier selection policy and guides decision maker for supplier performance evaluation based on urgency or need for a part.

Abbas Mardani et al. (2015) reviewed 413 papers from 1994 to 2014 on fuzzy MCDM techniques and applications. As per their study, out of 1081 applications, 356 applications are solved using hybrid techniques, 15.82% use AHP and 9.53% use Fuzzy AHP approach to solve the problem. It is mentioned in the paper that, "the FMCDM methodology has been used successfully in various applications and industrial sectors with different subjects and terms." Wang and Yang (2009) proposed AHP and fuzzy compromise program with illustrative example to solve multi objective linear programming problem.. Fuzzy approach is proposed by Amid el at.(2006),Wei pan(2012) to take care of imprecise and vague data along with the decision makers human judgment, experience and intuition to solve the supplier selection problem. Boran et.al (2009) proposed model using fuzzy TOPSIS method for supplier selection under multi criteria group decision making having vague and imprecise knowledge over criteria. Liao et al. (2011) proposed an integrated fuzzy TOPSIS for multi criteria supplier selection in supply chain using linguistic variable for qualitative criteria. The method was tested in watch manufacturing company." Shin-Chan Tang el at (2008) developed a two stage methodology by integrating AHP and MOLP. AHP process is used to evaluate the relative weight of the criteria and sub-criteria to rank the suppliers under consideration. The min-max model for MOLP is developed for order allocation to the supplier selected from the first step. The model has three objective functions for optimizing total purchasing costs, quality, and delivery reliability and a set of system constraints such as purchasing budget, production demand, suppliers' capacities, quality control, and inventory control.

Amin et al. (2009) ,Arash S. M. et al.(2013) have proposed model for internet service provider based on QFD using fuzzy theory. Model proposed by Amin et al.(2009)advantage of combining supplier selection, evaluation and development phases in one framework. The decision makers experience and authority vary in reality. The reliability of the decision is higher with more experience and authority. The reliability of each decision maker change and hence different weights are to be assigned to the decision makers. In the model proposed by Arash S. M. et al.(2013) the weight of the decision maker are determined by using fuzzy inference system. This model considers qualitative criteria, quantitative criteria; model considers customer, competition, and performance simultaneously for effective supplier selection. Rajesh G. et al.(2013) proposed AHP QFD method for supplier selection. The determinants used are quality, cost, delivery, experience, technical capability,

quality system certification, geographical position, raw material procurement, financial stability, and attitude. The model considers crisp value and suitable for qualitative evaluation of supplier. Also William Ho et al.(2011) have proposed the method of AHP-QFD using the crisp value data. In their paper the autors have summerised the individual and integrated approaches in tabular form.

Bhattacharya et al. (2010) proposed integrated method using analytic hierarchy process (AHP), quality function deployment (QFD) and cost factor measure (CFM) for supplier selection. The author classifies the criteria as customer criteria and engineering criteria having total 8 criteria and 13 sub criteria. The four level hierarchical AHP structure is built for finding scores of the supplier. Hierarchical QFD (H-QFD) is developed. In the cost reduction, cost plays important role. So, five different cost measures are considered during the supplier selection process. A case study is illustrated applying this method. The model developed is useful, flexible, practical for ranking supplier and can incorporate additional criteria as per the need of the organization.. Purchasing decisions are effective due to hierarchical QFD. Dursun et.al. (2012), (2013),(2015) considered QFD along with other methods(2-tuple, fuzzy weighted average(FWA)) to solve the selection and evaluation problem. Dursun et. al (2013) developed fuzzy multi criteria group decision making approach using quality function deployment (QFD) concept. The proposed methodology initially identifies features that the purchase product must possess to meet customer needs and then establish relevant supplier assessment criteria. Earlier work of Bevilacqua was used to test effectiveness of proposed methodology. Houshang T. et al. (2013) developed integrated approach by combining quality function deployment and analytical network process (ANP) to evaluate supplier performance. ANP is useful for interdependence between criteria. They applied this in Watch Company for its effectiveness. Mousod Tavakoli et al. (2015) proposed integrated method fizzy QFD and fuzzy linear goal programming (FLGP). Fuzzy set is used for imprecise data and human judgments. Decision maker's brain storm for the key supply required its quantity and decides on the evaluation criteria. The buyer and supplier criteria are product quality, production cost, delivery performance, after-sell services and flexibility, experience of supplier, financial stability, optimum feature, quality system licenses, flexibility, and geographical location. GP is considered for the criteria weight and minimizing the deviation in objective functions. The ranks of the supplier are determined by FQFD. Similar approach is presented by Ahmad J.C. et al.(2015) by assigning different indices for evaluation criteria under fuzzy conditions in automotive supply chain. As per A. Mardani (2015), "the most important advantage of the fuzzy multiple criteria

methods is their capability of addressing the problems that are marked by different conflicting interests. Using these techniques, actors are capable of solving the problems that are not possible to be solved by the use of common optimization models."

2.5 Research problem

2.5.1 Identifying the research gap

Supply chain management (SCM) is one of the most important competitive strategies used by modern enterprises. The main aim of supply chain management is to integrate various suppliers to satisfy market demand. According to Liou James et al.(2013), "strategic partnership with better performing suppliers should be integrated into the supply chain to improve the performance in various aspects including reducing costs by eliminating wastages, continuously improving quality to achieve zero defects, improving flexibility to meet end customer needs, reducing lead time at different stages of the SC." The buyer expects a long-term strategic relationship with his supplier. Hence supplier selection is a strategic decision-making problem. In Business to Business (B2B) environment supplier relationship is of concern in volatile markets. First, spot market based on short term relationships has become a more cost-efficient sourcing option. Second, the growing concern on supply chain risk calls for reduction in supplier base and long term relationship, Talluri S.et al (2009). As per Gelderman and Van Weele,(2005), "Customer pressures for responsiveness force firms to tighten and focus internal and external organizational links towards the fulfilment of market needs." Position and professionalism of purchasing is important for taking purchasing decisions. Talluri and Narsimhan,2004) mention that, "the strategic sourcing methodologies in practice are of subjective in nature and argue that the objective decision models are limited to supplier evaluation and selection and do not cover the other sourcing decision such as development or pruning of supplier." A manufacturing firm primarily depends on the key supplier is more likely susceptible to operational risk, disruption risks (natural disaster), procurement risk, inventory risk if supplier base is small and need to be flexible in responding to changing market condition Talluri S.et al (2009). Selection of supplier is based on multi criteria. Criteria are quantitative and qualitative type; information is uncertain, vague and imprecise. Decision is taken by the group experts from different cross functional area. DM's judgments are often uncertain and cannot be estimated by crisp value. Supplier selection decision is to be taken in uncertain environment. Considering the uncertain environment, human judgment , conflicting criteria, firms

competing strategy, competitive position and the buyer-supplier integration company has to select potential supplier base such that total transaction cost are reduced, concentrate on core internal competencies and strategically outsource non core activities to derive competitive advantage in the market.

Talluri Srinivas et al. (2009) state that, "A manufacturing firm primarily depends on the key supplier and more likely susceptible to operational risk, disruption risks (natural disaster), procurement risk, inventory risk if supplier base is small and need to be flexible in responding to changing market condition". Supplier selection decision is to be taken in uncertain environment by the group of experts from various functional areas of the organization considering multiple criteria, firms competing strategy, competitive position and the buyer-supplier integration level S.Sen et al. (2008). It is evident that, organisation while taking decision for potential supplier base should concentrate on total transaction cost, core internal competencies and strategically outsource non-core activities to derive competitive advantage in the market. En Xie et al. (2012). Liao Chin-Nung et al. (2012) mentions that, "Selecting the right supplier significantly decrease purchasing cost, improves competitive advantage and enhances customer satisfaction." Considering the today's organizational position in the market and business environment conditions, the current methods give sub-optimal solution. Hence to obtain the optimal solution for supplier selection problem the gap is to be filled. The following research gap is identified in the supplier selection problem:

(a) The recent work by Bhattacharya, Arijit et al.(2010); Dursun M.et al.(2012); Dursun M.et al.(2015); Masoud Tavakoli et al.(2015); Ahmad J. Chaghooshi et al.(2015) consider product/service criteria and treat operational or strategic criteria as qualitative though some of the criteria are measurable in nature. None of the literature fully explored and developed the fuzzy strategic relationship matrix of customer requirement and assessment criteria in uncertain environment En Xie et al.(2012). The academician/industry professionals expressed that, long term relationship is essential for strategic integration between buyer and supplier S.Sen et al. (2008), Sheth and Sharma(1997). Thus this research gap is to be filled by developing a supplier selection method under strategic outsourcing conditions for obtaining realistic results.

(b) Talluri S. et al (2004) has proposed data envelopment analysis (DEA) approach for supplier base with supplier development initiative (SDI). Wu desheng (2009) has presented a hybrid model using decision tree for supplier selection. We have not come across

any research paper/literature using decision tree approach for outsourcing decision and supplier base.

(c) Entropy is a measure for amount of information represented by probability distribution and hence can be employed for imprecise information and uncertainty Chan Lai-Kow et al.(2005); Huatuco L.H.et al.(2010). Limited research is noticed using entropy along with other techniques like AHP, TOPSIS, geometric programming, ELLECTRE- III in supplier selection Samanta Bablu (2008), Peide Liu et al.(2011), James Freeman et al.(2015). We have not come across any research paper/literature using entropy and quality function deployment for solving supplier selection problem.

The problem is to be solved by filling the above gaps noticed for optimal solution. Fuzzy set theory is applied in the supplier selection process to consider uncertainty En Xie et al. (2012), imprecise data and human judgment perception. Hence, our research proposes a new methodology to select the supplier in fuzzy environment considering the fuzzy relationship between customer requirement and assessment criteria (operational and strategic criteria) of the supplier and aligning supplier's business strategy with buyer's strategy. The proposed supplier selection methods are simple, easy to use, effective and efficient in selecting right supplier.

2.5.2 Research Significance

Supplier selection is a multi criteria decision making process. Supplier selection decision becomes complex due type of sourcing strategy, multiple conflicting criteria, and imprecise data. In addition the uncertainty and vagueness of the expert's opinion is the prominent characteristic of the problem. So, supplier selection tool is required which is easy to use, effective and efficient in selecting right supplier.

2.5.3 Problem Statement

Study of supplier selection process under strategic outsourcing conditions

2.5.4 Research Objective

The research objectives are derived from the literature surveyed above and also the research gap is identified accordingly. The research objectives are:

1. To analyse the strategic vendor selection process.

2. To develop a strategic vendor selection process in a dynamic environment under strategic outsourcing conditions and uncertainties.
3. To develop strategic vendor selection methods in a dynamic environment.

2.5.5 Scope of Study

It includes detail study of Supplier Selection process in manufacturing organization operating in uncertain environment considering strategic outsourcing.. The study includes the literature review and the exploratory study for understanding the criteria and methods used by the researchers, academicians and professionals to solve the supplier selection problem. The study is to identify the research gap and to develop a efficient method for supplier selection to assist the decision maker in selecting the right suppliers under strategic outsourcing conditions.. The method proposed will be tested in the manufacturing firm for its efficiency and effectiveness.

CHAPTER 3
RESEARCH METHODOLOGY

3.1 Introduction

The issue at hand of having an optimum supplier selection method given the dynamic nature of businesses gave rise to scanning the literature for existing methods and then supplementing them with Fuzzy numbers to enable a better fit.

To enable a new method of supplier selection to evolve it was necessary to adopt an exploratory path of research. After going through the secondary data from literature survey it was clear that different methods and criteria were used by organisations to identify suppliers who would deliver the needed material as per the financial, time, space and technical requirements. However when the organizational leaders, decision makers, influencers and team members of supplier selection process were interviewed (12 organisations were chosen) the varying requirements led to a complex requirement which was amenable to the use of fuzzy numbers and hence led to the proposed model of supplier selection.

The following is a diagrammatic representation of the research process:

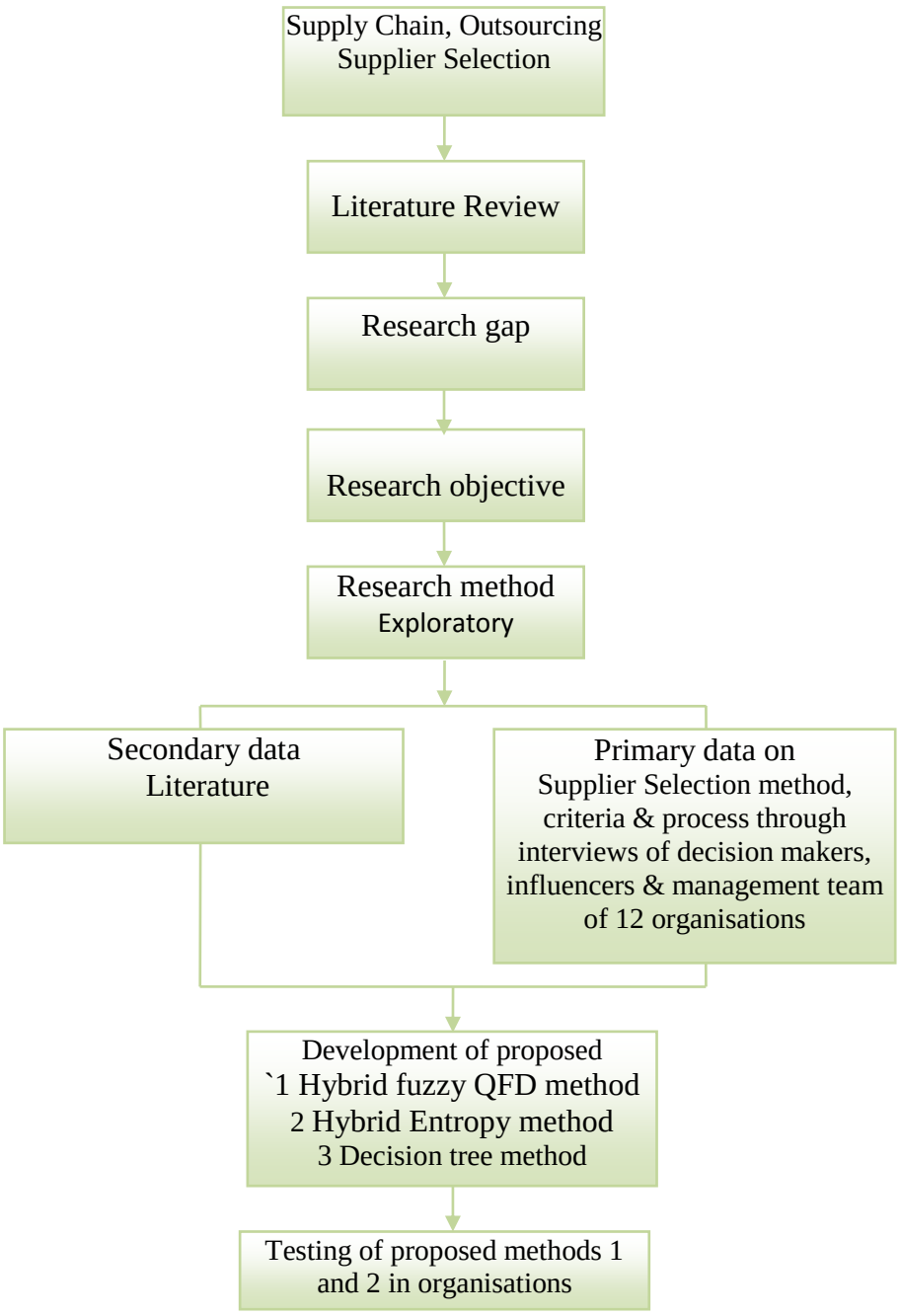


Figure 3.1 Research methodology

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3.2 Research process

1. Exploratory research is adopted to understand the supplier selection processes, supplier selection criteria and methods in the organizations.Furthermore,this is done through unstructured interviews with personnel from 12 different organizations, through a schedule of questions (Annexure C). The open ended discussions helped to know the insights regarding the various criteria preferred by the organisations during supplier selection

process. The visits to the organisations also supplemented the research to understand the perception of decision maker towards the supplier and its selection criteria like quality, delivery, price, service etc.. It is noticed that the supplier does not excel in all criteria; hence the selection of the supplier is based on the relative preference and trade off of criteria made by the decision makers during supplier selection process. Hence supplier selection is a multi criteria decision making problem. Exploratory research helped to understand that, organizations do not follow any supplier selection method. However selection of criteria and supplier selection decision is based on the condition and environment in which organisations operate.

2. Literature of the earlier work done by other researchers helped in analyzing and developing the supplier selection methods as well as designing combination of methods for better results. Literature survey tools used for source of information are journals, books, internet, conference proceedings, research papers, and other publications. Recent papers are reviewed to know the latest development in the research study. refer Table 2.1, Table 2.2 and Figure 2.3 above in chapter 2.. The organisation type, size and its operations are also responsible for supplier selection process, supplier selection criteria and supplier selection methods S.Kumar et al (2009). The information gathered is a part of problem identification and gave significance of research. Literature review gave direction to move ahead with existing methods and techniques for developing new efficient methods to deal with supplier selection problem.

As supplier selection is a practical problem. The primary and secondary data collection is of significant importance in method development phase. The responses were then aggregated to identify the supplier selection process used in the organizations. The data regarding supplier selection processes and the criteria in a dynamic environment was then used in the proposed methods to identify the efficacy of the method to give the optimum results and a supplier selection method that is better than the one used by the organization currently. The proposed methods were tested in the organisations and found to give better results in terms of supplier selection (Annexure D).

CHAPTER 4

DATA COLLECTION AND ANALYSIS

4.1 Introduction

The information and data collected from different organisation is of significant importance for taking supplier selection decision. Based on the response from different organisation and literature survey, information and data is collected for understanding the supplier selection process, supplier selection criteria and methods. The criteria are related to the different functional area of the organizations and supplier evaluation is based on the criteria decided by the buyer and depends on the buyer-supplier relationship. Supplier selection involves personnel from different functional areas of the organisation forming it as a multi criteria group decision making prolem.. The data collection requires involvement of all personnel from different functional areas and from all levels of management in the organisation. The organizations operate in uncertain environment En Xie et al.(2012). The flexibility of the organisation is improved by the supplier so that the organisation fulfill customer demands and customer satisfaction. Based on the exploratory research and literature survey the data collected on the response of organizations is analysed and discussed below.

4.2 Analyze and development of vendor selection process:

4.2.1 Study based on existing literature

Vendor selection process is developed using two approaches. First was the study of existing literature. The result of the vendor selection process depends on the adequacy and soundness of the methodology adopted for the process Bouchard Veronique (1997). K.C.Tan (2001) mentions that, "Purchasing function activities in organization has strong relation with buying process. These activities are: determining the need, selecting supplier, appropriate price, terms and conditions of supply, issuing the contracts or orders, and ensuring proper delivery of products." The need of the product/service is to be satisfied by the competent supplier. It is not the quality product/service, but the skill, knowledge, process and technology associated with the product is purchased. Innovative products/service, end user expectations, market responses set a new focus and agility for the organization to remain competitive and challenge-worthy. The supplier should be able to meet all needs of the organisation, so that the customer is satisfied. Hence the supplier selection process should have the component of assessing the competency level of the supplier. The

organisation than can concentrate on its core activities and outsource all the remaining non-core activities Quinn(1999). Hence supplier selection process includes the actions of outsourcing process. Outsourcing with long term relationship with the supplier has strong performance potential for the buyer and supplier Gustin C.M. et al. (1997); Kotabe M. et al. (2003).The strength of bond between buyer-supplier relationship define the integration level between buyer and supplier, which is required to be assessed in the supplier selection process. In strong bond business partnership exists between buyer and supplier S.Sen et al.(2008); Ghodsypour S.Het al.(1998); Perona, M. et al.(2004); Sheth and Sharma,(1997). To achieve this, supplier should be evaluated using strategic criteria like technology potential, financial position, management culture, production capability, quality management system etc.Ellram(1990), Talluri S.et al. (2004) in addition to operational criteria. Based on the literature, traditional vendor selection process (L.de Boer et al. 2001) should be replaced by strategic vendor selection process. William Ho et al. (2010) prove that, single criteria price/cost is not supportive for supplier selection. Suppliers are evaluated based on multiple criteria. (refer Table 1 above). The problem becomes multi criteria decision making problem, Each of the criteria relates to different functional area, hence experts from different functional area to be involved in the supplier selection process. It is a group decision making problem. According to Insinga and Werle (2000), "In order to do more with less, a company must focus its limited resources on those activities that are essential to its survival and must leverage activities that are peripheral. The result is a greater use of partnerships, collaborations, and simple buying to substitute for in-house capabilities." It is inferred from the literature that, the decision making team comprise members drawn from top management to operational level personnel.

4.2.2 Study based on exploratory study

Next method adopted is to do exploratory study, by visiting organisations in Goa with aim to understand procedure of supplier selection process, criteria used in supplier selection by the organisation. In all 12 organisations were visited for this study. The names of the organizations are not mentioned for the confidentiality. The details of the organization are shown in the Table 4.1.

Sr. No.	Industry	Type	Product/Production	Suppliers	No. Of Products	Selection	Official
1	Shipping	Large Scale	Customi Product. Project Type	FDL	Custom made	Purchase Finance Production	DGM Material
2	Shipping	Large Scale	Customi Product. Project Type	FDL	Custom made	Supplier List and Govt Procedure	DGM Material
3	Ophthalmic Lenses	Medium	Batch/Mass Production	FDL	More Than 4	Individual Group	Manager Production
4	Corrugated Products	Small/ Medium	Batch/Mass Production	Domestic	More than 4	Marketing/Purchase Production and M.D.	Production Manager / Director
5	Fibre Glass	Small/ Medium	Batch/Mass Production	FDL	More than 4	Purchase Finance Production	HOD-Purchase and GM
6	Elevator Components	Small/ Medium	Batch/Mass Production	FDL	More than 4	Group Individual	Director Manager Engineer
7	Telecommunication	MNC		FDL	More than 4	Group Individual	Purchase Officer
8	Pharma	MNC	Batch Production	FDL	More than 4	Group Individual	HOD-Procurement Team
9	Manufacturing	MNC	Custom Product Capital Goods	FDL	Custom made	Group Individual	Manager Purchase
10	Manufacturing	Medium	Custom Product Capital Goods Batch Production	FDL	Custom made	Group Individual	AVP Product Manufacturing AVP,Process & Engg AVP Metering Measurement
11	Manufacturing	Medium	Batch/Mass Production	FDL	More than 4	Group Individual	Director
12	Manufacturing	Medium	Batch/Mass Production	FDL	More than 4	Group Individual	Manager Purchase

F D L : Foreign , Domestic, Local

Table 4.1 Visit to organization for understanding supplier selection process

The scheduled visits were done for open ended discussion. It is found that all organisations follow group decision making approach for supplier selection. The decision maker group comprises of 3 to .6 members out of which members from **quality, production and purchase (commercial) are common** in all the companies considered for study. It is expressed by the organisation's personnel that 3 to 5 suppliers can be controlled and monitored comfortably. All organisations stress on quality, delivery, quantity and price at the initial stage of supplier selection process. The organizations consider strategic criteria like financial stability, quality system, manufacturing capacity/planning etc. Some companies

insist on regulation compliance, no child labor employment etc. and willing to develop/maintain long term relationship with the supplier. Based on the company visits the, the criteria the organizations generally consider are give in Table 4.2 below:

sr.no.	Supplier selection criteria	% response
1	Quality	100
2	Delivery	90
3	Price	80
4	quality system	70
5	manufacturing facility	70
6	Communication	70
7	Reliability	60
8	financial position	60
9	manufacturing capability	60
10	Quantity	60
11	Service	50
12	Attitude	50
13	Technical level	50
14	Flexibility	50
15	geographical location	50
16	cost reduction	40
17	Relationship	30
18	inspection facility	30
19	compliance response	30
20	commercial terms n conditions	20
21	Confidential	20
22	Management	20
23	Reputation	10
24	product range	10
25	customer base	10

Table 4.2: Response of companies on supplier selection criteria

Companies extend their support for developing tools and dies for manufacture of product, quality/production personnel visit the supplier premises to check the processes and for technical support. It is observed that, one company insisted on the confidentiality of the design and drawing from the supplier while selecting the supplier. Two companies are such that, their chemical formulation process is strictly kept confidential; only it is with general manager and head of the company in order to remain competitive in the market. However simple machining activities are outsourced to the nearby SSI units having expertise to minimize cost of special setup, transportation cost, transit risk, quick access to supplier premises. The procedure followed by each organization is as per their suitability and convenience. Based on research the supplier selection process followed by the different organizations is consolidated in nine steps as shown in Table 4.3 below:

Phase	Supplier selection process
1	Product requirement/specification given to supplier RFI
2	Supplier submits detailed quotation: product detail and company detail
3	Buyer visit supplier site for verification of information
4	If supplier meet requirement than termed as potential supplier
5	Commercial negotiation : price, payment term, delivery period etc.
6	Fill vendor registration form
7	Sample product inspection 100% inspection
8	If sample accepted order is placed.
9	Monitor the supplier. Check supplier processes periodically.

Table 4.3: company supplier selection process

Based on the literature review and the visit to companies, supplier selection process is divided in to two parts. The first part is the selection phase where supplier is evaluated for selection and the second phase is the post selection phase which involves evaluation, monitoring and control of the supplier for maintaining the consistency in the supply as per requirement. The supplier selection process is shown in the Figure 4.2 below.

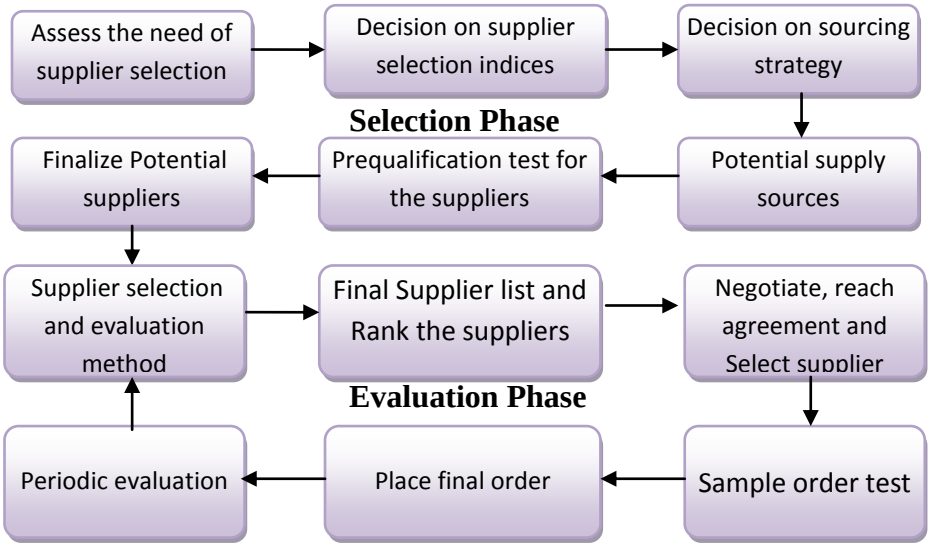

Figure 4.1 Simplified supplier selection and evaluation process

Based on the company visits it is found that the organisations interested in building relationship with supplier, outsourcing the activities and initially verifying the supplier details for capacity and capability of supply of product/services. Once the buyer is satisfied in all respect than only the supplier is placed in the final supplier list and orders are placed on these suppliers to supply the product/service. The companies are focusing on their core

activities and remaining activities which companies feel not important are outsourced and performed by the suppliers of their choice in whom the company has faith and confidence. Some statements of the company executive perception towards supplier are reproduced here:

1. General Manager says that, "Today shorter delivery means more business and if supplier performs well than he will be able to perform well to his customers"

2. Purchase executive statement is, "Vendor should walk with us – Vendor say we are with you"

3. Executive statement is, "Today it is not procurement of goods but also procurement of services of the supplier"

4. General Manager statement is, "Strategic vendor is a problem solver and very close with us, otherwise he is only supplier for items for us,"

5. Executive statement is, "Nowadays most companies look for strategic source. Strategic source is a close supplier, meeting all our requirements and having flexibility to meet changing needs of buyer"

These statements can be supported by the literature. According to Insinga and Werle (2000), "In order to do more with less, a company must focus its limited resources on those activities that are essential to its survival and must leverage activities that are peripheral. The result is a greater use of partnerships, collaborations, and simple buying to substitute for in-house capabilities." The companies view the supplier as an extension of their facilities and capabilities at supplier premises, where supplier is fully responsible for outsourced processes and its corresponding risks. Hence it is concluded that supplier selection process is strategic activity encompassing strategic outsourcing process. It is observed that, most of the companies prefer to select and evaluate the potential and preferred suppliers using group decision. The members of the decision team are from different functional departments of the organisation. Hence supplier selection decision is a group decision making problem. Company officials expressed the need of supplier selection process criteria and strategic outsourcing criteria. It is expressed by the company experts that, *periodic monitoring of the supplier performance is essential to remain competitive.* However due to resource constraints the organization find difficult to achieve desired targets (production, financial etc.). Company personnel expressed that, *organisation resources are improved due to supplemented capacity and capability of resources of selected suppliers*. Further it is expressed that, *supplier is required to follow the production schedule of the buyer and communicate frequently with the buyer.* Efforts from supplier are required to support the organization to achieve the desired performance target to remain competitive in the market.

The following supplier selection process criteria and strategic outsourcing criteria based on research study are proposed as a guideline for supplier selection or strategic outsourcing decision. Table 4.4 and Table 4.5

Strategic Outsourcing Parameters			
1	Quality System	8	Quality Improvement Measures (Kaizen etc.)
2	Production facility, and capability	9	Technology development potential
3	Technical expertise and capacity	10	Financial position
4	Management Structure , Goals and directives	11	confidentiality and security
5	Operational control	12	Flexible contract
6	In-plant effective training facility	13	CSR approach
7	Research and development initiative	14	Competency level

Table 4.4: Strategic outsourcing criteria

Criteria of strategic supplier selection process			
1	Quality	12	communication
2	Delivery	13	Commitment
3	Price	14	Past Business Experience
4	Testing and Calibration	15	Organizational culture
5	Geographical proximity	16	Reliability
6	Reputation	17	Response time
7	Service facility and response	18	Customer base
8	Attitude	19	Order cycle time
9	Packaging facility and methods	20	Product range
10	Procedure compliance approach	21	quantity
11	Employee relations	22	Industry knowledge

Table 4.5: Criteria of supplier selection process

4.3 Development of vendor selection methods:

4.3.1 Based on the literature review and exploratory study

There is extant literature on vendor selection methods. Figure 2.3 show the classification of available methods up to 2015 as per the literature referred for this research. Supplier selection methods are the models or approaches used to conduct the selection process (Li et al. 1997). The methods chosen are extremely important to the overall selection process and can have significant influence on the selection results. It is important to understand why a firm chooses one method or combination of different methods over another. Usually when the company sets out to develop or choose a supplier selection method, the result is a combination of several different methods with different strengths suited to meet the company's specific selection needs. Therefore it is important to explore a range of different selection methods.

Traditional supplier selection and evaluation methods are all too often based on quoted price, which ignore the significant costs associated with ordering, expediting, receiving, inspecting, and using purchased parts and materials. In single criteria one considers the cost as most important and selects the least cost/price supplier Timmerman (1986).

However vendor selection problem usually involves more than one criteria and these criteria often conflict with each other. These criteria are either qualitative or quantitative in nature. The scoring models like weighted-point plan or categorical methods are used Dickson (1966). The vendor with maximum score is selected. Ghodsypour and O"Brien(2001) developed mixed integer non linear programming method to minimize cost of logistic, inventory, ordering cost in supplier selection. However the vagueness in information related to criteria, these deterministic models are unsuitable to obtain an effective solution for supplier selection problem. In the literature, there are research papers on supplier selection methods in order to handle imprecise information and uncertainty in supplier selection models using Analytic hierarchy process(AHP), Analytic network process(ANP),Technique for the order performance by similarity to initial solution(TOPSIS),Multi attribute utility technique(MAUT). (Nydick and Hill,1992;ozeden Bayazit,2006; Palanisamy P. et al.(2011); Omid Jadidi et al.(2010)). AHP is introduced by Saaty(1980) with wide application in the literature and ANP is the extended version of AHP. AHP can handle qualitative and quantitative information and human judgment in the problem. Ghodsypour and O"Brien(2001) developed integrated AHP-LP(linear

programming) model to consider qualitative and quantitative criteria in supplier selection problem. The authors have used fuzzy set theory to deal with uncertainty William Ho et al.(2010). In fuzzy programming, a decision maker (DM) is no longer forced to formulate the problem in a precise and rigid form. In a real situation, decision makers do not have the exact and complete information related to decision criteria and constraints. For supplier selection problems the collected data does not behave crisply and they are typically fuzzy in nature due to linguistic interpretation. Sarkis and Talluri(2002) use the ANP approach using strategic criteria for supplier selection problem. Talluri and Narsimhan(2004) use strategic criteria in data envelopment analysis (DEA) to find the supplier base. However based on the research it is found that the relationship exist between operational criteria and strategic criteria. This relationship can be established by building house of quality in quality function deployment process. Some authors propose linear weighting models (LWM) in which suppliers are weighted on several criteria and in which these ratings are combined into single final score and it is quick, easy and least costly to implement. We apply LWM to supplier selection problem to analyse quantitative data.

According to exploratory study, it is found that, every company has its own way of selection of supplier and no specific supplier selection method is used. The company officials expressed that, quality, delivery and price are important and used by them in supplier selection. It is observed that, Criteria from 4 to 15 are considered by 50% to 70% companies which include strategic criteria. Criteria from 16 to 19 have 30% to 40% importance and remaining criteria has 10% to 20% importance.(Table 4).

Based on literature and the exploratory study, supplier selection process begins once the outsourcing decisions are finalized. The focus of orgnisations is on long term relationship with supplier S.Sen et al.(2008), Ghodsypour SH et al.(1998), Perona(2004), Ellram (1994). The strategic criteria have the potential for achieving long term buyer-supplier relationship Sheth and Sharma(1997). The supplier selection decision is taken in the uncertain environment where in human perception and judgment, imprecise information of qualitative supplier criteria and quantitative supplier criteria, purchasing situation, competitive strategy of buyer, buyer-supplier relationship or type integration level and varied customer requirements exists. The individual or hybrid methods developed by the authors are mostly case specific William Ho et al.(2010). A generic systematic approach is required for selection of supplier in uncertain environment.

In this research three methods are proposed, 1. The decision tree method for internalizing or outsourcing decision and also decides the supplier base. 2. The supplier

selection using hybrid fuzzy QFD in uncertain environment having qualitative and quantitative criteria. 3. Hybrid entropy-QFD method for supplier selection.

The method 2 and method 3 proposed use the house of quality to build the relationship matrix between customer requirement and the assessment criteria for the supplier Bhattacharya, Arijit et al.(2010); Dursun M.et al.(2012); Dursun M.et al.(2015); Masoud Tavakoli et al.(2015); Ahmad J. Chaghooshi et al.(2015).The qualitative and quantitative criteria proposed are separated for better evaluation of the supplier by the buyer. However the qualitative criteria should also include strategic criteria as the companies expressed their interest for long term relationship for competitive advantage with the supplier. The literature also focus on long term relationship and shift in the buying behavior of the supplier from domestic sourcing to global sourcing by the organization Ellram (1994) ,Sheth and Sharma(1998), S.Sen et al (2008). Considering this we propose general qualitative criteria and quantitative criteria applicable to any organization based on the literature review and exploratory study. Further proposed criteria are referred as customer (buyer) requirement and the assessment criteria (evaluation factors) in the analysis. The proposed criteria with description are shown in the Table 4.6 to Table 4.10 below:

qualitative criteria	quality, reliability, flexibility, stability, capability, availability & sustainability.
quantitative criteria	price, quantity, proximity, credit time, delivery time

Table 4.6 Customer (buyer) qualitative and quantitative criteria requirement

Sr. No.	Customer Requirements Quantitative	Abbriv	Description
1	price	PR	The selling price offered by the supplier.
2	quantity	QN	The number of products supplied by the supplier.
3	proximity	PX	The distance of supplier's operation site.
4	credit time	CT	The payment time allowed by the supplier.
5	delivery time	DT	The time taken by supplier to fulfill the supply order.

Table 4.7: Description of customer (buyer) quantitative criteria requirement

Sr. No.	Customer Requirements Qualitative	Abbrev	Description
1	Quality	Q	Suppliers are responsible to supply product conforming to specification.
2	Reliability	R	The supplier should be reliable with respect to product quality, supply quantity, delivery time, security and maintaining confidentiality of information, data, core competency, processes etc.
3	Flexibility	F	The supplier should be flexible for demand changes like supply volume, delivery time, credit payment time etc.
4	Stability	S	Strong financial backup, stable management e.g. cordial employee-employer relationship, strong business foundation, number of years in business
5	Capability	C	risk mitigation ca`pability, strong technological setup, problem solving ability,
6	Availability & Sustainability	AS	Supplier should be ready for service and support to buyer and customer round the clock, quick responsiveness.

Table 4.8 Description of customer (buyer) qualitative criteria requirement

Sr. No.	Assessment Factors	Abbriv	Description
1	Standard Quality Management System	SMS	Quality management system(ISO 9001), environment mamagement system(ISO 14001), Occupational health and safety system,18001), Just in time(JIT),5S.
2	Testing Facility and Inspection	TFI	Inspection methods(sampling methods or 100% inspection), production part approval process(PPAP)
3	Organisational Structure and Management	OSM	management stability,management culture, management initiative for new methods,
4	Business Experience	BE	number of years in business
5	Human Resource	HR	knowledge and skill, attrition rate, training and dvelopment methods,
6	Enabling Technology	ET	phone,fax,mobile,electronic data exchange(EDI), email, kanban, display boards,
7	Planning and Control	PC	material requirement planning(MPR),manufacturing resource planning(MRP-II),inventory managemnt, scheduling and sequencing
8	Latest Technology	MT	use of technology in design(CAD softwares), manufacturing (CNC,FMS etc) , inspection(CMM), material handling systems (Robots,AGVs),maintenance methods, and business processes
9	Production Layout	PL	product,process,mixed or fixed layout
10	Manufacturing Facilities	MF	machinery,equipments and tools , utility equipments
11	Machinery and Equipments	ME	conventional, automatic or advanced, number of year in use, machinery condition.
12	Product Range	PR	potential to manufacure wide range of products
13	Business Volume	BV	Annual Turnover
14	Reputation	RP	market share,listing in stock market, brand name ,catalogues, customer base.
15	Innovation/Improvement Potential	IIP	initiative to use Kaizen,total quality management, quality circles or new techniques to improve quality, cycle time reduction. New products,Implementation of cost reduction measures.
16	Problem Mitigation Techniques	PMT	interest in statistical quality control,statistical process control,f ailure mode effect analysis,pareto distibution, six sigma ,
17	Research and Development setup	RND	testing facility, research environment, earlier research outcomes, dedicated persons, intrest to invest in research,design software
18	Service support	SS	customer support, response time, service quality.
19	Risk management	RM	potential to control union risk,supplier risk,demand risk, manufacturing risk, information risk
20	Standard practices	SP	standardisation of processes, efforts for patents and trade marks,
21	Key skills and Expertise	KSE	external expert support(contract or visit), degree of internal expertise (internal key skills)
22	Relatiionship	RRA	type of buyer/supplier relationship, supply exchange between buyer and supplier, buyer/supplier investment etc
23	Security and Confidentiality	SC	security measures taken for confidentialty of information of core competecy,core processes, customer data,
24	Coding system	CS	barcode,colorcode,tags for ease and accessability
25	Compliance and Response	CR	terms and conditions, rules and regulation, legal,
26	Financial Position	FP	support of financial institutions, credit offering capacity(limit and period,) assets and liabilities.

Table 4.9: supplier assessment criteria

Sr. No.	Assessment Factors Supplier Strength	Abbriv	Description
1	Quality Strength	QS	standard quality management system, testing facility and inspection, standard practices
2	Management Strength	MNS	human resource,organisational structure and Management
3	Support strength	SS	Key skills and expertise,problem mitigation techniques,service support
4	Planning strength	PS	planning and control, compiance
5	Technology strength	TS	Technology, innovation and improvement potential, research and dvelopment setup
6	Financial strength	FS	Business volume,financial position
7	Manufacturing strength	MFS	production layout, manufacturing facilities,machinery and equip0ments
8	Other strength	OS	enabling technology,security and confidentiality,coding systems, relationship,reputation,riskmanagement,business exprrience,product range,safety methods

Table 4.10: assessment criteria with focus on supplier strength

This study also proposes:

a. General algorithm for Outsourcing and Supplier Selection process.

b. Supplier selection algorithm of Hybrid fuzzy QFD method.

c. Guideline algorithm for Risk Assessment during Outsourcing.

4.3.2 Quality function deployment (QFD)

Global competitiveness is a concern to the organizations, which seek for higher quality of product and service to the customer and continuous improvement due to advancement in technology and dynamic environment. Total quality management offers many techniques for improvement of quality and productivity. QFD is one of the techniques, which aims for customer satisfaction from product design or improvement to product manufacturing through all the phases of the process. QFD employs cross functional team to ascertain the customer needs or desire of customer called voice of customer and translate them into product design through structured and documented framework. As per Karsak E.E. et al.(2002), “QFD helps companies to maintain competitiveness using three strategies: decreasing cost, increasing revenue and reducing the time to produce new product or services(cycle time reduction).” Taghizadeh Houshang et al. (2013) state that, “comparison with traditional requirements of engineering methodologies, benefits of using QFD are such as: Transfer the voice of the customer into the process; waste disposal and creates flexibility; supports customer-oriented

decisions of design process; determines objectives and focus on the essential; takes interests of various groups into account; systematizes communication and provides for continuity and responsiveness; creates transparency and makes coordination processes easier in the organizations; and speeds up development process." The fundamental concept of QFD is to translate the voice of customer into engineering characteristic and subsequently into parts characteristics, process planning and production requirement. Dursun M et al.(2015) mentions that, "the essence of QFD is to translate the desires of customers into technical attributes (TAs), and subsequently into parts characteristics,"

In order to establish the relationship between these phases QFD requires the matrices for each phase and each of these matrices is termed as house of quality (HOQ). The final HOQ gives the product as per customer requirement. The data is collected to build the matrix by survey, direct customer interaction, warranty reports etc.. Customer needs are "what the customer wants" and how these customer needs can be satisfied is decided by the team while building the matrix. The two dimensions of matrix are customer requirement 'WHAT' and engineering requirement 'HOW'. At each phase single matrix is constructed to obtain the stage result. A chain of matrices is built using the result of the previous phase matrix. The end phase gives the desired solution Figure 4.2.

QFD method follow KAIZEN concept of continuous improvement. Product improvement on regular bases requires involvement people of all functional areas like design/development, Planning, manufacturing, quality, sales, marketing, customer care etc. Each section actively involves in the process to reach a balance and rational decision. This helps in free and frank transparent communication and discussion between the members at each phase of translation. It is an opportunity for each one to express their views and share their hidden knowledge for effective translation from 'WHAT' to 'HOW'. The discussion helps for understanding weaknesses, strengths and constraints of the organization. Management can plan the strategy and decide about the requirements so that the customer's needs are satisfied. As mentioned by Masoud Tavakoli et al. (2015), "QFD advantages include higher customer satisfaction, greater customer focus, shorter lead time, and knowledge preservation." Taghizadeh Houshang et al. (2013) mentions QFD functional areas such as , "customer needs analysis, product development, quality management, product design, planning, decision making, engineering, management, teamwork, timing, and costing."

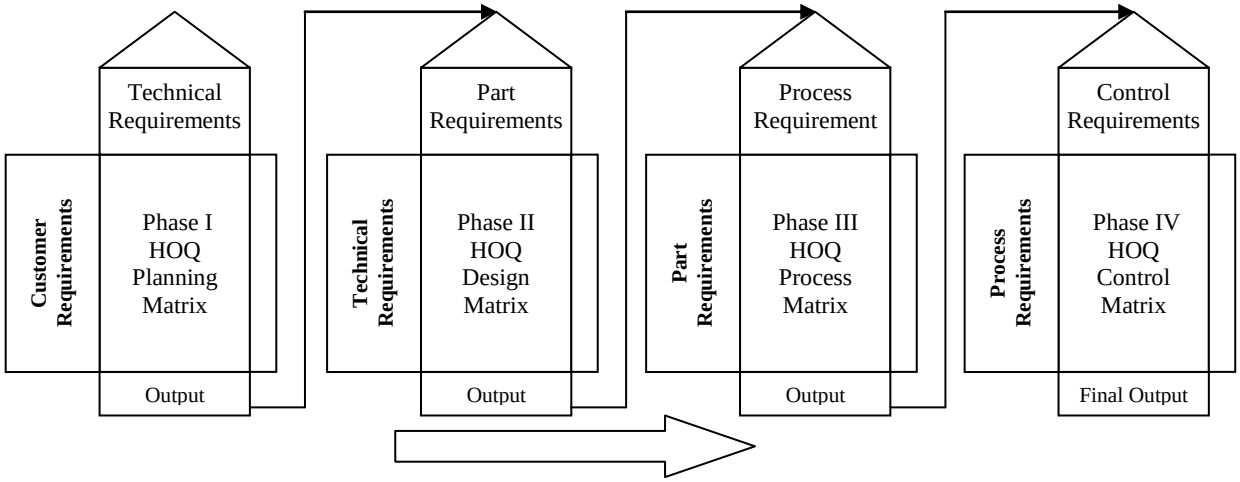

Figure 4.2 QFD process

The important activity while using of QFD is to build house of quality (HOQ) precisely Figure 4.3. This activity includes determining customer requirement weight, correlation matrix of engineering requirements, and building relationship matrix between 'WHAT' and 'HOW'. The main intent of HOQ is to convert "WHATs" into "HOWs".

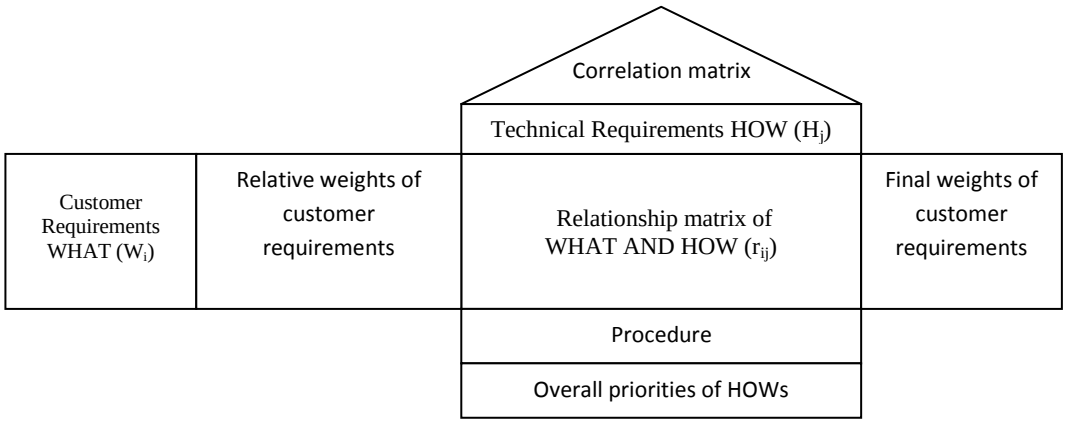

Figure 4.3 House of Quality

4.3.2.1 Steps in building house of quality.

Step 1: The critically assess the customer expectations and decide which requirements are essential for customer satisfaction. List the customer requirements and term as 'WHATs.' which are obtained from business research and analysis.

Step 2: Decide the technical requirements (HOW) based on customer requirement (WHAT).

Step 3: Build a relationship matrix of customer requirements and technical requirements considering the correlation between the two, which expresses how much each HOW affects each WHAT.

Step 4: Assessment of market strength of product by customer in relation to competitor product and customer wants. Assign important rating to each want by the customer. Market evaluation is compared with technical requirement by the organization. Relative importance of WHATs denotes relative weights of the WHATs;

Step 5: Clearly benchmark each technical requirement. This benchmark is termed as target value. Target values depend on customer importance level and competitive position in the market.

Step 6: Correlation matrix of WHAT (inner dependence of WHAT), Correlation matrix of HOW (inner dependence of HOW).

Step 7: Select the best solution from available solution from for implementation.

4.3.2.2 QFD in supplier selection process:

Considering the strength of QFD many researchers have utilized QFD for supplier selection Bhattacharya, Arijit et al.(2010); Dursun M.et al.(2012); Dursun M.et al.(2015); Masoud Tavakoli et al.(2015); Ahmad J. Chaghooshi et al.(2015), Taghizadeh Houshang et al. (2013). Though the earlier studies developed methods for supplier selection process, further work is required to include imprecise information related to importance of purchased product characteristics, relationship between purchased product characteristics and supplier evaluation criteria and interdependence of supplier evaluation criteria within the analysis. The proposed methodology uses two HOQ matrices for supplier selection.

Based on literature and company discussion relationship exists between input and output parameters. The QFD process in supplier selection developed comprising of two HOQ phases as shown in Figure 4.4 below:

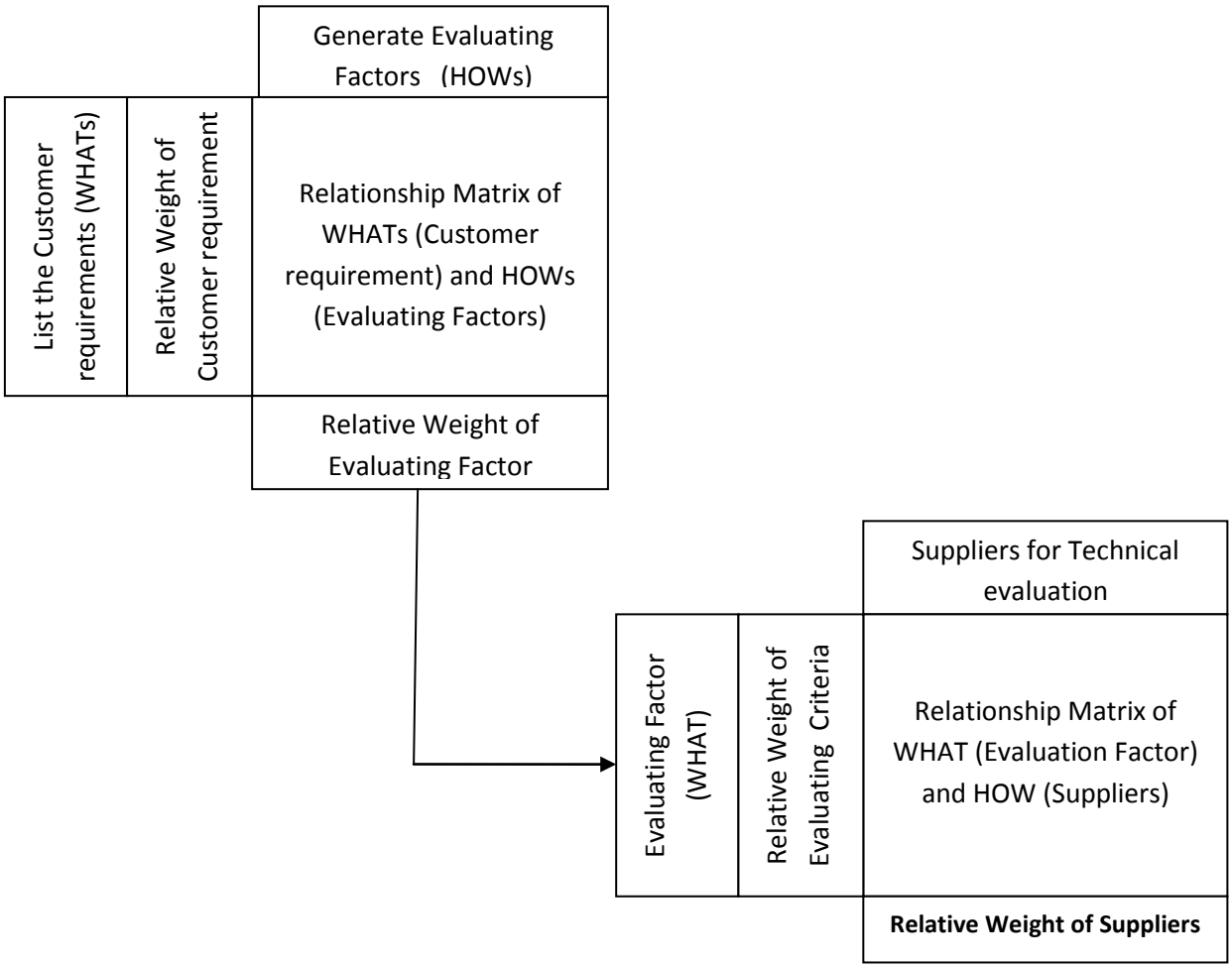

Figure 4.4: House of Quality (HOQ) for Supplier Selection

4.3.2.3 Building house of quality for supplier selection

Phase 1:

1. List the customer or buyer requirement criteria essential for the company.
2. Decision maker team to rate criteria based on its importance to the organization and find the weight of each criteria.
3. Decision maker to prepare the list of criteria on which the supplier is to be evaluated. These criteria are responsible for meeting the customer requirements,
4. Build the relationship matrix of customer requirement and assessment criteria.
5. Find the weight of each evaluation criteria.

Phase II

1. List the number of supplier to be evaluated on assessment factors.
2. The decision maker to assign weight to evaluating factor of each supplier.
3. Build the relationship matrix for evaluating factor and supplier.

4. Find the weight of each supplier under consideration.

4.4 Analytical Hierarchy Process (AHP) in supplier selection process

In the real world the decision maker has to choose best alternative from the set of alternatives. These alternatives are evaluated on multiple criteria and sub-criteria. As the number of criteria increases the process of evaluation becomes tedious and the decision making problem becomes complex. Saaty (1980) introduced the analytical hierarchy process (AHP) to overcome this difficulty. It is a structured methodology to deal with complex decision problems Figure 4.5.

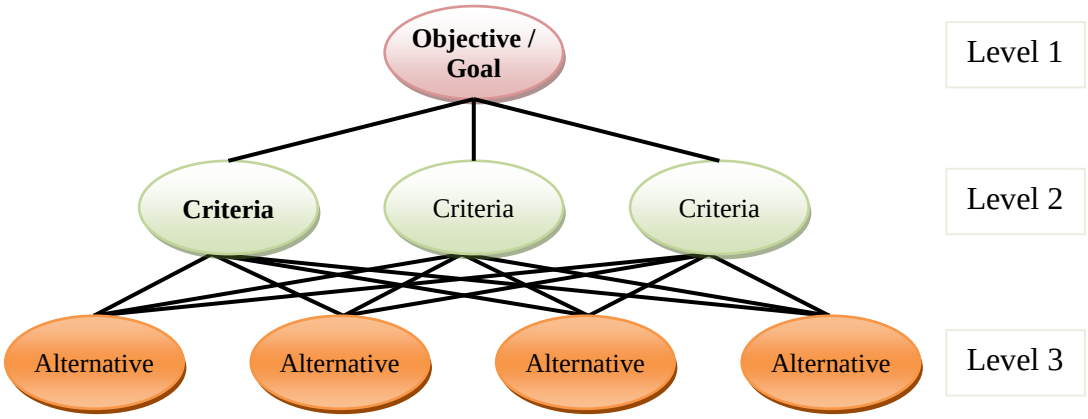

Figure 4.5 Building Hierarchy structure for decision goal Saaty(1980)

The researchers are attracted to this method for its mathematical properties and ease of obtaining input data. The goal for the analysis is at the top of the structure followed by criteria at the lower levels. The lowest level in the structure is the decision alternatives. AHP is comprised of three steps 1. Decompose the multi criteria problem into different hierarchical levels with manageable criteria/sub criteria at each level. 2. Comparative analysis based on pair wise comparison is done to derive the priorities of criteria at each level. 3. The synthesis of priorities of criteria is performed to obtain overall priorities of the decision alternatives. The steps of AHP process in supplier selection is as follows

1. The plant head constitute the decision team for deciding the goal, alternative suppliers, intermediate levels and the criteria/sub criteria for supplier selection. The plant head compare the decision team members. Than team decompose the problem and constructs the hierarchical structure by connecting the relationship links.

2. The pair wise comparison is performed and the results are presented in matrix form to evaluate the relative importance of alternatives. The decision matrix of m

alternatives and n criteria take the form D= $[d_{ij}]_{m \times n}$. The elements {dij} signify the rating of the ith alternative in respect to the jth criteria. For a square matrix for n criteria, if n (n - 1)/2 comparisons are consistent then the elements {aij} will satisfy the conditions: *a*ij = 1/*a*ji and *a*ii = 1 with *i, j*. Such matrices are constructed for all sets of nodes of the AHP model. In the comparison matrix each element represents the degree of preference of one element over other. The weights determined by pair wise comparison are more reliable than obtaining directly, because it is easier to make a comparison between two attributes than make an overall weight. The ratio scale is used for deciding priority. Saaty's 9 point fundamental scale generally used for the comparison is:

Verbal Judgment	**Definition**	**Explanation**
1	Equal Importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one activity over another
5	Strong importance	Experience and judgment strongly favor one activity over another
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	For compromise between the above values	Sometimes one needs to interpolate a compromise judgment numerically because there is no good word to describe it. Provides additional level of discrimination
Reciprocals: If activity i has a specific numerical rating with respect to activity j, then j has the reciprocal value when compared to i		

Table 4.11 Saaty's 9 point comparison scale (Saaty(1980); Nydik & Hill(1992))

As suggested by Saaty(1980) the test of consistency is performed,

"For each matrix, priority vector is derived as the normalized principal eigenvector. Find the priority weight of alternatives using equation 4.1

$AW=\lambda_{max} W, \quad W= (w_1, w_2, w_3, \ldots. w_n)^T$ (4.1)

Where A is an n dimensional comparison matrix, λ_{max} is maximum eigen value. of A and W is the eigenvector corresponding to λ_{max}.

Redundancy of pair wise comparisons generates the problem of inconsistency. Test of consistency is a critical step in the AHP and should be performed for each matrix.

1. Consistency index (C.I.) is defined to measure the inconsistency within the pair wise comparison matrix A

$$C.I = \frac{\lambda max - n}{n-1} \quad (4.2)$$

2. Consistency ratio C.R. is used to measure the degree of C.I. by the following equation:

$$C.R = \frac{C.I}{R.I} \quad (4.3)$$

Where, R.I. is the random consistency index, its value is related to the dimension of the matrix, listed in Table 4.12.

N	1	2	3	4	5	6	7	8	9	10
R.I	0	0	0.52	0.89	1.12	1.26	1.36	1.41	1.46	1.49

Table 4.12: Random consistency index Saaty (1980)

C.R. < 0.10 is acceptable inconsistency level and the eigenvector w is considered as weight vector after normalization." Otherwise, the comparison matrix is reconstructed again i.e. the respondent is required to revise his judgments until the acceptable level of consistency of CR<10% is obtained. One of the general principles of constructing the hierarchy states that no more than 7+/-2 elements (a so called „magical number") should be considered in one group (node), otherwise the inconsistency of judgments could be very high Prusak A.et al. (2013).

Global priorities are found multiplying the priority of the criterion with respect to the goal. Global priorities for sub-criteria are derived as a multiplication of their individual priorities by the priority of the relevant criterion. Overall priorities for the alternatives are calculated by adding their global priorities. The alternatives are selected based on the priority obtained. The alternative with the highest priority is placed at the top and remaining in the descending order of priorities. The easiest way to calculate priority vector is to use the relevant software, such as Super Decisions or by use of spread sheets using three methods:

matrix multiplication, arithmetic mean and geometric mean. The most frequently used method is geometric mean.

Advantages of AHP:

1. Hierarchical structure assists to assess the effect of priority changes at each level.
2. Addition and deletion in the structure do not affect the performance of AHP method.
3. Monitoring of supplier performance is possible by buyer on regular basis.
4. Easy to rank and rate the supplier due to weight calculation in AHP.
5. Importance is given to experts experience and judgment in decision making. And hence qualitative and quantitative criteria can be simultaneously considered in the AHP.
6. It provides a mechanism for checking the consistency of the evaluation measures and alternatives.
7. AHP approach by integrating improved managerial decision making.

Limitations of AHP:

1. Use of statistical method makes the process complex and tedious.
2. AHP process cannot handle risk and uncertainty because relative importance of criteria affecting suppliers' performance is known with certainty
3. It is time consuming process. Team member take time to reach consensus.
4. AHP works on pair wise comparison. Insufficient information lead invalid comparison and unrealistic results.
5. AHP method decomposes the problems into a various subsystems and need to do the pair-wise comparisons, so sometimes it is a lengthy task. Whole process has to be repeated, when a new criterion is added.
6. AHP method solves only problems with a hierarchy where there are lower level elements that depend on the higher-level elements, so if the problem cannot be built hierarchically, this method is not valid.
7. The major limitation is the scale use to evaluate criteria and alternatives. Sometimes, the decision maker might find difficult to distinguish among scales and conclude, whether one alternative how much time more important than other. Here human judgment, experience and insight of the subject play important roles. Different decision makers will have different values for the same comparison. AHP cannot

take care of uncertainties and imprecision inherent in the problem. This is overcome by using the triangular fuzzy numbers in the Saaty scale and called as fuzzy analytical hierarchy process (FAHP).

8. The process of evaluation becomes complex and tedious as the order of comparison matrix increases.

The supplier selection is a group decision making process. The decision group comprises of experts from different functional area of the company. The selection of the decision team member is done by the head of the organization based on the experience, authority, responsibility and the position level in the organization. The pair wise comparison matrix is constructed for supplier for assessing the weight to each supplier involved in the supplier selection decision process. The consistency test is performed for assessing the decision of organization head. FAHP is used for evaluation of weight of each decision maker.

4.5 Fuzzy set theory and fuzzy numbers

In real world the information obtained is insufficient and vague. The decision capabilities are improved by using fuzzy set theory pioneered by Zhadeh (1965) while gathering imprecise or vague information. It is difficult for the decision maker to quantify such information precisely in a complex or ill-defined problem. However, linguistic variable is usually defined based on the nature of the problem. As per Chen L.H. et al. (2010), "linguistic terms are used to compare the evaluation criteria/sub-criteria because of their intuitiveness and ease of use in expressing decision makers' subjective assessments, and to reflect the imprecision of the decision-making nature." The judgment is not precise but close to reality and is associated with probability.

The fuzzy set theory overcomes imprecision and uncertainty inherent in human judgment by the use of linguistic term, linguistic variable and degree of membership. Chen L.H. et al.(2010) mention that, "the determination of the membership function of a linguistic term for a particular linguistic variable is generally based on three factors: (1) the decision makers' previous knowledge of the linguistic variable, (2) simple geometric forms having slopes (triangular, trapezoidal or s-functions) as per the nature of the variables, (3) trial and error learning processes." The value of membership function represents the degree of membership of x in fuzzy subset Ã of universe of discourse X in the interval (0,1). The fuzzy opinions of the decision maker are represented as fuzzy numbers. There are different types of fuzzy numbers, each one having its own suitability for analyzing the decision

making problem. The membership function of TFN is shown below Figure 4.6. A fuzzy number $\widetilde{M}$ must possess three important properties:

(1) $\widetilde{M}$ must be normal fuzzy set.

(2) The alpha level M(α) must be closed for every α ϵ (0,1).

(3) The support of $\widetilde{M}$, M (0^{+}), must be bounded.

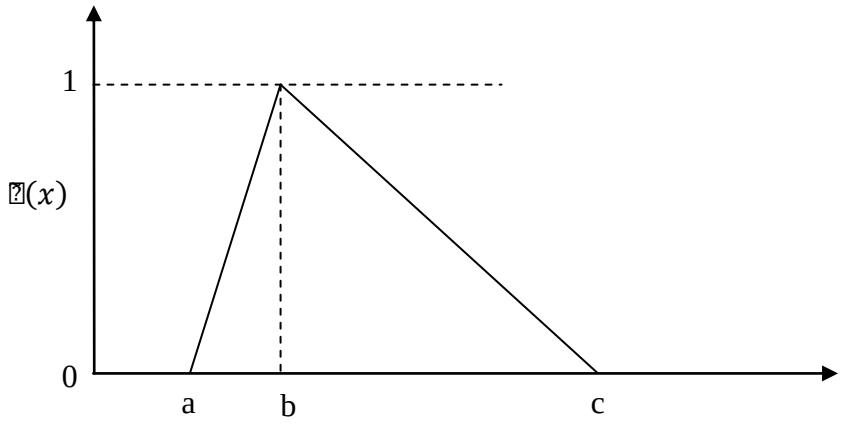

Figure 4.6 Triangular fuzzy number

$$□(x) = \begin{cases} 0, & x < a \\ \dfrac{x-a}{b-a}, & a \le x \le b \\ \dfrac{c-x}{c-b}, & b \le x \le c \\ 0, & \text{Othewise} \end{cases} \qquad (4.4)$$

The linguistic variable are not mathematically operable, to overcome this difficulty each linguistic variable is transformed into a fuzzy number using a conversion scale Zadeh (1965); Saaty(1980);Chen L.H. et al (2010); Shan-yan Huang et al.(2014); Sivrikaya B.T. et al.(2015); Krishnendu Shaw et al.(2012); Bhattacharya A.et al.(2010); Lamata (2004);Dursun M.et al(2011). In general, triangular fuzzy number (TFN) is simple to interpret, easy to use, efficient in computation and describes fuzzy information sufficiently. Therefore, TFN is adopted in this research study for subjective assessment of criteria and alternatives by the decision maker. TFN is denoted simply as $\widetilde{M}$= (a, b, c), where 'a' and 'c' are the lower and upper bounds of the TFN having magnitude relationship as ($a \le b \le c$). TFN represent uncertain event called fuzzy event. The supplier selection is a multi criteria decision making problem. The supplier selection decisions are taken in the uncertain environment and hence, the importance and rating of the criteria and alternatives are measured in triangular fuzzy numbers to obtain a realistic solution to accommodate the

human judgment, uncertain, imprecise and vague data in dynamic environment conditions. The solution of the problem in hand is also in the form of TFN. The defuzzification methods are applied to obtain a single value from TFN by performing the defuzzification operation. The centroid method is simple and widely used Shuo-Yan Chou et al. (2008). This research study also adopts centroid method during analysis of supplier selection problem for obtaining the solution.

4.6 Linear weighted method in supplier selection

The data collected consists of quantitative and qualitative type. The subjective data is measured in linguistic term and are quantified by using crisp numbers or triangular fuzzy numbers. Than treated using qualitative techniques like AHP etc.. Similarly, the direct measurable data like, price, quantity, delivery time, geographical distance or proximity, credit time offered by the supplier are synthesized and relative analysis is performed for finding the weights of the suppliers and ranking these suppliers in the ascending order of merit in the supplier selection process. The supplier selection is based on multiple quantitative parameters; the decision maker has to relatively evaluate the supplier. Thus the supplier selection problem becomes complex as number of parameters increases and has effect on the supplier selection decision. Ng and Lung (2008) proposed simple weighted linear model for multi criteria supplier selection problem. This research adopts linear weighted method for analyzing multiple quantitative criteria for ranking the supplier. This method comprises of following 08 steps.

1. The decision team need to list down the quantitative criteria to be considered in the supplier selection problem.
2. Collect the data of each supplier pertaining to each quantitative criterion.
3. Check and segregate the data based on cost factor and benefit factor.
4. Check the data for positivity otherwise transform the data.
5. Normalizing the data,

$$Yij = \frac{Xij - \text{Min}\,(Xij)}{\text{Max}\,(Xij) - \text{Min}\,(Xij)}$$

$$i = 1,2,3,\ldots M, \text{where M is number of suppliers} \qquad (4.5)$$

6. Calculate the partial average of each supplier across all criteria.

$$\text{Partial average } Yij = \frac{1}{N}\sum_{j=1}^{J} Yij \qquad j = 1,2,..N \quad N \text{ is number of criteria} \quad (4.6)$$

7. Find the score of each supplier.

$$\text{Score of } S_i = \max (Y_{ij}) \quad i = 1,2,3,...M; \quad j = 1,2,..N \qquad (4.7)$$

8. Arrange the score of supplier in descending order to rank the supplier. Supplier with maximum score is at the top of ranking.

The method is simple and easy to use to evaluate quantitative data. The time required to find the ranking is minimum without tedious calculation.

4.7 Entropy in supplier selection process

The performance of the company depends on the supplier to whom the company has outsourced its activities/functions. However these activities performed in turn depend on the facility, capacity and capability available with the supplier. The buyer requirements are satisfied if the supplier performs well with available resources and processes with it. The supplier selection as per the buyer requirement is difficult task as supplier is to be evaluated on multiple criteria. However the relative evaluation among suppliers is done for choosing the suppliers within the available suppliers. Each of these suppliers is assessed on the criteria decided by the decision team. The suppliers selected for the supply are evaluated periodically for their performance. This gives an opportunity to suppliers to compete among themselves to maintain or improve their purchase order volume. The buyer evaluates these suppliers on the pre decided benchmark and compares all the suppliers against the benchmark. The information of assessment criteria for the buyer and supplier can be measured by the entropy of the assessment criteria. The value of the entropy guides the buyer to understand the standing of the supplier in the market and also guides supplier for deciding about the improvement strategy for better performance compared to other competitor suppliers. This helps the supplier to decide priority among the assessment criteria to create competitive advantage. The assigning the priority is related to entropy concept in information theory. This research adopts entropy concept proposed by shannon(1949) for information communication.

As mentioned by Huatuco L.H. et al.(2010), " Entropy is defined as expected amount of information necessary to describe the state of the system. It is a measure of uncertainty generated by the variety within the system." Variety and uncertainty are two characteristics of the Entropy. The variety describes the different states of the system and the probability of

occurrence of the state is related to uncertainty within the system. According to Chan Lai-Kow et al.(2005), "Entropy is a measure for the amount of information (or uncertainty, variations) represented by a discrete probability distribution, p_1, p_1, p_2, ….. p_n , E(p_1, p_1, p_2, ….. p_n) = $-\phi \sum pilnpi$ i=1,2 ….n.

The other term for entropy is dispersion. As mentioned in the paper by Lamata M. Teresa,(2004), "entropy is defined as H(W)=$-\sum wilnwi$, this helps measure the degree to which W takes into account all of the information in the aggregation." Higher the value of entropy indicates that less variation is among the state probabilities, with little information is available in the distribution.

In this research the system refers to the supplier selection process system. The different assessment criteria are the states of the system and the strength of each assessment criteria of supplier refers to uncertainty associated with supplier selection process. The comparison matrix of assessment criteria and supplier is

$$X = [xij] \quad i=1,2\ldots N \ , j=1,2\ldots M \tag{4.8}$$

Where *xij* is the comparative measure of supplier and assessment criteria

N is the number of suppliers

M is the number of assessment criteria.

For the mth row of the supplier comparison matrix X corresponding to the assessment criteria,Hm; (xm1; xm2; : : : ; xmN), Let the total score with respect to Hm be

$$\text{Xscore} = \sum_{n=1}^{N} xmn \tag{4.9}$$

.Than normalized ratings pmi = xmi / X_{score} for i = 1; 2; : : : ; N can be viewed as the "probability distribution" of Hm on the N suppliers with entropy as

$$E\ (Hm) = -\phi \sum_{n=1}^{N} pmn\ ln\ pmn \tag{4.10}$$

If all suppliers performance ratings on Hm; (xm1; xm2; : : : ; xmN), are the same, Hm has zero variations and E (Hm) achieves its maximum of 1. So E (Hm) can be used to reflect the relative competitive advantage in terms of the assessment criteria, Hm. All these E (Hm) values, after normalization:

$$En = \frac{E\ (Hm)}{\sum_{m=1}^{M} E\ (Hm)} \qquad m = 1, 2, \ldots\ldots M, \tag{4.11}$$

can be considered as the supplier competitive priority ratings for supplier on the M assessment criteria, with a larger En indicating higher competitive priority for the corresponding Hm.

The ranking of the supplier gives the guideline to the decision maker to decide on work allocation based on the capacity and capability of the supplier. The periodic evaluation

is necessary to keep check on the performance of the supplier. However the suppliers are suppose to compete among them for the work order of high volume to increase the annual turnover and improve the financial stability. It is essential for the supplier to focus on their resources, processes and systems of the organisation which can build competitive advantage among the suppliers of the buyer and also satisfy the customer needs simultaneously. Supplier must adopt all methods to find out technical performance level of other suppliers of organisation. This information is essential to find out own strengths and weaknesses to improve its competitiveness. Based on this evaluation each supplier can decide about its improvement ratio by setting the improvement goals for evaluating factors (assessment factor). Entropy of the evaluating factor is calculated by applying entropy method. Entropy reflects the relative competitive advantage in terms of evaluating factors. Competitive priorities of evaluating factor guide the supplier for the course of action to be taken for competitive advantage which will indirectly improve customer satisfaction and fulfill customer requirements. The customer requirements WHAT are realized through the HOW i.e. evaluating factors, the necessary technical measures to be considered by the organization.

Entropy is defined by the expected amount of information necessary to describe the states of the system referred in Huatuco L.H.et al.(2010) . The state is the condition at a given point of time and the likelihood of occurrence of that condition. Likelihood is the probability of occurrence of the state. So at a given time there exists a state and the uncertainty associated with that state. We apply this concept in our study to the suppliers under consideration referring evaluating factor as state and the levels of given evaluating factor is the associated likelihood. The entropy, H for each supplier is calculated for each evaluating factor by using the following formula, where n is the number of suppliers of the organization.

$$H = -\theta \sum pi \log pi \quad i = 1,2, \ldots . n \tag{4.12}$$

Where pi is the probability of evaluating factor of respective supplier and θ is the normalization constant. The value of the entropy gives the guideline to the supplier to decide on the Competitive priority, (CP) for competitiveness. However this priority is for all the suppliers of the organization. Based on the resources available, supplier has to decide on the improvement efforts necessary to achieve the decided goal of the buyer. The relative evaluation of each supplier by decision maker set the goal, G for its suppliers. From the comparison matrix X the maximum value of the evaluating factor is set as the goal by the

buyer. Each supplier has to calculate its own improvement ratio,(IR) for each evaluating factor based on resources available. The improvement ratio analysis guides the buyer to prioritize the suppliers. Minimum total improvement ratio across all the evaluating factors (HOW) for each supplier rank the supplier at the higher level.

$$\text{Total improvement ratio} = \sum_{i=0}^{m} \text{IRi} \quad (4.13)$$

The minimum value of the sum of improvement ratio is equal to the number of evaluating factors.

The final importance rating,(FIR) of each evaluating factor HOW for each supplier for further improvement is calculated as follows,

$$R_i = CP_i \text{ x } IR_i \text{ x } W_{\text{relative}} \; i=1, 2\ldots m \text{ (evaluating factors)} \quad (4.14)$$

Supplier now assesses the level of difficulty faced for achieving the performance goals set by buyer and decide the strategies for achieving these goals for competitive advantage.. This also assists buyer to decide about the buyer-supplier relationship and action for supplier development initiatives. This method is supporting evaluation and ranking of suppliers by the buyer.

4.8 Decision theory for outsourcing and supplier selection

Accoring to Loomba (1978) "A decision is the conclusion of a designed to weigh the relative utilities of a set of available alternatives so that the most preferred course of action can be selected for implementation". Decision maker assess the advantages gained to the organization after implementation of decision. The decisions depend on the environment in which the organization functions. The decisions are taken between certain environmental conditions and uncertain environmental conditions for proper utilization of resources and reduce the cost of organisation. The decisions are taken under risk between these two extremes. The degree of certainty is associated with environmental conditions of organizations. The decision models are classified according to degree of certainty. The decision models are two types, deterministic model and probabilistic model. In deterministic model each strategy has unique payoff and in probabilistic model each strategy leads to more than one pay-off. Decision line is shown in Fig.4.7

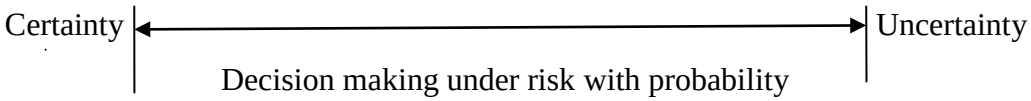

Figure.4.7 Decision Region

The decisions are made to improve the resource capacity of the organization to gain the competitive advantage in the market. The organization can improve its capacity by investing internally or access the suppliers' resources to remain competitive. Hence the decision maker has to decide whether to insource or outsource the activities which are not critical for competitive advantage Holcomb and Hitt (2007); Quinn and Hillmer (1994); Insinga and Werle (2000). The outcome of the decision is deterministic if decision is taken with certainty and probabilistic if decision is taken under risk and uncertainty. The decision for investment is to improve internal resource capability or supplier development for outsourcing is a critical task for the decision maker. The decision is also taken once at the start of the activity or multi decision can be taken in sequence at various stages during the progress of the activity in the planning period. The decision horizon considers data related to payoff, strategies, state of nature, competitors' actions, demand uncertainty, customer uncertainty, and associated probability distribution etc. The information data is not subject to revision during planning horizon than, only one decision is made and if the information is revised due to business situation than manager has to take multiple decisions. The previous made decision has effect on the subsequent decisions in the planning horizon. The manager can use schematic device termed as decision tree to represent the decision problem.

The decision tree is graphical diagram consisting of nodes, branches, probability estimates and the payoffs. There are two types of nodes: decision node and chance node. At the decision node manager has to take judicious decision for choosing the strategy/alternative at the emanating branch of the decision node. The chance node environmental conditions like competitor policies, market condition, demand trend, customer perspective Loomba (1978) play important role. At the chance node manager has to assess the events like competitor policies, market condition, demand trend, customer perspective for the effect on chosen alternative. The branches are of three types: decision branch with alternatives, chance branch with chance determined event with associated probability and the terminal branch representing the decision alternative or chance outcome. The payoff will be based on the market environment eg demand, economic scenario, government policies, product life cycle (including perishable products) etc. which is important for the buyer to decide on the outsourcing and supplier selection. The purchasing

decision depends on the buyer-supplier relationship, firms strategy and the competitive situation S. Sen et al(2008).

The decision tree principle is applied to construct the schematic representation for the ease of taking decision to outsource or insource. The decision maker has two alternatives either to outsource or insource at the emanating branches of decision node. The environmental conditions are the states of nature at the chance nodes. Based on the buyer-supplier integration level (S.sen et al. (2008), Ghodsypour et al. (1998)) the planning horizon can be decided. The outsourcing and supplier selection decision tree problem can be modeled into four types

a. Single period deterministic decision tree
b. Multi period deterministic decision tree.
c. Single period stochastic decision tree.
d. Multi period stochastic decision tree.

4.9 Proposed decision tree approach for outsourcing and supplier base

The organisation has to evaluate the cost effectiveness of the product or the service rendered. Non value adding activities are to be eliminated rather than minimised. This saves time, effort and money. "Companies essentially have three kinds of processes:
a.Core processes (which give strategic advantage), b. Critical, Non-core processes (which are important but are not competitive differentiators), c. Non-core, Non-critical processes (which are needed to make the environment work). (Jaya Tripathi 2010)."

Outsourcing helps the firms to reduce cost and concentrate on their core competencies. Outsourcing demands right supplier for the success of the firm. Organisations have to decide about the economy of scale and return on investment while deciding for outsourcing or internalisation. Experts from all functional areas like production, product design, marketing, quality within the system are involved in the decision making process. Customer choice is evaluated and the market trend for the product is considered during the decision. Product design determines the amount of complexity and product life cycle. All costs involved in the product decide the price affordable by the customer. Outsourcing to a single supplier or multiple suppliers is also critical. Buyer-Supplier relationship and supplier development initiative are important in our opinion for deciding about internalisation or externalisation. Choosing a source from marketplace is considering the boundary conditions is discussed by (Quinn 1999).

Cost efficiency is the major factor for the strategic outsourcing. "A strategic outsourcing model developed by (Holcomb and Hitt, 2006) accommodates the view of boundaries in which firms join with exchange partners to create synergies between them to be more successful than independently competing in the market." Operational efficiency, cost effective methods, financial efficiency are determined for the effectiveness of the organisation. The primary advantage associated with relative evaluation methods is that they allow for grouping suppliers based on performance, which provides useful insights to management in identifying benchmarks for inefficient suppliers and assists in decision relating to supplier development initiatives (SDI) and programs (Talluri and Narsimhan, 2004). A frame work for strategic outsourcing is developed and methodology is suggested using DEA approach considering input and output parameters developed a cross efficiency matrix, identified the homogeneous groups and performance differences across supplier groups. "The level of supply chain performance in a firm is positively and significantly associated with the firm's business performance (Kroes and Ghosh.2010)".

To survive, the organization has to develop new cost effective methods on the operational front as well as at the management level. The companies have to benchmark and decide about the strategies to be implemented (Dani and Dayanand 2011).The decision trees are used for social, economical, financial areas. "Outsourcing complete or partial activities create great opportunities but also new types of risks. Management's main strategic concerns are (1) loss of critical skills or developing wrong skills, (2) loss of cross functional skills, and (3) loss of control over suppliers (Quinn & Hilmer 1994)."We have not come across any paper on decision tree for outsourcing. Here a decision tree with heuristic approach is proposed for outsourcing and supplier base.

In reality the variations exist in the market. To accommodate this we consider stochastic decision tree for our model. In this research study two stage DTS model is considered Figure 4.8.

Assumptions are:

1. Two alternatives are available at decision node either outsource or insource.
2. Single source or multiple source is chosen based on environmental conditions..
3. Uncertainties exist during planning horizon like demand uncertainty, customer expectations etc .
4. Predicted payoff on investments.
5. Decision makers judgment based on perceptions, experience and intuition.
6. Past data is considered to forecast the payoff.

7. Decision team consists of members from different functional areas of the organization.
8. Firms opt for supplier development initiative for long term relationship.
9. Probability of demand does not change during the planning horizon.

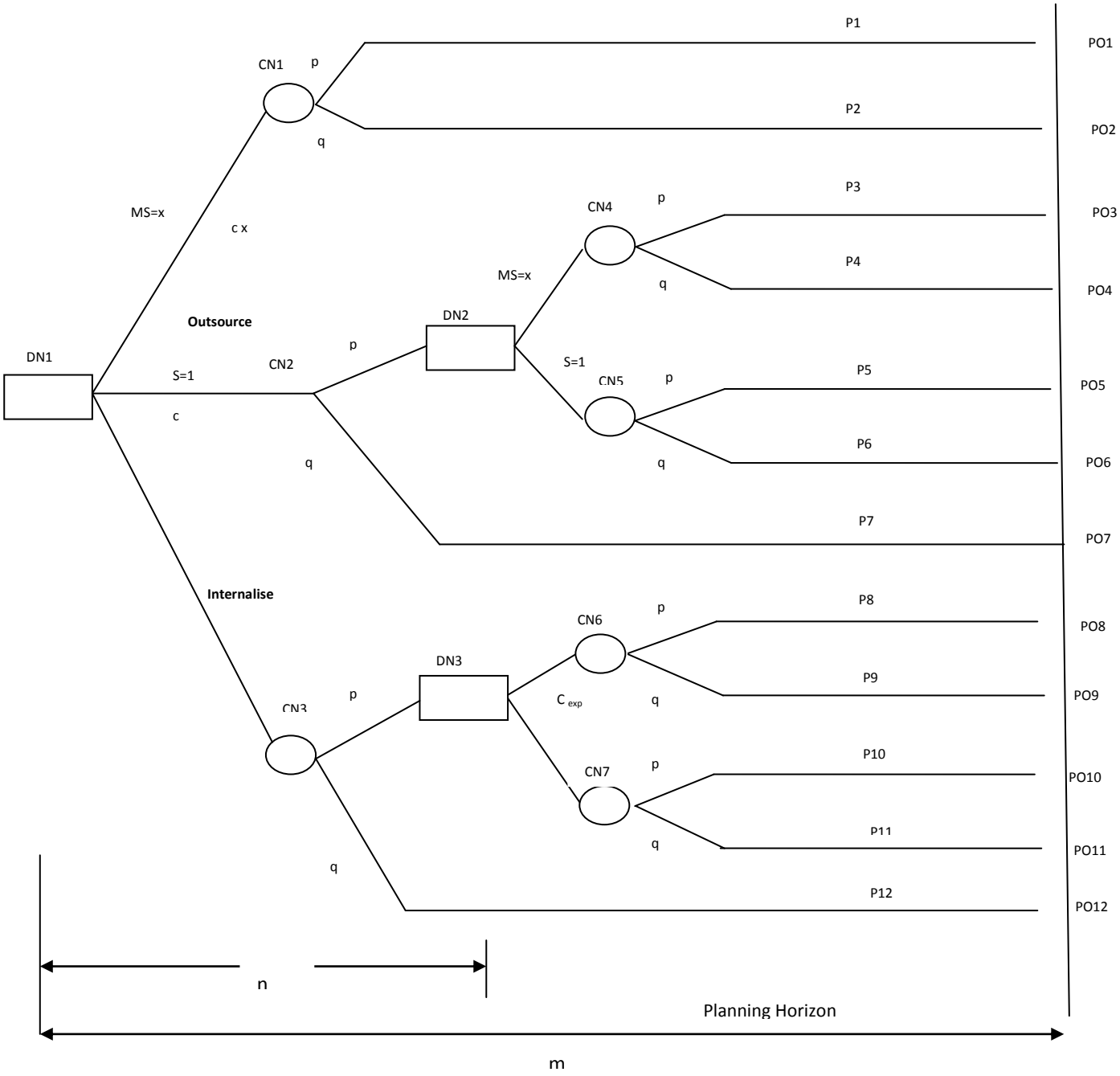

Figure 4.8 Two stage Decision Tree Structure for Outsourcing and Supplier Selection

Let

p=Probability of high demand

q=1-p= Probability of less demand.

x=number of suppliers

C_b= Amount to be invested by the buyer with each supplier. b= 1, 2….n

C_{exp}=Expansion cost.

PO_i = Payoff at the end of planning horizon i=1.2……..k

P_i=Cash flow in the given period in a given planning horizon

DN_j = Decision Node j=1, 2 ….a

CN_k = Chance Node k=1, 2 ...b

k=number of payoff options

a=number of decision nodes m= Planning horizon number of years

b=number of chance nodes n= Number of years for the first stage

Position value of the chance node is the expected value of payoff from all the options from emanates. Position value of each node is found by the process of rollback.

$$PVCN1 = pmP1 + qmP2 \quad \text{--------(4.15)}$$

$$PVCN4 = p(m-n)P3 + q(\mathrm{m}-n)P4$$
$$PVCN5 = p(m-n)P5 + q(m-n)P6$$
$$PVDN2 = max\{[PVCN4 - C(x-1)]\ or\ PVCN5\}$$
$$PVCN2 = p\{nP13 + \ max\{[PVCN4 - C(x-1)]\ or\ PVCN5\}\} + q(m+n)P \quad \text{-------(4.16)}$$

$$PVCN6 = p(m-n)P8 + q(m-n)P9$$
$$PVCN7 = p(m-n)P10 + q(m-n)P11)$$
$$PVDN3 = max\{[PVCN6 - Cexp]\ or\ PVCN7\}$$
$$PVCN3 = p[nP14 + PVDN3] + q(m+n)P12 \quad \text{--------(4.17)}$$

From above we get the decision equation as

$$PVDN1 = max\{PVCN1\ or\ PVCN2\ or\ PVCN3\} \quad \text{--------(4.18)}$$

We derive following options.

3.1. Organisation can decide to only to outsource

$$If\ PVCN3 < PVCN1\ and\ PVCN3 < PVCN2 \quad \text{--------(4.19)}$$

$$If\ PVCN3 > PVCN1\ and\ PVCN3 < PVCN2 \quad \text{--------(4.20)}$$

$If\ PVCN2\ > PVCN1$ Then single source is preferred.

$If\ PVCN3\ < PVCN1\ and\ \ PVCN3\ > PVCN2$ --------(4.21)

$If\ PVCN1\ > PVCN2$ Then multiple sources are preferred.

3.2. Organisation can decide to only internalise

$If\ PVCN3\ > PVCN1\ and\ \ PVCN3\ > PVCN2$ --------(4.22)

Any organisation has a budget for the expansion of the plant facilities which includes investment in plant and machinery, employment of man power to improve and meet the demand for the product in the market. Investment is to be justified and logical. Quick decisions without time loss are expected by the management to overcome the competitors' strategies. The management can plan to outsource the non value adding activities by selecting the vendor who can meet their requirement of quantity, quality, delivery, service, flexibility and price. This will help the organisation to concentrate on their core activities to improve the efficiency and effectiveness of the organisation. Supplier development initiative by the organisation in terms partnership, resource sharing or investment at supplier base is essential. The organisation can use the budget for expansion or SDI purpose. For the purpose of simplicity we assume equal investment or average investment with the supplier by the buyer.

$$Cexp = \sum_{b=1}^{n} Cb$$

$$c = \frac{\sum_{b=1}^{n} Cb}{n} \qquad \text{--------(4.23)}$$

We use the decision equation 4, the position value of DN1 with SDI investment is

$$PVDN1 = max\ of \begin{cases} PVCN1 - SDI\ investment\ for\ multiple\ suppliers\ (Outsourcing) \\ PVCN2 - SDI\ investment\ Single\ \ Source\ (Outsourcing) \\ PVCN3\ (Internalisation) \end{cases}$$

$$PVDN1 = max\ of \begin{cases} PVCN1 - cx \\ PVCN2 - c \\ PVCN3 \end{cases} \qquad \text{--------(4.24)}$$

It is important to decide about the optimum number of suppliers to be considered for the SDI. We suggest a heuristic method to reach to the decision point. Consider the decision to be taken based on the maximum position value of the decision node. Find the difference between the position value of decision node and the remaining position value of the chance nodes. This difference we call as risk factor. Calculate the total risk factor for each supplier under consideration. Minimum value of risk factor is decision point under consideration. This decision point gives the number of suppliers in supply base.

4.10 Proposed hybrid fuzzy QFD method for supplier selection

4.10.1 Introduction

The proposed method integrates three methods to select suppliers. The three methods are analytical hierarchy process, quality function deployment and linear weighted method. The method accommodates qualitative and quantitative criteria and is a group decision making approach. The decision team member gives his/her independent judgment towards the criteria and the supplier. The subjective assessment is associated with human judgment, vagueness and imprecision in the data. This is overcome by the use of fuzzy set theory. The triangular fuzzy numbers are used for its ease of mathematical operation. The Block diagram of proposed supplier selection process is shown Figure 4.9 below.

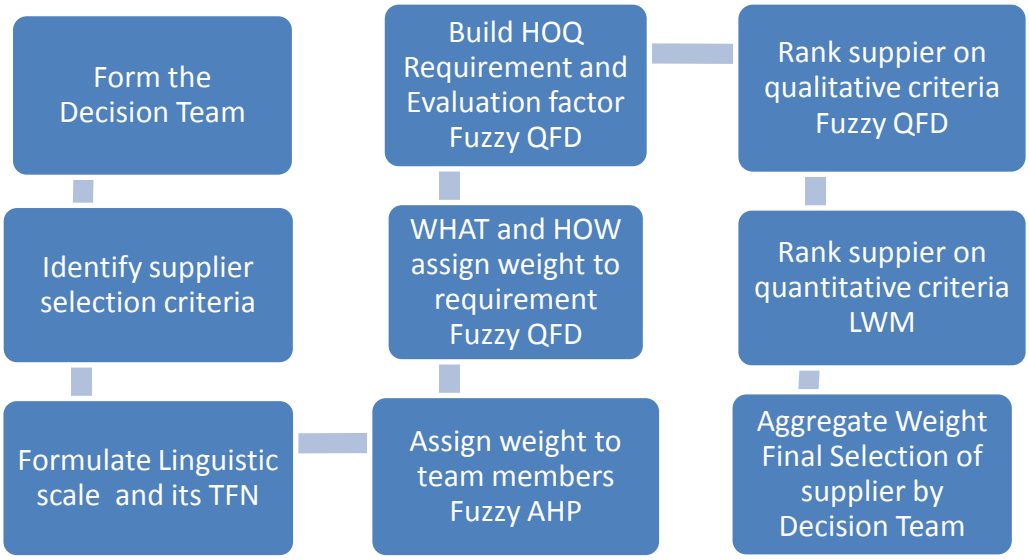

Figure 4.9 Block diagram of proposed supplier selection Process

The major steps in the proposed supplier selection method are:

Step 1: Need and goal as supplier selection by head or top management of the company.

Step 2: Selection of group decision making team members by head or top management of the company from different functional departments.

Step 3: The weights are assigned to decision makers based on their field experience, authority; responsibility, management position level .which is aggregated with weights given by organization head.

Step 4: Organization head assign preference weights to decision makers. These are calculated using fuzzy AHP module.

Step 5: Find the final weight of decision makers by combining weight at step3 and step 4.

Step 6: The decision maker prepare list of buyer qualitative and quantitative criteria.

Step 7: The decision maker prepare list of essential supplier assessment(evaluation) criteria.

Step 8: The decision maker find relative importance of qualitative and quantitative criteria.

Step 9: The decision maker find the relative weight of buyer qualitative criteria.

Step 10: Construct the relationship matrix with the help of experts from different organizations.

Step 11: Build house of quality of phase I and find weight of assessment criteria.

Step 12: The relative comparison is done of supplier against assessment criteria and house of quality of phase II of assessment criteria and suppliers is constructed to find the qualitative weight of suppliers.

Step 13: The buyer quantitative criteria are used to evaluate the supplier. Linear weighted method is employed to find the score of each supplier.

Step 14: The qualitative and quantitative score is aggregated to obtain the final score of each supplier. The score is arranged in descending order to rank the supplier. The supplier with highest score is placed at the top.

4.10.2 Modules in proposed method.

The proposed method is combination of fuzzy AHP, fuzzy QFD and linear weighted point method. The three methods are applied in phase wise to find the rank of suppliers.

4.10.2.1 Fuzzy AHP module

In this module fuzzy numbers are used in the AHP analysis. The fuzzy AHP along with synthetic extent analysis is employed to determine the weights of the decision team members and the preference weights of the qualitative and quantitative criteria based on the judgment given by the plant head and decision makers of the company respectively. AHP pair wise comparison demonstrate the consistency of response by strategic head, whereas extent analysis is used to determine the decision weight in fuzzy environment. AHP uses the ratio scale for pair wise comparisons Saaty (1980). Steps are:

Step 1: Construct the pair wise comparison matrix $A_{nxn}=[\tilde{a}_{ij}]$ of decision makers by plant head using fuzzy numbers. Where, $\tilde{a}_{ij}$ is relative importance of decision maker `i ' over decision maker `j '. $\tilde{a}_{ij}=1$ for all i=j otherwise $\tilde{a}ij = \frac{1}{\tilde{a}ji}$ for all $i \neq j$.

Step 2: Perform consistency test using equation (3,2), (3,3), and (3,4). Consistence index (CI) and consistency ratio (CR) is calculated. The set of numbers in Table 4.12 (Saaty(1980)) is average random consistency index derived from sample of randomly generated reciprocal matrices using the scale 1/9, 1/8..... 8, 9 .If CR< 0.1, accept the pair wise comparison matrix. An inconsistency of 10 percent or less implies that the adjustment is small compared to the actual values of the eigenvector entries.

Step 3: The weights and scores in fuzzy environment can be determined using synthetic extent analysis or Geometric mean estimation. In this study synthetic extent analysis applied to find the weights and scores of the decision makers and the criteria preference Da-Yong Chang 1996). The uncertainty and imprecision exists during prioritization in AHP. Synthetic extent analysis, on fuzzy AHP depends on the degree of possibilities of each criterion Zeydan Mithat et al (2011), Koul, and Verma, (2009), Aggarwal, R.et al (2013), Da-Yong Chang,(1996).

(a) The synthetic extent analysis using fuzzy number is used to calculate the fuzzy priorities. The pair wise comparison matrices should satisfy consistency condition for applying extent analysis. According to Da-Yong Chang,(1996), "level of goal satisfaction by an object is assessed by extent analysis method.

Let there be n object and m goals. Each object will have m extent analysis.

Let $X=\{x_1, x_2, x_3, \ldots\ldots x_n\}$ be an object set and $G=\{g_1, g_2, g_3, \ldots\ldots g_m\}$be a goal set. Consider each object and perform extent analysis for each goal respectively. Therefore, we can get m extent analysis values for each object, with the following signs: M^1_{gi} , , M^2_{gi} ,, ... M^m_{gi}, i = 1 2 . . . . . n, where all the M^j_{gi} (j= 1, 2, ,m) are triangular fuzzy numbers.

The extent analysis method is performed at each level by decision maker to obtain fuzzy synthetic extent. For i^{th} decision maker,

$$Si = \sum_{j=1}^{m} M_{gi}^{j} \; X \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1} \qquad (4.25)$$

Where,

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1} = \left[\frac{1}{\sum_{i=1}^{n} ci}, \frac{1}{\sum_{i=1}^{n} bi}, \frac{1}{\sum_{i=1}^{n} ai} \right] \qquad (4.26)$$

By applying the degree of possibility principle and normalizing non-fuzzy priority vector is calculated."

(b) The second approach to find the fuzzy weights is applying geometric mean estimation, where x̃ij are the elements of pair wise comparison matrix.

$$\widetilde{Xi} = \left(\prod_{i=1}^{n} \tilde{x}ij\right)^{\frac{1}{n}} \quad i = 1,2,\dots n\,, j = 1,2,\dots n \tag{4.27}$$

$$\widetilde{Wi} = \widetilde{Xi} \otimes \left(\sum_{i=1}^{n} \widetilde{Xi}\right)^{-1} \quad i = 1,2,\dots\dots n \tag{4.28}$$

Where $\widetilde{Wi}$ is the priority weight vector of decision maker and preference criteria.

The estimated fuzzy weights are transformed into crisp value by applying centroid method. Chang and Wang (2009) refer the non fuzzy weights as best "non fuzzy performance values."

4.10.2.2 Fuzzy QFD module

Qualitative criteria are used in proposed QFD module.QFD allows taking into account judgment of decision makers to establish relationship between customer (buyer) requirements (WHAT) and assessment (evaluation) criteria (HOW) of the supplier. The buyer requirements are translated in the QFD to obtain the rank of suppliers.

Step 1: The strategic head use fuzzy AHP for importance of decision maker, Assign weight based on experience, authority and designation to decision makers. Determine the aggregated weight of decision makers (Dw). Each decision maker determines the importance of qualitative and quantitative criteria and also sub criteria's within qualitative criteria.

Step 1: The decision makers determine the customer criteria and evaluation criteria.

Step 2: Decision maker assign weight to customer qualitative requirement.

Step 3: Construct the relationship matrix based on experts' judgments and opinions between customer requirement and evaluating factor.

Step 4: Build the HOQ phase I using customer requirements and assessment factors.

Step 5: Complete the HOQ phase I by calculating the weights of evaluating factors.

Step 6: Build the HOQ phase II using evaluating factors and potential suppliers.

Step 7: The decision makers assess each supplier on the evaluating factors. The decision makers' assessment is aggregated to find the final supplier assessment on evaluating factor.

Step 8: Complete the HOQ phase II by calculating the weights of each supplier.

Step 9: Use centroid method to defuzzify supplier fuzzy weights.

Step 10: Perform normalization on supplier weights to obtain the score. Finally rank the supplier based on normalized score.

4.10.2.3 The weighted linear model for quantitative criteria

Consider a set of preferred suppliers S_i (i=1, 2, 3.....M) available for an organization. The suppliers evaluated on set of quantitative criteria C_j (j=1,2,3.....N) criteria. The quantitative measures are denoted by X_{ij} for all i=1,2,3.....M, j=1,2,3.....N. It is assumed that the positivity exists between all the measurers, otherwise transform for positivity. The quantitative criteria measure have different units of measurement, hence normalization is performed to obtain the uniformity among all the measures. Let Y_{ij} for all i=1,2,3.....M, j=1,2,3.....N be the normalized values of the quantitative criteria. Estimate the score to rank the suppliers. This method comprises of following 08 steps.

1. The decision team need to list down the quantitative criteria to be considered in the supplier selection problem.
2. Collect the data of each supplier pertaining to each quantitative criterion.
3. Check and segregate the data based on cost factor and benefit factor.
4. Check the data for positivity otherwise transform the data.
5. Normalizing the data, Use equation (4.5)

$$\mathrm{Yij} = \frac{\mathrm{Xij} - \mathrm{Min}\ (\mathrm{Xij})}{\mathrm{Max}\ (\mathrm{Xij}) - \ \mathrm{Min}\ (\mathrm{Xij})}$$

$$\mathrm{i} = 1,2,3, \ldots \mathrm{M}, \text{where M is number of suppliers}$$

6. Calculate the partial average of each supplier across all criteria using equation (4.6)

$$\text{Partial average Yij} = \frac{1}{\mathrm{N}} \sum_{\mathrm{j}=1}^{\mathrm{J}} \mathrm{Yij} \qquad \mathrm{j} = 1,2,..\mathrm{N} \quad \mathrm{N} \text{ is number of criteria}$$

7. Find the score of each supplier by equation (4.7)

$$\text{Score of } S_i = \max\ (Y_{ij}) \ \ \mathrm{i} = 1,2,3, \ldots \mathrm{M}; \ \ \mathrm{j} = 1,2,..\mathrm{N}$$

8. Arrange the score of supplier in descending order to rank the supplier. Supplier with maximum score is at the top of ranking.

The quantitative score obtained is used for combining with the qualitative score.

4.10.2.4 Aggregation procedure for supplier ranking.

The supplier is evaluated based on criteria. The qualitative criteria, quantitative criteria and evaluating criteria are decided as per the need of the organisation and employed in the QFD module to find the final score of the supplier. The importance of supplier is evaluated based on quantitative and qualitative criteria of each supplier in terms of score. The scores obtained are combined to find the final score of each supplier.

1. S_{QLT} is the supplier score based on qualitative analysis
2. S_{QNT} is the supplier score obtained by quantitative analysis
3. Let 'α' be the coefficient of preference. The coefficient of preference 'α' is the normalized weight assigned by the decision makers' based on the importance and need of the organization. Consider α_1 and α_2 are coefficient of preference of quantitative criteria and qualitative criteria respectively.
4. If $\alpha_1 = \alpha$ and $\alpha_2 = 1 - \alpha$ Than, $\alpha_1 + \alpha_2 = 1$.
5. The final score of suppliers is

$$FS_{SCORE} = \alpha_1 * S_{QNT\,i} + \alpha_2 * S_{QLT\,i} \quad (4.29)$$

where, i=1,2,……..N, N is number of suppliers

The final score obtained is arranged in the descending order. The supplier with highest score is at the top and is ranked as 1. The supplier with the minimum score is palced at the last in the sequence.

The process of supplier selection using the fuzzy QFD is schematically represented in the form of algorithm Figure 4.10. The supplier selection goal is placed at the top of the algorithm. This is followed by the team building, identification of criteria by the decision team members. The sub-algorithms of AHP module, QFD module and the quantitative module is embedded in the main structure of the algorithm. The output of the each module is combined to obtain the final score of each supplier. The score is used to rank the suppliers. The 'GOTO B' represents the connectivity of the algorithm with the general algorithm (Figure 4.12) proposed for outsourcing and supplier selection.

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4.10.2.5 Algorithm for supplier selection process:

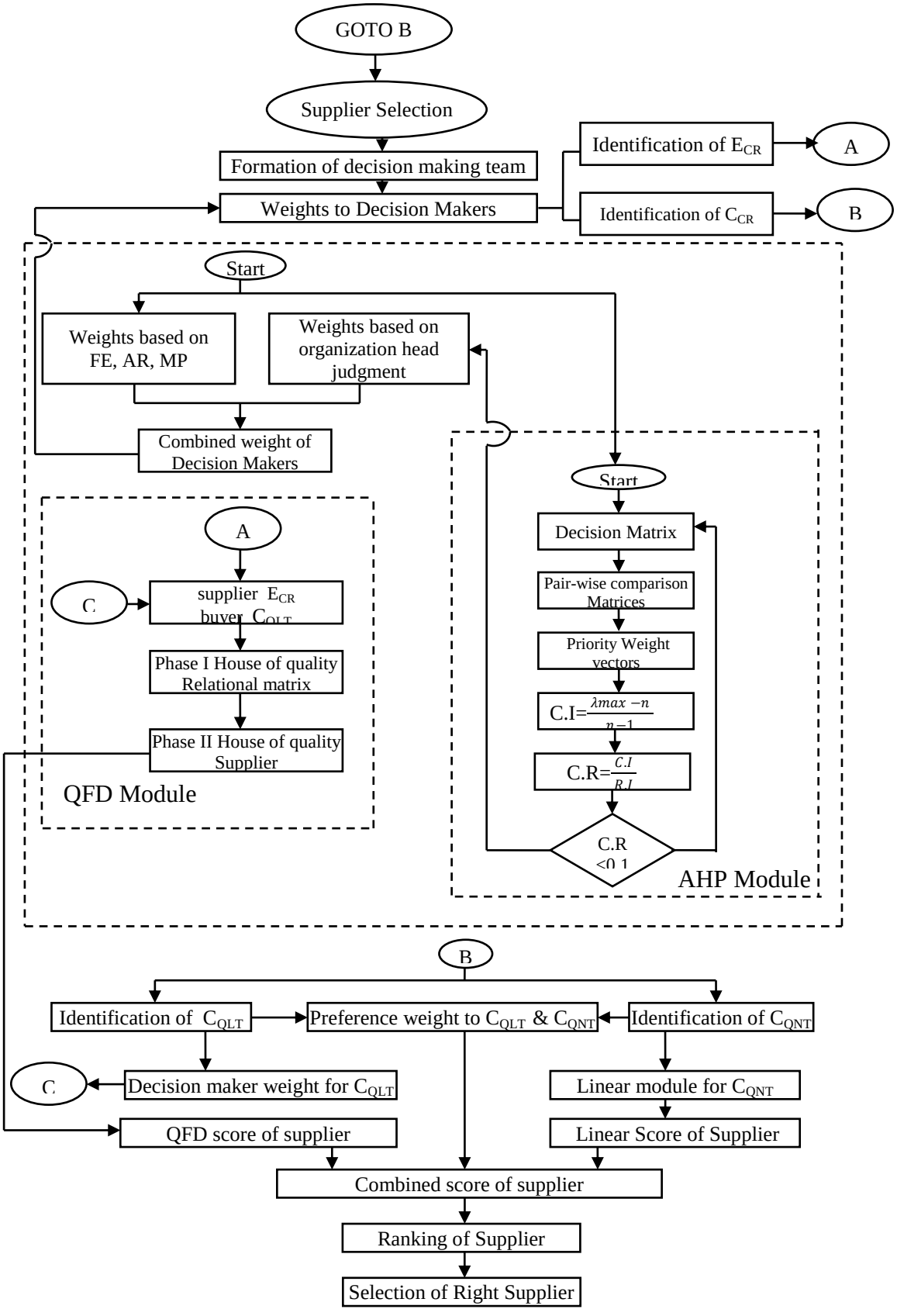


Figure 4.10 Algorithm for supplier selection process

4.11 Proposed hybrid QFD-Entropy approach for supplier selection

The entropy is the measure of amount of information represented by probability distribution. According to Chan Lai-Kow et al.(2005), "Entropy is a measure for the amount of information (or uncertainty, variations) represented by a discrete probability distribution, p_1, p_1, p_2, ….. p_n , E(p_1, p_1, p_2, ….. p_n) = $-\phi \sum pilnpi$ i=1,2 ….n. Higher the value of entropy indicates that less variation is among the state probabilities, with little information is available in the distribution. Entropy is characterized by variety (state) and uncertainty associated with the variety. The customer requirements WHAT are realized through the HOW i.e. evaluating factors, the necessary technical measures to be considered by the organization. Each evaluating factor act as a state and the degree of strength of evaluating factor associated with each supplier support buyer for competitive advantage in the market.

The entropy method guides the supplier on competitive priority for obtaining the competitive advantage. The ranking of the supplier gives the guideline to the decision maker to decide work allocation based on the capacity and capability of the supplier. The periodic evaluation is necessary to keep check on the performance of the supplier. However the suppliers are suppose to compete among them for work order of high volume to increase the annual turnover and improve the financial stability. It is essential for the suppliers to focus on their resources, processes and systems of the organisation which can build competitive advantage among them and also satisfy the customer needs simultaneously. Supplier must adopt methods to find out technical performance level of other suppliers of organisation. This information is essential to find out own strengths and weaknesses and hence to improve its competitiveness. Based on this evaluation each supplier can decide about its improvement ratio by setting the improvement goals for evaluating factors. Entropy of the evaluating factor is calculated by applying entropy method. Entropy reflects the relative competitive advantage in terms of evaluating factors. Competitive priorities of evaluating factor guide the suppliers for the course of action to be taken for competitive advantage which will indirectly improve customer satisfaction.

The proposed method applies the entropy concept in the QFD process to rank the suppliers. To minimize the complex calculations due to fuzzy numbers we use crisp values generated from the defuzzification of the fuzzy numbers of linguistic values of decision makers. The QFD process has two HOQ matrices in two phases. The first relational matrix gives the initial HOW rating. The second matrix gives competitive priority for the supplier to

decide for action based on the goal set by the buying organization. Each supplier has the level or degree of strength of evaluating factor depending on resources and constraints of its organization. Hence each evaluating factor of each supplier has defined state and uncertainty associated with it called as entropy. By use of entropy and buyer set goal, competitive priority and improvement ratio for each evaluating factor assist supplier for type of action to be taken for further improvement and for buyer for supplier selection. Proposed step are as follows.

Step1. Find the relative weight of qualitative criteria by the decision makers.

Step2. Form the relationship matrix of WHAT (customer requirements) and HOW (evaluating factors) with the help of experts from different organizations.

Step3. Build the HOQ and find the initial evaluating factor weights.

Step4. Find the relative weight of evaluating factor for each supplier by the decision makers

Step5. Calculate the entropy for each evaluating factor of supplier by using the formula and normalize the values.

$$H = -\theta \sum pi \; log \; pi \quad i = 1,2, \ldots . n \tag{4.30}$$

Step6. Calculate the Competitive priority for evaluating factor,

$$Competitive\ Priority = \frac{H = -\theta \sum pi \; log \; pi \quad i = 1,2, \ldots . n}{\sum_{j=1}^{m} H \qquad j = 1,2, \ldots m} \tag{4.31}$$

Based on the rank of competitive priority supplier can decide on the action for competitiveness depending on evaluating factors.

Step7. Find the improvement ratio of each supplier for evaluating factor as per formula

$$\text{IRij} = \frac{\text{Gj}}{\text{Ri}} \quad \text{i=1,2,...n, j=1,2,..m., relative weight is } R_i \text{ i=1,2,....n,} \tag{4.32}$$

Select the $H_{i\ max}$ i=1,2,…m from each evaluating factor Goal Gj= $H_{i\ max}$ j=1,2,…m

Minimum improvement ratio for each supplier is 1 (one). Find $Sum = \sum_{j=1}^{m} IRij$ and normalize and calculate percentage deviation from the minimum value. Arrange the deviation in ascending order and rank the supplier in ascending order of improvement ratio.

Step8: Compute the Final importance rating (FIR) of evaluating factors 'HOW' by equation (4.33)

Final Importance Rating FIR= IR X Initial HOW weight X CP_j

Step9: Rank each HOW of each supplier for further improvement strategy by the supplier.

Step10: Prioritise the evaluating factor on initial relative weight by the decision maker

Step11: Assess the difficulty level of implementation of the improvement strategy by the supplier with respect to the priority of the HOW by the decision maker. The difficulty level scale is as

Difficulty Level of action: High: >1.5 Medium: 1.25-1.50 Low: 1.0-1.25 Nil: ≤ 1.0

Step 12: Consolidate the difficulty levels of each supplier and rank the supplier with difficulty level for the easy reference to the decision maker.

. The hybrid QFD-entropy method is suitable for qualitative criteria only. This method is easy and efficient for implementation and takes care of uncertainties in the supplier selection process. The method is tested with data in organization in Goa, India.

4.12 Proposed procedure in the Outsourcing and Supplier selection

Step 1: The organization head has to critically select the team members from different functional areas of the organization based on the experience, attitude, knowledge, skill, authority, responsibility, authority and designation. It is assumed that the members are energetic, loyal and focused for the success of the organization. Here below we propose the sequence of actions to be taken for selection of supplier in strategic outsourcing Figure 4.11. Secondly, we propose the detailed algorithm for outsourcing and supplier selection along with guideline algorithm for risk assessment Figure 4.12.

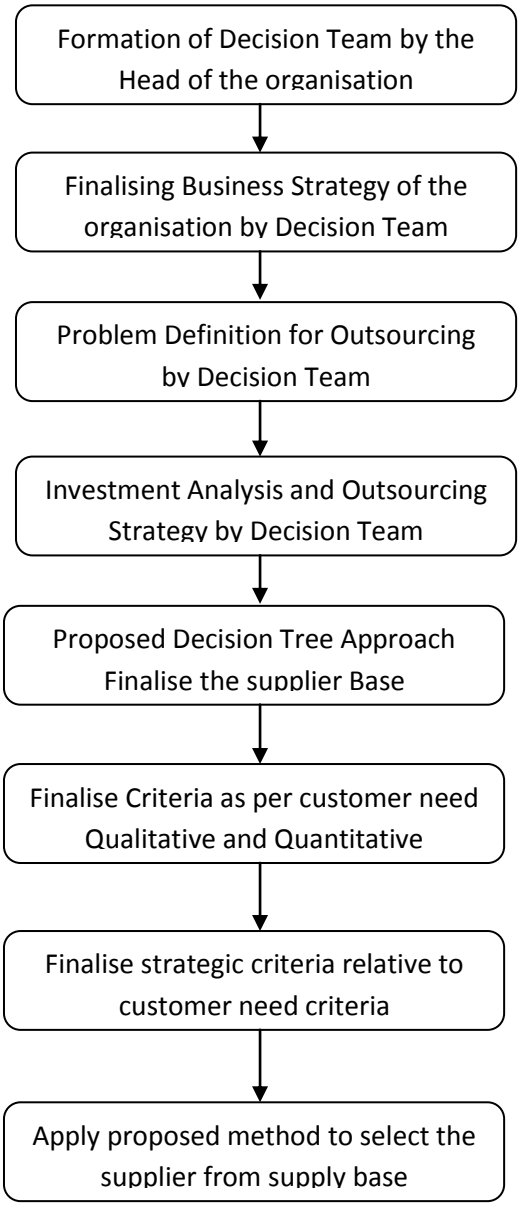


Figure 4.11 Flow Chart for action for outsourcing and supplier selection

Step 2: General integrated algorithm.

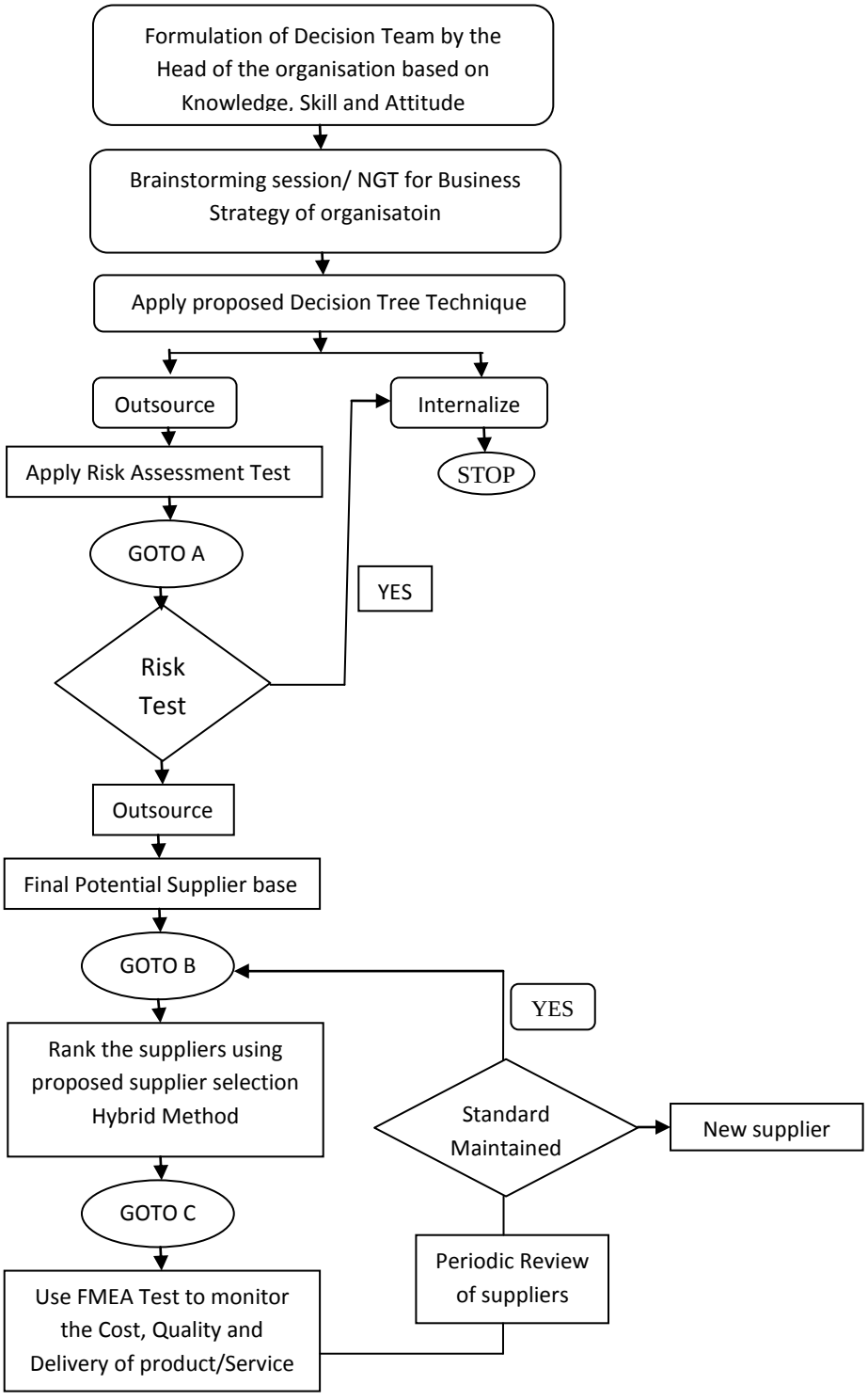


Figure 4.12 Proposed general algorithm for outsourcing and supplier selection

Step 3: Decision Tree approach for outsourcing and supplier base detailed in section 4.9

Step 4: Assess risk in outsourcing:

Organisation outsource activities/processes to the supplier/vendor, however the buyer has little or no control on the internal processes of the supplier. Supplier performs the activities on behalf of the buyer, as set of tasks are beyond the capacity and capability of the buyer. Customer requirements are to be satisfied by the buyer. As some tasks are performed by the supplier, supplier is also responsible for the reputation and brand name of the buyer's product/service.

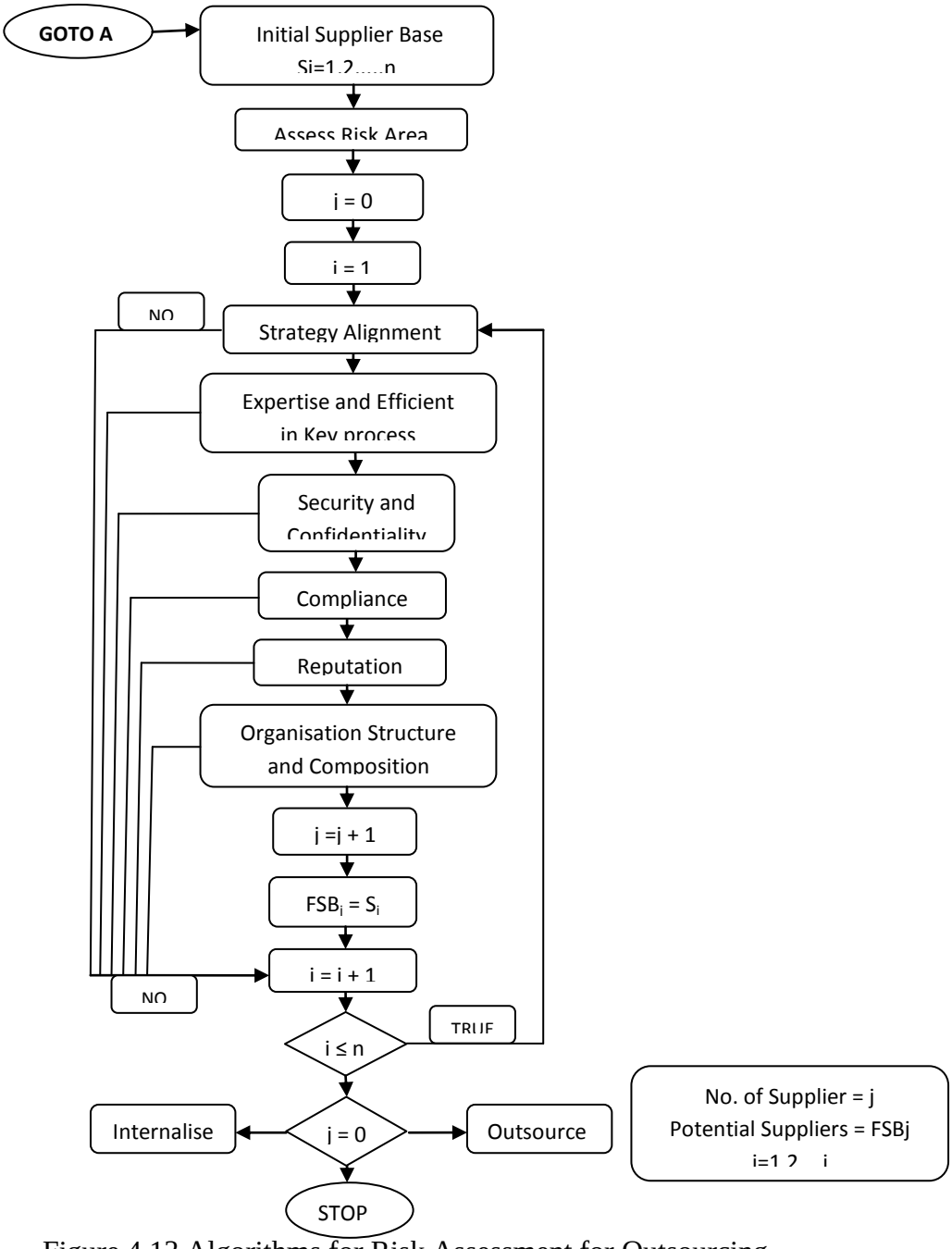


Figure 4.13 Algorithms for Risk Assessment for Outsourcing

Sometimes the key processes are outsourced to the experts in the supplier because of no expertise and uneconomical to manufacture internally. Utmost care need to be taken by the

buyer as it may have severed effect on the functionality of the product delivered/service rendered to the customer. Supplier need to comply all regulations and guidelines of the customer. Outsourced activities/processes may have effect on the business strategy of the organization, in such case the type and level of training and management of the supplier is required to be assessed so that strategic objective of the organization is achieved. As per Mosher and Mainquist (2011) the key risk areas are "1.Reputation 2.Strategy 3.Compliance 4.Security and confidentiality 5.Organisation structure and composition 6. Key processes." Based on the discussions with the professionals and academicians the above risk factors are considered for the risk assessment guideline algorithm shown in Figure 4.13.

Step5: Use proposed hybrid QFD algorithm for supplier selection detailed in section 4.10

Step6: Once the supplier is selected, the periodic evaluation is performed to monitor the supplier. Here we propose and suggest use of Failure Mode Effects Analysis (FMEA) approach to assess each supplier for the risk and periodic evaluation of supplier. The factors used for FMEA are Price/Cost, Quality and Delivery. In the literature review it is found that Quality, Price/Cost and Delivery are prominently referred by most of the researchers. To mention few as per Dickson (1966) "Out of 23 criteria in order of importance; Quality, Delivery and performance History are the top three." "Gonzalez et al (2004) found that quality is the most significant attribute in supplier selection." "Bayrak et.al (2007) considered Delivery, Quality, Flexibility and Service for evaluating the supplier." "William Ho et.al (2010)carried out study on 78 journal articles in the period of 2000 to 2008.. It is observed that the criteria used for evaluating the performance of supplier is quality followed by delivery, price or cost." Each supplier is evaluated on opportunity, probability and severity of risk on the factors considered. As suggested by Mosher and Mainquist(2011), the decision maker can either use 5-point or 10-point scale to find the score for opportunity, probability and the severity.

Opportunity Score	Probability Score	Severity Score
Frequency of occurrence	Likelihood of Occurrence	Impact of Occurrence

Combining the score Risk Priority Number (RPN) is calculated as

$$RPN = Opprtunity\ Score\ X\ Probaility\ Score\ X\ Severity\ Score$$

The risk with low severity causes minimum impact on operations. The impact may be in terms of cost, delivery, or loss of quality or intellectual property. The Pareto distribution is used to analyse risk associated with outsourced supplier. Actions are taken to reduce risk, and the process can be performed again to evaluate the residual risk.

4.13 Application of decision tree and heuristic approach for outsourcing and supplier base in multi period business environment.

The intent is to develop the new method for supplier selection. However the suppliers are selected from the group of preferred suppliers called supplier base based on the outsourcing decision. Hence to understand the proposed decision tree method for outsourcing and supplier base, hypothetical problem is considered for the analysis; a corporate group consisting of personnel from various disciplines like, research and development, manufacturing, finance marketing etc. has to decide about the investment and strategy to be implemented for new product to be introduced in the market. The group has to study investment analysis that will consider expenditure for expansion, sales forecast, supplier development initiative expenditure and net cash flow for the expected life of the product. The data from Loomba (1978) is used and is fitted in the proposed decision tree method. The data is shown below in Table 4.13 and Table 4.14.

Demand Probability		SDI and investment strategy		
High	Low	Single Supplier	Multiple Supplier	Internalisation
p	q	x =1	x = 1 to7	Cexp
0.7	0.3	15	c	15

Table 4.13 Probability and SDI

Annual Cash flow	Amount in Lac's/yr	Payoff at Planning Horizon	Amount in Lac's
P_1	5.0	PO_1	35
P_2	1	PO_2	7
P_3	6	PO_3	3
P_4	2.5	PO_4	12.5
P_5	3	PO_5	15
P_6	1	PO_6	5
P_7	1	PO_7	7
P_8	3.5	PO_8	12.5
P_9	1.25	PO_9	6.25
P_{10}	2.5	PO_{10}	12.5
P_{11}	0,75	PO_{11}	3.75
P_{12}	0.75	PO_{12}	3.75

Table 4.14 Annual cash flow and payoff at planning horizon

We assume the planning horizon for 7 years and two stage decision tree for outsourcing Figure 4.8. Once the relevant information regarding decision nodes, chance nodes, decision and chance branches, reward or cost of decision branches, probabilities and payoffs associated with chance branches are known we find the values for taking the decision. Position value of the chance nodes calculated is the expected value. We show the sample calculation for one chance node and decision node.

$$PVCN1 = 0.7(5 \times 5) + 0.3(1 \times 5)$$
$$PVCN1 = 26.6 \qquad \text{-------(7)}$$

$PVCN1$	$PVCN2$	$PVCN3$	$PVCN4$	$PVCN5$	$PVCN6$	$PVCN7$
26.6	14.525	9.8875	24.75	11.4	14.125	9.875

$PVDN2$	$PVDN3$
14.75	9.875

We use the decision equation 4, the values are

$$PVDN1 = \max of \begin{cases} PVCN1 - SDI\ investment\ for\ multiple\ suppliers\ (Outsourcing) \\ PVCN2 - SDI\ investment\ Single\ \ Source\ (Outsourcing) \\ PVCN3\ (Internalisation) \end{cases}$$

$$PVDN1 = \max of \begin{cases} PVCN1 - cx \\ PVCN2 - c \\ PVCN3 \end{cases}$$

Total risk factor for each supplier under consideration is shown in the column in the Table 3. Minimum value of risk factor in column 7 is called decision point. This decision point gives the number of suppliers in supply base. The number of supplier for outsourcing strategy is three.

No. of Vendors	PVDN1			RF1	RF2	Decision Value
	Multi Source	Single Source	Internalise			
0	0	0	9.8875	0	9.8875	9.8875
1	9.6	0	9.8875	9.6	9.8875	19.4875
2	9.6	7.025	9.8875	2.575	2.8625	5.4375
3	9.6	9.525	9.8875	0.075	0.3625	**0.4375** ⇦
4	9.6	10.775	9.8875	1.175	0.8875	2.0625
5	9.6	11.525	9.8875	1.925	1.6375	3.5625
6	9.6	12.025	9.8875	2.425	2.1375	4.5625
7	9.6	12.382	9.8875	2.782	2.4945	5.2765

Table 4.15 PVDN1 for different values of x & Decision Values

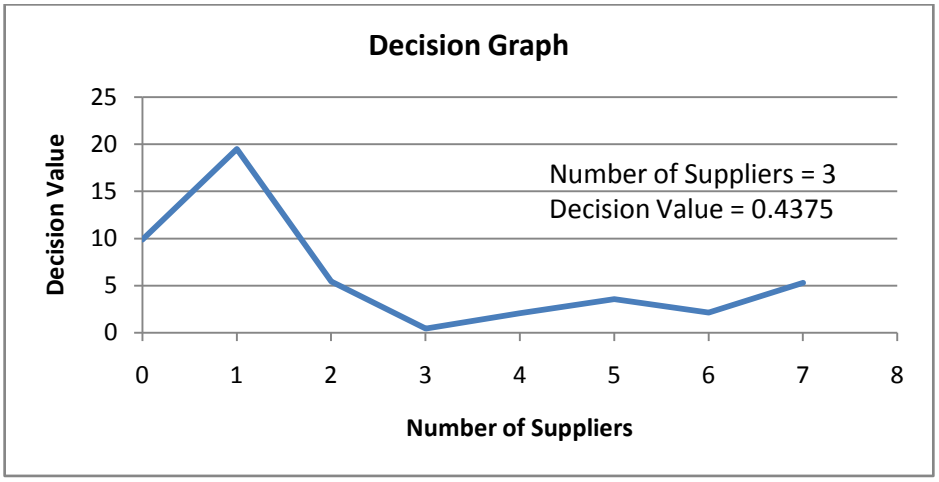


Figure 4.14 Decision Graph

Conclusion:

In the competitive environment the organisation has to concentrate on their core activities to improve performance of the organization. Outsourcing and internalisation decision is crucial. Decision making involves all the thinking and activities that are required to identify the most preferred choice (Loomba 78). To survive, the organization has to develop new cost effective methods on the operational front as well as at the management level. The companies have to benchmark and decide about the strategies to be implemented .In the proposed approach the managers involved in decision making will be able to decide not only the outsourcing strategy but also the number of suppliers in the supply base. Our future work is to use the simulated data for result and apply the proposed method in industry.

4.14 Application of proposed hybrid fuzzy QFD approach for supplier selection.

4.14.1 Group decision making and multiple suppliers

The proposed method is applied in a medium scale private limited company in the state of Goa, India. The name and the location of the company is not mentioned to maintain the confidentiality of the company. The company manufactures fiber reinforced polymer products. The company requires corrugated boxes as packaging material. The company needs suppliers for supplying corrugated boxes without interruption to meet the demand of final products. The head of company constitute a four member supplier selection committee to select suppliers. The four members are referred as decision makers (D1, D2, D3 and D4). The decision makers prepare list of ten potential suppliers (S1, S2, S3, S4, S5, S6, S7, S8, S9,S10) for the corrugated boxes. The criteria for the supplier selection were finalized based on the literature review and the open ended discussions during the industry visits in Goa. The same were further discussed with the company supplier selection committee. The criteria important for the analysis were finalized. The company requirement criteria are divided into two criteria: qualitative criteria and quantitative criteria. The company expects that supplier should meet these criteria at the time of supply. These criteria are termed as customer requirement criteria. The customer requirements are divided into qualitative and quantitative criteria. The set of criteria, whose influence has effect on customer requirement are finalized. These criteria are termed as evaluation or assessment criteria. These are also called as evaluation factors. This is the technical requirement of the suppliers. The method employed uses quality function deployment (QFD) for evaluation stage. The house of quality of QFD require relationship matrix between customer requirement and evaluation criteria. The relationship matrix is built with the help of experts from different industry verticals. The WHAT and HOW of QFD are customer requirement criteria and evaluation criteria respectively. The Table 4.6 to Table 4.9 referred above are considered here for the analysis:

qualitative criteria	quality, reliability, flexibility, stability, capability, availability & sustainability
quantitative criteria	price, quantity, proximity, credit time, delivery time

Table 4.6 buyer requirement (qualitative and quantitative criteria)

Sr. No.	Customer Requirements Qualitative	Abbriv	Description
1	Quality	Q	Suppliers are responsible to supply product conforming to specification.
2	Reliability	R	The supplier should be reliable with respect to product quality, quantity, delivery time. security and confidentiality of Information, core competency, processes etc.
3	Flexibility	F	The supplier should be flexible for demand changes like supply volume, delivery time, credit payment time etc.
4	Stability	S	Strong financial backup, stable management e.g. cordial employee-employer relationship, strong business foundation, number of years in business
5	Capability	C	risk mitigation capability, strong technological setup, problem solving ability,
6	Availability & Sustainability	AS	Supplier should be ready for service and support to buyer and customer round the clock.

Table 4.8 Description of buyer requirements (WHAT)

Sr. No.	Assessment Factors	Abbriv	Description
1	Standard Quality Management System	SMS	Quality management system (ISO-9001), environment management system (ISO-14001), Occupational health and safety system (18001), Just in time(JIT), 5S.
2	Testing Facility and Inspection	TFI	Inspection methods (sampling methods or 100% inspection), production part approval process(PPAP)
3	Organisational Structure and Management	OSM	management stability, management culture, management initiative for new methods,
4	Business Experience	BE	number of years in business
5	Human Resource	HR	knowledge and skill, attrition rate, training and development methods,
6	Enabling Technology	ET	phone, fax, mobile, electronic data exchange (EDI), email, kanban, display boards,

7	Planning and Control	PC	material requirement planning(MPR), manufacturing resource planning (MRP-II), inventory management, scheduling and sequencing
8	Latest Technology	MT	use of technology in design(CAD software), manufacturing (CNC,FMS etc) , inspection (CMM), material handling systems (Robots, AGVs),maintenance methods, and business processes
9	Production Layout	PL	product, process, mixed or fixed layout
10	Manufacturing Facilities	MF	machinery, and tools utility equipments
11	Machinery and Equipments	ME	conventional, automatic or advanced, number of year in use, machinery condition.
12	Product Range	PR	potential to manufacture wide range of products
13	Business Volume	BV	Annual Turnover
14	Reputation	RP	market share, listing in stock market, brand name, catalogues, customer base.
15	Innovation/Improvement Potential	IIP	Initiative to use Kaizen, total quality management, quality circles or new techniques to improve quality, cycle time reduction. New products, Implementation of cost reduction measures.
16	Problem Mitigation Techniques	PMT	interest in statistical quality control, statistical process control, failure mode effect analysis, pareto distribution, six sigma ,
17	Research and Development setup	RND	testing facility, research environment, earlier research outcomes, dedicated persons, interest to invest in research, design software
18	Service support	SS	customer support, response time, service quality.
19	Risk management	RM	potential to control trade union risk, supplier risk, demand risk, manufacturing risk, information risk.
20	Standard practices	SP	Standardization of processes, efforts for patents and trademarks, good manufacturing practices(GMP).
21	Key skills and Expertise	KSE	external expert support(contract or visit), degree of internal expertise (internal key skills)
22	Relationship	RRA	type of buyer-supplier relationship, supply exchange between buyer and supplier, buyer/supplier investment etc

23	Security and Confidentiality	SC	security measures taken for confidentiality of information of core competency, core processes, customer data,
24	Coding system	CS	barcode, color code, tags for ease and accessibility.
25	Compliance and Response	CR	terms and conditions, rules and regulation, legal compliance.
26	Financial Position	FP	support of financial institutions, credit offering capacity(limit and period), assets and liabilities.

Table 4.9 Description of supplier assessment factor

In this study, the hierarchy structure of decision problem is shown in figure 4.6. The block diagram for the proposed supplier selection process is shown in figure 4.10. The fuzzy AHP, fuzzy QFD and linear weighted method are integrated to develop hybrid method. The developed method is applied to solve supplier selection problem. Algorithm is as shown in Figure 4.11.

Linguistic terms		Intensity of importance	Fuzzy Number	Reciprocal of fuzzy Number
Equally Strong	ES	1	(1,1,1)	(1,1,1)
Equally Preferred	EP	1	(1,1,3)	(1/3,1,1)
Moderately Important	MI	3	(1,3,5)	(1/5,1/3,1)
Strongly Important	SI	5	(3,5,7)	(1/7,1/5,1/3)
Very Strongly Important	VSI	7	(5,7,9)	(1/9,1/7,1/5)
Extremely Important	EI	9	(7,9,9)	(1/9,1/9,1/7)

Table 4.16 Linguistic term for decision maker and criteria
Lamata(2004), Liang-Husan Chen et al.(2010), Shan-Yan Huang et al.(2014)

Linguistic terms		Assigned intensity	Fuzzy number
No Relationship	NR	0	(0,0,1)
Very Weak Relationship	VWR	1	(0,1,3)
Weak Relationship	WR	3	(1,3,5)
Moderate Relationship	MR	5	(3,5,7)
Strong Relationship	SR	7	(5,7,9)
Very Strong Relationship	VSR	9	(7,9,9)

Table 4.17.Linguistic term for relationship matrix (a)

Bhattacharya A. et al. (2010) suggested intensity of 0, 1, 5 and 9. The intermittent fuzzy numbers are considered for this study with range of 1 to7 and 5 to 9.

Linguistic terms		Assigned intensity	Fuzzy number
No Relationship	NR	0	(0,0,1)
Weak Relationship	WR	1	(0,1,3)
Moderate Relationship	MR	5	(1,4,7)
Strong Relationship	SR	9	(5,6,9)

Table 4.18 Linguistic term for relationship matrix (b) Bhattacharya A. et al. (2010)

Linguistic terms		Field experience	Authority & responsibility	Management Position	Fuzzy number
Low	L	$0 \leq 5$	Low	Officer	(0, 0.2, 0.4)
Medium	M	$5 \leq 10$	Medium	Senior Officer	(0.2, 0.4, 0.6)
High	H	$10 \leq 20$	High	Section Head	(0.4, 0.6, 0.8)
Very High	V	20 > above	Very High	Department Head	(0.6, 0.8, 1)

Table 4.19 .Linguistic term for the Field experience, authority, responsibility and management position Dursun M. et al.(2010)

The steps involved in the in the supplier selection process are explained in the sequence with the help of the data collected from the company considered for this study. The plant head of the company chose the decision makers from purchase section, production section, quality section, and the finance section. Each of the decision makers has varied

experience, skill, knowledge, qualification, authority, responsibility and is in different management level. The plant head has confidence in the team. The importance assigned to each decision member by the plant head is not equal. Hence weight of each decision maker is calculated as follows.

Step 1: The weight of decision makers based on importance given by plant head. Use Saaty(1980) comparison principle to develop the fuzzy comparison matrix. Apply synthetic extent analysis Chang, (1996) to find the decision maker weights. Apply consistency test.

Decision Maker	D1	D2	D3	D4
D1	ES	SI	VSI	EI
D2		ES	MI	SI
D3			ES	EP
D4				ES

Table 4.20 comparison matrix by plant head

Decision Maker	D1	D2	D3	D4	Weights
D1	(1,1,1)	(3,5,7)	(3,5,7)	(5,7,9)	(0.23,0.54,1.15)
D2	(1/7,1/5,1/3)	(1,1,1)	(1,3,5)	(3,5,7)	(0.11,0.26,0.64)
D3	(1/7,1/5,1/3)	(1/5,1/3,1)	(1,1,1)	(1,3,5)	(0.05,0.14,0.35)
D4	(1/9,1/7,1/5)	(1/7,1/5,1/3)	(1/5,1/3,1)	(1,1,1)	(0.03,0.05,0.12)

$\lambda_{max} = 4.26$, C.I = 0.085, C.R = 0.096 < 0.1

Table 4.21 Decision maker weights by plant head.

Step 2: Assign weights to the decision maker based on field experience, authority, responsibility and management position in the organization.

Decision Maker	Linguistic terms		
	FE	AR	MP
D1	H	V	V
D2	M	V	H
D3	H	M	H
D4	M	M	M

Table 4.22 .Linguistic matrix of decision maker

Decision Maker	Fuzzy number			weight
	FE	AR	MP	
D1	(0.4, 0.6, 0.8)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.53, 0.73, 0.93)
D2	(0.2, 0.4, 0.6)	(0.6, 0.8, 1)	(0.4, 0.6, 0.8)	(0.4, 0.6, 0.8)
D3	(0.4, 0.6, 0.8)	(0.2, 0.4, 0.6)	(0.4, 0.6, 0.8)	(0.33, 0.53, 0.73)
D4	(0.2, 0.4, 0.6)	(0.2, 0.4, 0.6)	(0.2, 0.4, 0.6)	(0.2, 0.4, 0.6)

Table 4.23 Decision maker weight on parameters

Step 3: Find the final weight of the decision maker. Aggregate the weight obtained in step 1 and step2.

Decision Maker	Weight on field experience, authority & management position.	Weight on perception of plant head	Final weight
D1	(0.53, 0.73, 0.93)	(0.23,0.54,1.15)	(0.38,0.64,1.04)
D2	(0.4, 0.6, 0.8)	(0.11,0.26,0.64)	(0.26,0.43,0.72)
D3	(0.33, 0.53, 0.73)	(0.05,0.14,0.35)	(0.19,0.34,0.54)
D4	(0.2, 0.4, 0.6)	(0.03,0.05,0.12)	(0.12,0.23,0.36)

Table 4.24.Final weight of decision maker

Step 4: The organization give different importance to qualitative criteria and quantitative criteria. Find the degree of importance of qualitative criteria and quantitative criteria in terms of weight.

	Criteria	C_{QNT}	C_{QLT}	(0.38,0.64,1.04)	Weight
D!	C_{QNT}	(1,1,1)	(1,3,5)	(0.25,0.75,1.86)	(0.1,0.48,1.93)
	C_{QLT}	(1/5,1/3,1)	(1,1,1)	(0.15,0.25,0.62)	(0.06,0.16,0.64)
	Criteria	C_{QNT}	C_{QLT}	(0.26,0.43,0.72)	Weight
D2	C_{QNT}	(1,1,1)	(3,5,7)	(0.43,0.83,1.56)	(0.11,.36,1.12)
	C_{QLT}	(1/7,1/5,1/3)	(1,1,1)	(0.12,0.17,0.26)	(0.03,.07,0.19)

D3	Criteria	C_{QNT}	C_{QLT}	(0.19,0.34,0.54)	Weight
	C_{QNT}	(1,1,1)	(5,7,9)	(0.5,0.86,1.39)	(0.1,0.29,0.75)
	C_{QLT}	(1/7,1/5,1/3)	(1,1,1)	(0.1,0.14,0.28)	(0.02,0.05,0.15)
D4	Criteria	C_{QNT}	C_{QLT}	(0.12,0.23,0.36)	Weight
	C_{QNT}	(1,1,1)	(1,1,3)	(0.33,0.50,1.20)	(0.04,0.12,0.43)
	C_{QLT}	(1/3,1,1)	(1,1,1)	(0.22,0.50,0.60)	(0.03,0.12,0.22)

Table 4.25.Pair-wise comparison matrix for qualitative and quantitative criteria

Step5: Find the coefficient of preference of both criteria by decision makers.

Criteria	Weight	crisp value	Normalized Value
C_{QNT}	(0.09,0.31,1.06)	0.49	0.77
C_{QLT}	(0.04,0.1,0.3)	0.15	0.23

Table 4.26 Defuzzification of qualitative and quantitative weights

Coefficient of preference of quantitative and qualitative criteria shown in table below:

Criteria	Coefficient of preference
C_{QNT}	0.77
C_{QLT}	0.23

Table 4.27 Coefficient of preference

Step 6: The decision makers find the weight of the customer qualitative criteria.

WHAT's	D1	D2	D3	D4	Qualitative Criteria Weights
Q	(7,9,9)	(7,9,9)	(5,7,9)	(7,9,9)	(1.57,3.52,5.99)
R	(5,7,9)	(7,9,9)	(1,3,5)	(5,7,9)	(1.13,2.75,5.45)
F	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(0.71,2.1,4.66)
S	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(1.19,2.87,5.99)
C	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(0.71,2.1,4.66)
AS	(1,3,5)	(1,3,5)	(3,5,7)	(1,3,5)	(0.33,1.4,3.60)

Table 4.28 Aggregate weight of qualitative criteria

Step 7: The response from experts from different companies to develop relationship matrix. Find the importance of HOW

Build phase I HOQ matrix of customer requirement and technical assessment criteria of the suppliers.

WHAT \ HOW	Weights	H1	H2	H3	H4	H5	H6
Quality	(1.57,3.52,5.99)	(4.5,8)	(6,7,9)	(3.33,4.33,7.67)	(4.67,5.67,8.33)	(4.67,5.67,8.33)	(3.67,4.5,7)
Reliability	(1.13,2.75,5.45)	(4,5,8)	(4.33,5.17,3.33)	(4.67,5.67,8.33)	(4,5,8)	(3.33,4.17,6.33)	(2.67,3.67,7.33)
Flexibility	(0.71,2.1,4.66)	(1.67,2.5,5)	(0.67,1.33,3.6)	(3.67,4.5,7)	(4.67,5.67,8.33)	(2.67,3.5,6)	(2.33,3.17,6.33)
Stability	(1.19,2.87,5.99)	(3.67,4.5,7)	(2.33,3,5)	(5.33,6.33,8.67)	(4.67,5.67,8.33)	(3,3.83,6.67)	(2.67,3.5,6)
Capability	(0.71,2.1,4.66)	(2.67,3.5,6)	(3,3.67,5.33)	(6,7,8)	(4.67,5.67,8.33)	(4.67,5.67,8.33)	(3,3.83,6.67)
Availability	(0.33,1.4,3.60)	(0.33,0.83,2.67)	(2,2.67,5.33)	(4.67,5.67,8.33)	(4,6,7)	(3,4,7)	(3.67,4.5,7)
Weights of How		(18.36,58,02,194.32)	(20.35,61.71,162.81)	(25.25,81.08,243.16)	(25.36,82.19, 246.23)	(20.9,67.27, 216)	(17,57,204)

H7	H8	H9	H10	H11	H12	H13
(4.33,5.17,3.33)	(5.33,6.33,8.67)	(3,4,7)	(4.67,5.67,8.33)	(5.33,6.33,8.67)	(1.67,2.67,5.33)	(2,2.83,5.67)
(4.67,5.67,8.33)	(4.67,5.67,8.33)	(1.67,2.33,4.6)	(4.33,5.33,7.67)	(4.33,5.17.7.33)	(0.67,1.33,3.67)	(1.67,2.17,4.33)
(5.33,6.33,8.67)	(3.33,4.33,7.67)	(2.33,3.17,5.33)	(4.67,5.67,8.33)	(4,5,8)	(2.67,3.5,6)	(0.67,1.17,3.33)
(3.67,4.67,7.33)	(2.33,3.17,5.33)	(1.67,2.33,4.67)	(4,4.67,6.33)	(3.33,4,6)	(3.67,4.5,7)	(2.33,3,5)
(4.33,5.17,7.33)	(5.33,6.33,8.67)	(3.33,4.17,6.33)	(5.33,6.33,8.67)	(4.67,5.67,8.33)	(4.33,5.17,7.33)	(3.67,4.5,7)
(2.67,3.5,6)	(3.33,4.33,7.67)	(0.33,0.83,2.67)	(2.67,3.5,6)	(2,2.83,5.67)	(0.33,1,3)	(0,0.33,1.67)
(24.2,76.2,205)	(23.7,75.4,233)	(12.7,43.8, 159.3)	(24.97,78.12, 230.4)	(24.04,74.35, 224.3)	(12.83,45.58, 166.8)	(10.88,36.91, 141.7)

H14	H15	H16	H17	H18	H19	H20
(1.67,2.67,5.33)	(2,2.83,5.67)	(4.67,5.67,8.33)	(5.33,6.33,8.67)	(2.33,3.33,6.67)	(0.33,1,3)	(4,5,8)
(0.67,1.33,3.67)	(2.67,3.5,6)	(2.67,3.33,5.67)	(4,4.67,6.33)	(2,2.67,5.33)	(3.33,4.33,7.67)	(4,5,8)
(2.67,3.5,6)	(2.67,3.33.5.67)	(3,4,7)	(2.33,3,5)	(3,3.83,6.67)	(2.33,3.17,6.33)	(3,3.67,5.33)
(3.67,4.5,7)	(3.33,4.17,6.33)	(4.33,5.17,7.33)	(4.33,5.17,7.33)	(2.67,3.5,6)	(2.67,3.67,7.33)	(3.67,4.5,7)
(4.33,5.17,7.33)	(1.67,2.33,4.67)	(4.67,5.67,8.33)	(4.67,5.67,8.33)	(2.67,3.33,5.67)	(4.67,5.67,8.33)	(3.67,4.5,7)
(0.33,1,3)	(2.67,3.33,5.67)	(2.67,3.33,5.67)	(3,3.83,6.67)	(4,4.67,6.33)	(1,1.83,4.67)	(1.33,2.17,5.33)
(12.83,45.58, 166.8)	(14.08,48.1, 173.2)	(21.83,68.92, 216.6)	(24,73.15, 216.5)	(14.44,50.68, 185.2)	(12.76,47.09,188.8)	(20.34,64.46,210.1)

H21	H22	H23	H24	H25	H26
(4.67,5.67,8.33)	(0.67,1.33,3.67)	(0.67,1.33,3.67)	(1.67,2.33,4.67)	(4,5,8)	(1.67,2.33,4.67)
(2.67,3.5,6)	(1.67,2.5,5)	(3,4,7)	(0.67,1.5,4)	(3.67,4.5,7)	(4.67,5.67,8.33)
(2.33,3.17,5.33)	(4.33,5.17,7.33)	(0.33,0.83,2.67)	(0.33,0.83,2.67)	(5.33,6.33,8.67)	(4.67,5.67,8.33)
(2,2.67,5.33)	(2.67,3.5,6)	(1.67,2.33,4,67)	(0.83,1.33,2.67)	(3.67,4.5,7)	(6,7,9)
(4.67,5.67,8.33)	(3,3.83,6.67)	(0.67,1.33,3.67)	(0,0.5,2)	(4.67,5.67,8.33)	(4.67,5.67,8.33)
(2.67,3.33,5.67)	(3.33,4,6)	(0.67,1.33,3.67)	(0.33,0.67,2.33)	(3,3.83,5.67)	(0.33,2.33,5.67)
(18.58,60.47,198.6)	(12.42,46.1,172)	(7.36,28.77,130.9)	(4.71,19.87,95.92)	(22.88,73.45, 227.6)	(21.78,70.96, 225.3

Table 4.29.Relationship matrix between WHAT’s and Evaluating factors (HOW’s)

Step 8: The decision makers D1, D2, D3 and D4 rate each supplier based on technical assessment criteria (evaluation criteria) using linguistic terms in Table 4.17 & Table 4.18. Find the combined weight of each technical assessment criteria (evaluation criteria) of each supplier.

SUPPLIER EVALUATION CRITERIA (HOW) WEIGHT														
S1			**S2**			**S3**			S4			S5		
0.36	1.76	4.84	0.81	2.14	5.47	1.19	2.46	5.99	0	0.41	2	0	0.41	2
0.52	1.49	4.16	0.55	1.93	5.11	0.55	1.93	5.11	0.03	0.58	2.36	0.21	1.41	4.03
0.93	2.25	5.63	0.43	1.81	4.93	0.29	1.43	4.12	0.21	1.47	4.3	0.24	1.64	4.66
1.07	2.35	5.81	0.43	1.81	4.93	0.07	0.73	2.72	0.93	2.25	5.63	0.24	1.64	4.66
0.81	2.14	5.47	0.81	2.14	5.47	0.81	2.14	5.47	0	0.41	2	0.1	0.89	3.04
0.36	1.76	4.84	0.36	1.76	4.84	0.36	1.76	4.84	0.36	1.76	4.84	0.36	1.76	4.84
0.43	1.81	4.93	0.33	1.17	3.11	0.25	1.18	3.58	0.05	0.67	2.54	0.14	1.15	3.58
1.07	2.35	5.81	0.47	1.68	4.66	0.74	2.08	5.36	0.07	0.73	2.72	0.21	1.47	4.3
0.43	1.81	4.93	0.43	1.81	4.93	0.43	1.81	4.93	0.24	1.64	4.66	0.43	1.81	4.93
1	2.29	5.72	0.36	1.76	4.84	0.36	1.76	4.84	0.14	1.15	3.58	0.36	1.49	4.21
1.19	2.46	5.99	0.36	1.76	4.84	0.74	2.08	5.36	0.14	1.16	3.62	0.24	1.64	4.66
0.55	1.93	5.11	1.19	2.46	5.99	1.19	2.46	5.99	0.55	1.93	5.11	0.43	1.81	4.93
1	2.29	5.72	1	2.29	5.72	0.33	0.81	2.63	0	0.35	1.82	0.21	1.47	4.3
0.48	1.6	4.39	0.74	1.81	4.73	0.15	0.7	2.54	0.05	0.67	2.54	0.14	1.15	3.58
0.24	1.64	4.66	0.81	2.13	5.45	0.1	0.91	3.08	0	0.41	2	0.1	0.89	3.04
0.05	0.67	2.54	0.05	0.67	2.54	0	0.41	2	0	0.41	2	0	0.41	2
0.24	1.64	4.66	0.55	1.64	4.46	0.13	1.06	3.4	0.1	0.89	3.04	0.1	0.89	3.04
0.1	0.89	3.04	0.14	1.15	3.58	0.1	0.89	3.04	0	0.41	2	0.14	1.15	3.58
0.19	1.39	4.12	0.13	1.06	3.4	0.19	1.39	4.12	0.1	0.89	3.04	0.13	1.06	3.4
0.05	0.67	2.54	0.1	0.89	3.04	0.05	0.67	2.54	0	0.41	2	0.05	0.67	2.54
0.57	1.71	4.64	0.74	2.08	5.36	0.69	1.82	4.82	0.48	1.21	3.56	0.13	1.06	3.4
0	0.41	2	0.74	1.81	4.73	1.07	2.35	5.81	0	0.41	2	0	0.41	2
0.08	0.84	2.9	0.1	0.89	3.04	0	0.41	2	0	0.41	2	0	0.41	2
0	0.41	2	0	0.41	2	0	0.41	2	0	0.41	2	0	0.41	2
0.55	1.93	5.11	0.55	1.93	5.11	0.17	1.32	3.94	0.08	0.84	2.9	0.08	0.84	2.9
0.55	1.64	4.46	0.55	1.64	4.46	0.07	0.73	2.72	0.07	0.73	2.72	0.14	1.16	3.62

SUPPLIER EVALUATION CRITERIA (HOW) WEIGHT															
S6			S7			S8			S9			S10			
0	0.41	2	0.03	0.58	2.36	0	0.41	2	0.24	1.64	4.66	0.24	1.64	4.66	
0.14	1.16	3.62	0.15	0.7	2.54	0.03	0.58	2.36	0.36	1.76	4.84	0.24	1.64	4.66	
0.31	1.5	4.3	0.15	0.7	2.54	0.2	0.95	3.08	0.24	1.64	4.66	0.24	1.64	4.66	
0.81	2.14	5.47	0.36	1.76	4.84	0.08	0.84	2.9	0.14	1.16	3.62	0.14	1.16	3.62	
0	0.41	2	0.03	0.58	2.36	0	0.41	2	0.24	1.64	4.66	0.24	1.64	4.66	
0.29	1.43	4.12	0	0.41	2	0	0.41	2	0.36	1.76	4.84	0.24	1.64	4.66	
0.17	1.32	3.94	0.03	0.58	2.36	0.03	0.58	2.36	0.36	1.49	4.21	0.36	1.49	4.21	
0.19	1.39	4.12	0.05	0.67	2.54	0	0.41	2	0.17	1.32	3.94	0.24	1.64	4.66	
0.24	1.64	4.66	0.24	1.64	4.66	0.19	1.39	4.12	0.43	1.81	4.93	0.19	1.39	4.12	
0.17	1.32	3.94	0	0.41	2	0	0.41	2	0.17	1.32	3.94	0.36	1.49	4.21	
0.19	1.39	4.12	0	0.41	2	0	0.41	2	0.24	1.64	4.66	1.19	2.46	5.99	
0.43	1.81	4.93	0.13	0.98	2.99	0	0.41	2	0.27	1.01	3.17	0.55	1.93	5.11	
0.1	0.89	3.04	0.03	0.58	2.36	0	0.41	2	0.4	1.64	4.57	0.62	1.97	5.2	
0.17	1.32	3.94	0	0.41	2	0.05	0.67	2.54	0.27	1.01	3.17	0.36	1.49	4.21	
0.19	1.39	4.12	0	0.41	2	0	0.41	2	0.27	1.01	3.17	0.24	1.64	4.66	
0	0.41	2	0	0.41	2	0	0.41	2	0.05	0.67	2.54	0.24	0.84	2.81	
0.1	0.89	3.04	0	0.41	2	0	0.41	2	0.17	1.32	3.94	0.13	1.06	3.4	
0.14	1.15	3.58	0	0.41	2	0	0.41	2	0.05	0.67	2.54	0.14	1.15	3.58	
0.19	1.39	4.12	0	0.41	2	0.1	0.89	3.04	0.33	1.32	3.85	0.16	1.21	3.76	
0.05	0.67	2.54	0	0.41	2	0	0.41	2	0.05	0.67	2.54	0.05	0.67	2.54	
0.13	1.06	3.4	0.1	0.89	3.04	0	0.41	2	0.03	0.58	2.36	0.45	1.6	4.48	
0.24	1.64	4.66	0	0.41	2	0	0.41	2	0	0.41	2	0	0.41	2	
0	0.41	2	0	0.41	2	0	0.41	2	0	0.41	2	0.17	1.32	3.94	
0	0.41	2	0	0.41	2	0	0.41	2	0	0.41	2	0	0.41	2	
0.17	1.32	3.94	0.08	0.84	2.9	0.08	0.84	2.9	0.39	1.12	3.35	0.48	1.6	4.39	
0.1	0.89	3.04	0.07	0.73	2.72	0	0.41	2	0.55	1.93	5.11	0.24	1.64	4.66	

Table 4.30 Supplier evaluation criteria (HOW) weight

Step 9: Build the phase II HOQ matrix for evaluation criteria as WHAT and supplier as HOW to find the supplier weights and scores

EVALUATION CRITERIA HOW				S1			S2			S3		
H1	18.36	58.02	194.32	0.36	1.76	4.84	0.81	2.14	5.47	1.19	2.46	5.99
H2	20.35	61.71	162.81	0.52	1.49	4.16	0.55	1.93	5.11	0.55	1.93	5.11
H3	25.25	81.08	243.16	0.93	2.25	5.63	0.43	1.81	4.93	0.29	1.43	4.12
H4	25.36	82.19	246.23	1.07	2.35	5.81	0.43	1.81	4.93	0.07	0.73	2.72
H5	20.9	67.27	216	0.81	2.14	5.47	0.81	2.14	5.47	0.81	2.14	5.47
H6	16.95	57	204	0.36	1.76	4.84	0.36	1.76	4.84	0.36	1.76	4.84
H7	24.2	76.2	205	0.43	1.81	4.93	0.33	1.17	3.11	0.25	1.18	3.58
H8	23.7	75.4	233	1.07	2.35	5.81	0.47	1.68	4.66	0.74	2.08	5.36
H9	12.7	43.8	159.3	0.43	1.81	4.93	0.43	1.81	4.93	0.43	1.81	4.93
H10	24.97	78.12	230.4	1	2.29	5.72	0.36	1.76	4.84	0.36	1.76	4.84
H11	24.04	74.35	224.3	1.19	2.46	5.99	0.36	1.76	4.84	0.74	2.08	5.36
H12	12.83	45.58	166.8	0.55	1.93	5.11	1.19	2.46	5.99	1.19	2.46	5.99
H13	10.88	36.91	141.7	1	2.29	5.72	1	2.29	5.72	0.33	0.81	2.63
H14	12.83	45.58	166.8	0.48	1.6	4.39	0.74	1.81	4.73	0.15	0.7	2.54
H15	14.08	48.1	173.2	0.24	1.64	4.66	0.81	2.13	5.45	0.1	0.91	3.08
H16	21.83	68.92	216.6	0.05	0.67	2.54	0.05	0.67	2.54	0	0.41	2
H17	24	73.15	216.5	0.24	1.64	4.66	0.55	1.64	4.46	0.13	1.06	3.4
H18	14.44	50.68	185.2	0.1	0.89	3.04	0.14	1.15	3.58	0.1	0.89	3.04
H19	12.76	47.09	188.8	0.19	1.39	4.12	0.13	1.06	3.4	0.19	1.39	4.12
H20	20.34	64.46	210.1	0.05	0.67	2.54	0.1	0.89	3.04	0.05	0.67	2.54
H21	18.58	60.47	198.6	0.57	1.71	4.64	0.74	2.08	5.36	0.69	1.82	4.82
H22	12.42	46.1	172	0	0.41	2	0.74	1.81	4.73	1.07	2.35	5.81
H23	7.36	28.77	130.9	0.08	0.84	2.9	0.1	0.89	3.04	0	0.41	2
H24	4.71	19.87	95.92	0	0.41	2	0	0.41	2	0	0.41	2
H25	22.88	73.45	227.6	0.55	1.93	5.11	0.55	1.93	5.11	0.17	1.32	3.94
H26	21.78	70.98	225.3	0.55	1.64	4.46	0.55	1.64	4.46	0.07	0.73	2.72
SUPPLIER WEIGHT				259.8,16459.02,22267.7			227.67,12483.5,21931			181.6,14404,19221		

S4			S5			S6			S7		
0	0.41	2	0	0.41	2	0	0.41	2	0.03	0.58	2.36
0.03	0.58	2.36	0.21	1.41	4.03	0.14	1.16	3.62	0.15	0.7	2.54
0.21	1.47	4.3	0.24	1.64	4.66	0.31	1.5	4.3	0.15	0.7	2.54
0.93	2.25	5.63	0.24	1.64	4.66	0.81	2.14	5.47	0.36	1.76	4.84
0	0.41	2	0.1	0.89	3.04	0	0.41	2	0.03	0.58	2.36
0.36	1.76	4.84	0.36	1.76	4.84	0.29	1.43	4.12	0	0.41	2
0.05	0.67	2.54	0.14	1.15	3.58	0.17	1.32	3.94	0.03	0.58	2.36
0.07	0.73	2.72	0.21	1.47	4.3	0.19	1.39	4.12	0.05	0.67	2.54
0.24	1.64	4.66	0.43	1.81	4.93	0.24	1.64	4.66	0.24	1.64	4.66
0.14	1.15	3.58	0.36	1.49	4.21	0.17	1.32	3.94	0	0.41	2
0.14	1.16	3.62	0.24	1.64	4.66	0.19	1.39	4.12	0	0.41	2
0.55	1.93	5.11	0.43	1.81	4.93	0.43	1.81	4.93	0.13	0.98	2.99
0	0.35	1.82	0.21	1.47	4.3	0.1	0.89	3.04	0.03	0.58	2.36
0.05	0.67	2.54	0.14	1.15	3.58	0.17	1.32	3.94	0	0.41	2
0	0.41	2	0.1	0.89	3.04	0.19	1.39	4.12	0	0.41	2
0	0.41	2	0	0.41	2	0	0.41	2	0	0.41	2
0.1	0.89	3.04	0.1	0.89	3.04	0.1	0.89	3.04	0	0.41	2
0	0.41	2	0.14	1.15	3.58	0.14	1.15	3.58	0	0.41	2
0.1	0.89	3.04	0.13	1.06	3.4	0.19	1.39	4.12	0	0.41	2
0	0.41	2	0.05	0.67	2.54	0.05	0.67	2.54	0	0.41	2
0.48	1.21	3.56	0.13	1.06	3.4	0.13	1.06	3.4	0.1	0.89	3.04
0	0.41	2	0	0.41	2	0.24	1.64	4.66	0	0.41	2
0	0.41	2	0	0.41	2	0	0.41	2	0	0.41	2
0	0.41	2	0	0.41	2	0	0.41	2	0	0.41	2
0.08	0.84	2.9	0.08	0.84	2.9	0.17	1.32	3.94	0.08	0.84	2.9
0.07	0.73	2.72	0.14	1.16	3.62	0.1	0.89	3.04	0.07	0.73	2.72
71.26,5317.6,15053			76.26,10433.2,17721			84.73,9205.3,17968			28.84,4558.6,12261		

S8			S9			S10		
0	0.41	2	0.24	1.64	4.66	0.24	1.64	4.66
0.03	0.58	2.36	0.36	1.76	4.84	0.24	1.64	4.66
0.2	0.95	3.08	0.24	1.64	4.66	0.24	1.64	4.66
0.08	0.84	2.9	0.14	1.16	3.62	0.14	1.16	3.62
0	0.41	2	0.24	1.64	4.66	0.24	1.64	4.66
0	0.41	2	0.36	1.76	4.84	0.24	1.64	4.66
0.03	0.58	2.36	0.36	1.49	4.21	0.36	1.49	4.21
0	0.41	2	0.17	1.32	3.94	0.24	1.64	4.66
0.19	1.39	4.12	0.43	1.81	4.93	0.19	1.39	4.12
0	0.41	2	0.17	1.32	3.94	0.36	1.49	4.21
0	0.41	2	0.24	1.64	4.66	1.19	2.46	5.99
0	0.41	2	0.27	1.01	3.17	0.55	1.93	5.11
0	0.41	2	0.4	1.64	4.57	0.62	1.97	5.2
0.05	0.67	2.54	0.27	1.01	3.17	0.36	1.49	4.21
0	0.41	2	0.27	1.01	3.17	0.24	1.64	4.66
0	0.41	2	0.05	0.67	2.54	0.24	0.84	2.81
0	0.41	2	0.17	1.32	3.94	0.13	1.06	3.4
0	0.41	2	0.05	0.67	2.54	0.14	1.15	3.58
0.1	0.89	3.04	0.33	1.32	3.85	0.16	1.21	3.76
0	0.41	2	0.05	0.67	2.54	0.05	0.67	2.54
0	0.41	2	0.03	0.58	2.36	0.45	1.6	4.48
0	0.41	2	0	0.41	2	0	0.41	2
0	0.41	2	0	0.41	2	0.17	1.32	3.94
0	0.41	2	0	0.41	2	0	0.41	2
0.08	0.84	2.9	0.39	1.12	3.35	0.48	1.6	4.39
0	0.41	2	0.55	1.93	5.11	0.24	1.64	4.66
13.08,2698.8,11296			103.7,9704.7,18064			141,9612.8,20169		

Table 4.31 Supplier weight

Step 10: Find the score of supplier using the supplier weights obtained in step 8.

SUPPLIER	SUPPLIER WEIGHTS			CRISP VALUE	SCORE	RANK
S1	259.8	16459.02	22267.7	12995.5	1	**1**
S2	227.67	12483.51	21931	11547.4	0.8261	**2**
S3	181.64	14403.95	19221	11268.9	0.7926	**3**
S4	71.262	5317.667	15053	6813.98	0.2576	**8**
S5	76.25575	10433.17	17721	9410.14	0.5694	**5**
S6	84.73093	9205.33	17968	9086.02	0.5305	**7**
S7	28.83615	4558.564	12261	5616.13	0.1137	**9**
S8	13.0844	2698.804	11296	4669.3	0	**10**
S9	103.7087	9704.709	18064	9290.81	0.5551	**6**
S10	140.9962	9612.832	20169	9974.28	0.6371	**4**

Table 4.32 Supplier score and rank

Step 11: Arrange the obtained supplier score in descending order to rank the suppliers based on the qualitative criteria.

RANK OF SUPPLIERS										
RANK	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
SUPPLIER	**S1**	**S2**	**S3**	**S10**	**S5**	**S9**	**S6**	**S4**	**S7**	**S8**

Table 4.33 Rank of supplier on qualitative criteria

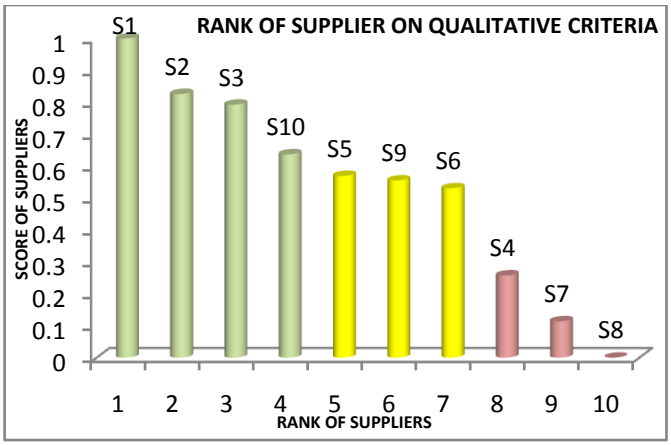


Figure 4.15 Rank of supplier on qualitative criteria

Stage II. The decision maker assesses the performance of the supplier on the five measurable criteria. the criteria considered are 1. Quantity the supplier is ready to supply to the buyer. 2. The price in rupees offered by the supplier for the minimum quantity to be purchased by the buyer. 3. The delivery time in days the supplier is assuring to the buyer to materialize the supply. 4. The time duration in days the supplier is ready to wait for the payment from the buyer. 5. The distance in kilometer of the supplier premises from the buyer receiving point. The data for these quantitative criteria is collected from ten suppliers for the assessment.

Step 1: The collected data is shown in the Table 4.34.

supplier	order quantity	price	delivery time	credit time	proximity
S1	500	340	2	30	57
S2	5000	200	4	45	45
S3	200	400	3	15	38
S4	500	358	10	45	25
S5	100	450	1	60	42
S6	300	320	4	15	20
S7	300	340	10	15	27
S8	500	300	8	30	12
S9	200	355	3	30	28
S10	300	330	15	60	17

Table 4.34 Quantitative measures

Step 2: Transform the data for positivity based on benefit criteria and cost criteria.

SUPPLIER	TRANSFORMED DATA				
S1	0.1837	0.2647	0.4641	0.33	0
S2	0	1	0.1961	0.67	0.071
S3	0.4898	0.1071	0.2855	0	0.134
S4	0.1837	0.2119	0.0354	0.67	0.343
S5	1	0.0079	1	1	0.096
S6	0.3197	0.3304	0.1961	0	0.496
S7	0.3197	0.2647	0.0354	0	0.298
S8	0.1837	0.4048	0.0622	0.33	1.005
S9	0.4898	0.2203	0.2855	0.33	0.278
S10	0.3197	0.2965	-0.0004	1	0.631

Table 4.35 Transformed quantitative measures

Step 3: Perform partial average analysis to obtain the supplier score.

SUPPLIER	PARTIAL AVERAGES					SCORE
S1	0.184	0.224	0.304	0.311	0.249	0.311
S2	0	0.5	0.399	0.467	0.387	0.5
S3	0.49	0.298	0.294	0.221	0.203	0.49
S4	0.184	0.198	0.144	0.275	0.289	0.289
S5	1	0.504	0.669	0.752	0.621	1
S6	0.32	0.325	0.282	0.212	0.268	0.325
S7	0.32	0.292	0.207	0.155	0.184	0.32
S8	0.184	0.294	0.217	0.245	0.397	0.397
S9	0.49	0.355	0.332	0.331	0.321	0.49
S10	0.32	0.308	0.205	0.404	0.449	0.449

Table 4.36 Partial averages of quantitative data

Step 4: Arrange the score in descending order to find the rank of supplier.

RANK OF SUPPLIERS										
RANK	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
SUPPLIER	**S5**	**S2**	**S3**	**S9**	**S10**	**S8**	**S6**	**S7**	**S1**	**S4**

Table 4.37 Rank of supplier on quantitative criteria

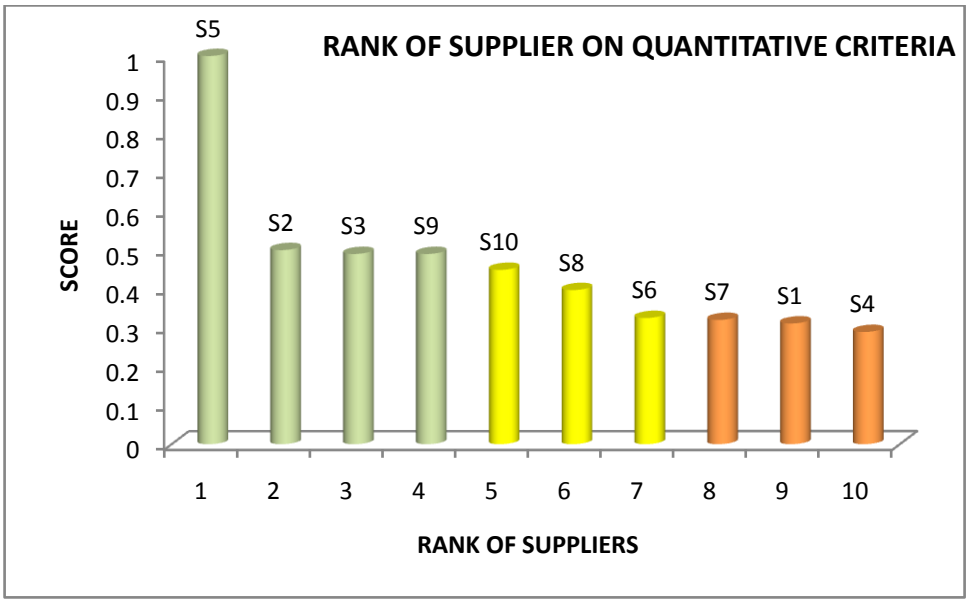


Figure 4.16 Rank of supplier on quantitative criteria

Stage III: The suppliers are assessed on both criteria. The scores obtained in stage I and stage II are combined to obtain the overall score for the performance of the supplier. The combined score is arranged in descending order to find the final rank of the supplier.

Step 1: Apply the equation of overall score: $S_{SCORE} = \alpha_1 * S_{QNT} + \alpha_2 * S_{QLT}$, where α_i i=1,2 are coefficient of preference α. $\alpha_1 = \alpha$ and $\alpha_2 = 1 - \alpha$

SUPPLIER	SCORE		OVERALL SCORE
	QUALITATIVE	QUANTITATIVE	
S1	1	0.311	0.46967
S2	0.8261	0.5	0.57514
S3	0.7926	0.49	0.56074
S4	0.2576	0.289	0.28177
S5	0.5694	1	0.90096
S6	0.5305	0.325	0.37226
S7	0.1137	0.32	0.27255
S8	0	0.397	0.30569
S9	0.5551	0.49	0.50497
S10	0.6371	0.449	0.49226

Table 4.38 Overall score of suppliers

Step 2: Arrange score in descending order to final rank the supplier.

OVERALL RANK OF SUPPLIERS										
RANK	1	2	3	4	5	6	7	8	9	10
SUPPLIER	S5	S2	S3	S9	S10	S1	S6	S8	S4	S7

Table 4.39 Final rank of suppliers

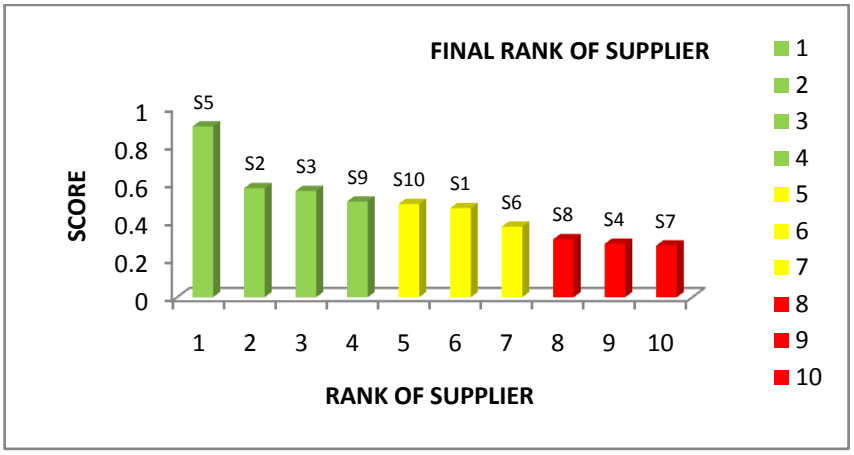


Figure 4.17 Final rank of suppliers

RANK OF SUPPLIERS										
QUANTITATIVE RANK	1	2	3	4	5	6	7	8	9	10
SUPPLIER	S5	S2	S3	S9	S10	S8	S6	S7	S1	S4
QUALITATIVE RANK	1	2	3	4	5	6	7	8	9	10
SUPPLIER	S1	S2	S3	S10	S5	S9	S6	S4	S7	S8
OVERALL RANK OF SUPPLIERS										
COMBINED RANK	1	2	3	4	5	6	7	8	9	10
SUPPLIER	S5	S2	S3	S9	S10	S1	S6	S8	S4	S7

Table 4.40 Comparison of rank of suppliers

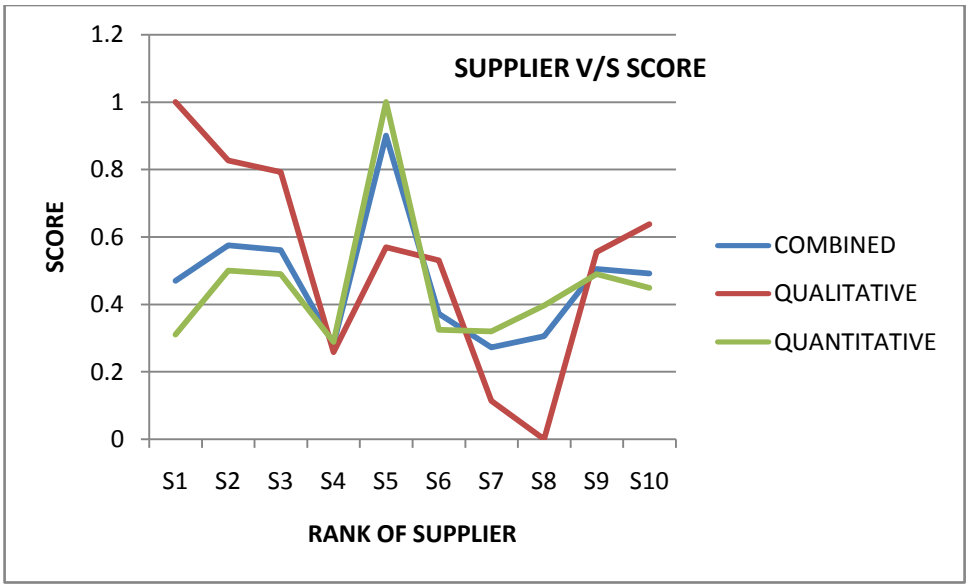


Figure 4.18 Comparison of rank of suppliers

Sensitivity Analysis: The effect of variation of qualitative coefficient of preference is assessed to understand the influence of qualitative and quantitative criteria on the supplier selection. Table 4.41 The suppliers are grouped into three categories. The group I is the preferred suppliers comprises of four suppliers, group II suppliers are considered for the supplier development initiative and group III suppliers are pruned. Group II and group III consists of three suppliers each.

α = COEFFICIENT OF PREFERENCE										
α	SUPPLIER PREFERENCE ORDER									
0	S5	S2	S3	S9	S10	S8	S6	S7	S1	S4
0.01	S5	S2	S3	S9	S10	S8	S6	S1	S7	S4
0.05	S5	S2	S3	S9	S10	S8	S1	S6	S7	S4
0.1	S5	S2	S3	S9	S10	S1	S8	S6	S7	S4
0.11	S5	S2	S3	S9	S10	S1	S8	S6	S7	S4
0.12	S5	S2	S3	S9	S10	S1	S6	S8	S7	S4
0.13	S5	S2	S3	S9	S10	S1	S6	S8	S7	S4
0.14	S5	S2	S3	S9	S10	S1	S6	S8	S7	S4
0.15	S5	S2	S3	S9	S10	S1	S6	S8	S7	S4
0.2	S5	S2	S3	S9	S10	S1	S6	S8	S4	S7
0.21	S5	S2	S3	S9	S10	S1	S6	S8	S4	S7
0.22	S5	S2	S3	S9	S10	S1	S6	S8	S4	S7
0.23	S5	S2	S3	S9	S10	S1	S6	S8	S4	S7

0.24	S5	S2	S3	S9	S10	S1	S6	S8	S4	S7
0.25	S5	S2	S3	S9	S10	S1	S6	S8	S4	S7
0.26	S5	S2	S3	S9	S10	S1	S6	S8	S4	S7
0.27	S5	S2	S3	S9	S10	S1	S6	S8	S4	S7
0.28	S5	S2	S3	S9	S1	S10	S6	S8	S4	S7
0.29	S5	S2	S3	S1	S9	S10	S6	S4	S8	S7
0.3	S5	S2	S3	S1	S9	S10	S6	S4	S8	S7
0.34	S5	S2	S3	S1	S9	S10	S6	S4	S8	S7
0.35	S5	S2	S3	S1	S10	S9	S6	S4	S8	S7
0.4	S5	S2	S3	S1	S10	S9	S6	S4	S8	S7
0.45	S5	S2	S3	S1	S10	S9	S6	S4	S7	S8
0.5	S5	S2	S1	S3	S10	S9	S6	S4	S7	S8
0.55	S5	S1	S2	S3	S10	S9	S6	S4	S7	S8
0.6	S5	S1	S2	S3	S10	S9	S6	S4	S7	S8
0.65	S1	S5	S2	S3	S10	S9	S6	S4	S7	S8
0.7	S1	S2	S3	S5	S10	S9	S6	S4	S7	S8
0.75	S1	S2	S3	S5	S10	S9	S6	S4	S7	S8
0.8	S1	S2	S3	S5	S10	S9	S6	S4	S7	S8
0.85	S1	S2	S3	S5	S10	S9	S6	S4	S7	S8
0.9	S1	S2	S3	S10	S5	S9	S6	S4	S7	S8
0.95	S1	S2	S3	S10	S5	S9	S6	S4	S7	S8
1	S1	S2	S3	S10	S5	S9	S6	S4	S7	S8

Table 4.41 Rank of suppliers and sensitivity analysis

with **'α' as qualitative coefficient of preference**

It is observed that supplier S1 is initially in the Group II and Group III in the range α=0 -0.28. As coefficient of preference increases the S1 occupies position in Group I. The S1 to maintain rank 1 in the range α=0.65-1 due to influence of qualitative criteria. The S2 and S3 are in Group I for entire α=0-1, and ranks 2 and 3. S1 and S2 are having balanced qualitative and quantitative criteria. The suppliers S4, S7 and S8 are in Group III, having last ranking in the supplier preference order and not considered in the final supplier selection list as S4, S7 and S8 are weak in both type of criteria. The supplier S6 is in Group II for α=0-1 except for range α=0.05 to α=0.11. The supplier S9 quantitative criteria are influence to remain in Group I in α=0 -0.28 and then as α value increase, supplier S9 shift to Group II. Finally supplier S10 is in Group II and shifts in Group I in range α=0.9-1 because supplier

S10 is strong in qualitative criteria and organisation prefer qualitative criteria for supplier selection. The quantitative ranking has influence of the operation and functions of the company. The qualitative ranking is subjective assessment of the suppliers. The combined score give final ranking of the suppliers. The organisation under research study has 77% quantitative preference and 23% qualitative preference. With the **'α=0.23' as qualitative coefficient of preference** supplier ranking is

S5	S2	S3	S9	S10	S1	S6	S8	S4	S7

The supplier ranking remains constant in the range **α=0.12 to 0.28.** The decision maker has to select the supplier from the available set of supplier. As supplier is not excel in all criteria, the trade off is to be made between the criteria during supplier selection decision. The coefficient of preference range **α=0.12 to 0.28** acts as a cushion for the decision maker during supplier selection process. Any variation in qualitative criteria among the supplier within the range does not have effect on the supplier selection decision and supplier ranking. The suppliers S5, S2, S3 and S9 are selected as final suppliers. Supplier S10, S1 and S6 are potential suppliers considered by buyer for supplier development initiative and are backup suppliers in case of emergency arises. The suppliers S4, S7 and S8 are not preferred due to weak performance and low potential in supplier development initiative. Based on the exploratory research the organisation can manage 3 to 5 suppliers comfortably. It can be inferred from the Table 4.40 that supplier S2, S3 and S5 are stable supplier and can be selected in any range of '**α'.** Suppliers S1, S10 and S9 are maintained as the backup suppliers. Hence for this research supplier base is S2, S3, S5, S1, S10 and S9 for the organisation .

4.14.2: Group decision making and two suppliers

The proposed method is applied in a medium scale company in Goa, India. The company is located in a rural area and is a principal vendor to multinational company having global operations. The company is named as XYZ firm for the confidentiality of information and data. The company supplies the products and components manufactured to the warehouses or the project sites in India as per the instructions of the customer. The supplied components are used on site by the customer. As per the standard procedure implemented by the customer all the vendors/suppliers are to be approved and certified by the customer. The company under is a ISO certified company. The company considered for study has its suppliers. These second tier suppliers are also required to be approved and certified by the customer. The functionality of the final installed product is main concern to the customer. The suppliers supplying critical components are assessed thoroughly before selecting as potential suppliers by the customer before giving supplier approval. The purchase orders are issued to the approved to these suppliers only by the company to mitigate on site problems. The company needs suppliers for the supply of corrugated boxes. The supplier criteria considered in the case 1 are used in this study after open discussion with the company officials and plant head.

The plant head constitute four members decision committee. The decision makers (D1, D2, D3 and D4) belong to manufacturing, quality, purchase and assembly production sections. The company has two suppliers for the corrugated products. The company has moderately high dependence on these suppliers due to difficulty of alternative suppliers. The steps followed in the supplier selection are as discussed in case 2 are applied for supplier selection. The linguistic tables shown in case 2 are adopted for assessment and linguistic variables.

Step 1: The customer criteria and the supplier technical assessment criteria are finalized. The customer (buyer) requirement criteria and assessment criteria are shown in Table 4.6 and Table4.9 above. The assessment (evaluating) criteria are explained in Table 4.9.

qualitative criteria	quality, reliability, flexibility, stability, capability, availability & sustainability
quantitative criteria	price, quantity, proximity, credit time, delivery time

Table 4.6 customer requirement criteria (WHAT)

Step 2: Assign weights to the decision maker based on field experience (FE), authority and responsibility (AR) and management position (MP) in the organization.

Decision Maker	Linguistic terms		
	FE	AR	MP
D1	M	M	H
D2	L	M	M
D3	L	M	M
D4	M	M	H

Table 4.42 Linguistic matrix of decision maker

Decision Maker	Fuzzy number			weight
	FE	AR	MP	
D1	(0.2, 0.4, 0.6)	(0.2, 0.4, 0.6)	(0.4, 0.6, 0.8)	(0.27,0.47, 0.67)
D2	(0,0.2, 0.4)	(0.2, 0.4, 0.6)	(0.2, 0.4, 0.6)	(0.13,0.33,0.53)
D3	(0,0.2, 0.4)	(0.2, 0.4, 0.6)	(0.2, 0.4, 0.6)	(0.13,0.33,0.53)
D4	(0.2, 0.4, 0.6)	(0.2, 0.4, 0.6)	(0.4, 0.6, 0.8)	(0.27,0.47, 0.67)

Table 4.43 Decision maker weight on parameters

Step 3: The organization give different importance to qualitative criteria and quantitative criteria. Find the degree of importance of qualitative criteria and quantitative criteria in terms of weight.

	Criteria	C_{QNT}	C_{QLT}	(0.27,0.47, 0.67	Weight
D1	C_{QLT}	(1,1,1)	(3,5,7)	(0.43,0.83,1.56)	(0.11,.39,1.01)
	C_{QNT}	(1/7,1/5,1/3)	(1,1,1)	(0.12,0.17,0.26)	(0.03,.05,0.17)
	Criteria	C_{QNT}	C_{QLT}	(0.13,0.33,0.53	Weight
D2	C_{QLT}	(1,1,1)	(1,1,3)	(0.33,0.50,1.20)	(0.04,0.17,0.64)
	C_{QNT}	(1/3,1,1)	(1,1,1)	(0.22,0.50,0.60)	(0.03,0.17,0.32)

	Criteria	C_{QNT}	C_{QLT}	(0.13,0.33,0.53	Weight
D3	C_{QLT}	(1,1,1)	(1,1,3)	(0.33,0.50,1.20)	(0.04,0.17,0.64)
	C_{QNT}	(1/3,1,1)	(1,1,1)	(0.22,0.50,0.60)	(0.03,0.17,0.32)
	Criteria	C_{QNT}	C_{QLT}	(0.27,0.47, 0.67	Weight
D4	C_{QLT}	(1,1,1)	(5,7,9)	(0.5,0.86,1.39)	(0.14,0.40,0.93)
	C_{QNT}	(1/7,1/5,1/3)	(1,1,1)	(0.1,0.14,0.28)	(0.03,0.07,0.19)

Table 4.44 Pair-wise comparison matrix for qualitative and quantitative criteria

Step4: Find the coefficient of preference of both criteria by decision makers.

Criteria	Weight	crisp value	Normalized Value
C_{QLT}	(0.08,0.28,0.81)	0.39	0.71
C_{QNT}	(0.03,0.12,0.33)	0.16	0.29

Table 4.45 Defuzzification of qualitative and quantitative weights

Coefficient of preference of quantitative and qualitative criteria shown in Table4.45 below:

Criteria	Coefficient of preference
C_{QLT}	0.71
C_{QNT}	0.29

Table 4.46 Coefficient of preference

Qualitative criteria dominate in this case. The value of qualitative importance is 71% and quantitative 29%. To avoid the last minute problem at site, customer dissatisfaction and after sales service the firm stress on the quality of the product rather than the quantitative criteria. The MNC like to protect its brand name in the market for competitive advantage. The production is scheduled as per the annual plan defined by the supplier's customer. Only qualitative model is used using QFD approach to select supplier. Analysis of qualitative model follows.

Step 5: Relative evaluation of customer criteria by the decision makers.

Customer criteria	D1	D2	D3	D4
Q	SI	SI	SI	SI
R	SI	SI	VSI	VSI
F	EP	MI	EP	SI
S	SI	SI	SI	EP
C	MI	MI	VSI	SI
AS	SI	SI	SI	VSI

Table 4.47 Linguistic assessment of customer qualitative criteria

Step 6: Find the relative weights of customer qualitative criteria.

Customer criteria	D1	D2	D3	D4	Qualitative Criteria Weights
	0.27,0.47,0.67)	(0.13,0.33,0.53)	(0.13,0.33,0.53)	(0.27,0.47,0.67)	
Q	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(0.6,2,4.2)
R	(3,5,7)	(3,5,7)	(5,7,9)	(5,7,9)	(0.8,2.4,4.8)
F	(1,1,3)	(1,3,5)	(1,1,3)	(3,5,7)	(0.34,1.04,2.74)
S	(3,5,7)	(3,5,7)	(3,5,7)	(1,1,3)	(0.47,1.53,3.53)
C	(1,3,5)	(1,3,5)	(5,7,9)	(3,5,7)	(.47,1.77,3.87)
AS	(3,5,7)	(3,5,7)	(3,5,7)	(5,7,9)	(0.74,2.24,4.54)

Table 4.48 Aggregate weight of customer qualitative criteria

Step 7: The response from experts from different companies to develop relationship matrix. Find the importance of HOW

Build phase I HOQ matrix of customer requirement and technical assessment criteria of the suppliers.

WHAT \ HOW	Weights	H1	H2	H3	H4	H5	H6
Q	(0.6,2,4.2)	(4.5,8)	(6,7,9)	(3.33,4.33,7.67)	(4.67,5.67,8.33)	(4.67,5.67,8.33)	(3.67,4.5,7)
R	(0.8,2.4,4.8)	(4,5,8)	(4.33,5.17,3.33)	(4.67,5.67,8.33)	(4,5,8)	(3.33,4.17,6.33)	(2.67,3.67,7.33)
F	(0.34,1.04,2.74)	(1.67,2.5,5)	(0.67,1.33,3.6)	(3.67,4.5,7)	(4.67,5.67,8.33)	(2.67,3.5,6)	(2.33,3.17,6.33)
S	(0.47,1.53,3.53)	(3.67,4.5,7)	(2.33,3,5)	(5.33,6.33,8.67)	(4.67,5.67,8.33)	(3,3.83,6.67)	(2.67,3.5,6)
C	(.47,1.77,3.87)	(2.67,3.5,6)	(3,3.67,5.33)	(6,7,8)	(4.67,5.67,8.33)	(4.67,5.67,8.33)	(3,3.83,6.67)
AS	(0.74,2.24,4.54)	(0.33,0.83,2.67)	(2,2.67,5.33)	(4.67,5.67,8.33)	(4,6,7)	(3,4,7)	(3.67,4.5,7)
Weights of How		(9.42,38.96.148.13)	(11.29.40.24,127.82)	(15.84,51.9,193.71)	(15.03,50.75,192.46)	(12.25,42.76,171.64)	10.56,35.16,162.74)

H7	H8	H9	H10	H11	H12	H13
(4.33,5.17,3.33)	(5.33,6.33,8.67)	(3,4,7)	(4.67,5.67,8.33)	(5.33,6.33,8.67)	(1.67,2.67,5.33)	(2,2.83,5.67)
(4.67,5.67,8.33)	(4.67,5.67,8.33)	(1.67,2.33,4.6)	(4.33,5.33,7.67)	(4.33,5.17.7.33)	(0.67,1.33,3.67)	(1.67,2.17,4.33)
(5.33,6.33,8.67)	(3.33,4.33,7.67)	(2.33,3.17,5.33)	(4.67,5.67,8.33)	(4,5,8)	(2.67,3.5,6)	(0.67,1.17,3.33)
(3.67,4.67,7.33)	(2.33,3.17,5.33)	(1.67,2.33,4.67)	(4,4.67,6.33)	(3.33,4,6)	(3.67,4.5,7)	(2.33,3,5)
(4.33,5.17,7.33)	(5.33,6.33,8.67)	(3.33,4.17,6.33)	(5.33,6.33,8.67)	(4.67,5.67,8.33)	(4.33,5.17,7.33)	(3.67,4.5,7)
(2.67,3.5,6)	(3.33,4.33,7.67)	(0.33,0.83,2.67)	(2.67,3.5,6)	(2,2.83,5.67)	(0.33,1,3)	(0,0.33,1.67)
(13.99,48.79,161.7)	(14.2,48.63,186.42)	(6.57,28.59,123.33)	(14.31,50.34,179.92)	(13.34,48.06,174.72)	(6.5,29.53,125.52)	(5.6,25.44,107.74)

H14	H15	H16	H17	H18	H19	H20
(1.67,2.67,5.33)	(2,2.83,5.67)	(4.67,5.67,8.33)	(5.33,6.33,8.67)	(2.33,3.33,6.67)	(0.33,1,3)	(4,5,8)
(0.67,1.33,3.67)	(2.67,3.5,6)	(2.67,3.33,5.67)	(4,4.67,6.33)	(2,2.67,5.33)	(3.33,4.33,7.67)	(4,5,8)
(2.67,3.5,6)	(2.67,3.33.5.67)	(3,4,7)	(2.33,3,5)	(3,3.83,6.67)	(2.33,3.17,6.33)	(3,3.67,5.33)
(3.67,4.5,7)	(3.33,4.17,6.33)	(4.33,5.17,7.33)	(4.33,5.17,7.33)	(2.67,3.5,6)	(2.67,3.67,7.33)	(3.67,4.5,7)
(4.33,5.17,7.33)	(1.67,2.33,4.67)	(4.67,5.67,8.33)	(4.67,5.67,8.33)	(2.67,3.33,5.67)	(4.67,5.67,8.33)	(3.67,4.5,7)
(0.33,1,3)	(2.67,3.33,5.67)	(2.67,3.33,5.67)	(3,3.83,6.67)	(4,4.67,6.33)	(1,1.83,4.67)	(1.33,2.17,5.33)
(6.5,29.53,125.52)	(8.62,29.83,136.46)	(12.22,43.48,167.73)	(13.69,47.09,171.38)	(9.55,30.26,145.78)	(7.89,32.66,148.57)	(11.11,42.27,164.98)

H21	H22	H23	H24	H25	H26
(4.67,5.67,8.33)	(0.67,1.33,3.67)	(0.67,1.33,3.67)	(1.67,2.33,4.67)	(4,5,8)	(1.67,2.33,4.67)
(2.67,3.5,6)	(1.67,2.5,5)	(3,4,7)	(0.67,1.5,4)	(3.67,4.5,7)	(4.67,5.67,8.33)
(2.33,3.17,5.33)	(4.33,5.17,7.33)	(0.33,0.83,2.67)	(0.33,0.83,2.67)	(5.33,6.33,8.67)	(4.67,5.67,8.33)
(2,2.67,5.33)	(2.67,3.5,6)	(1.67,2.33,4,67)	(0.83,1.33,2.67)	(3.67,4.5,7)	(6,7,9)
(4.67,5.67,8.33)	(3,3.83,6.67)	(0.67,1.33,3.67)	(0,0.5,2)	(4.67,5.67,8.33)	(4.67,5.67,8.33)
(2.67,3.33,5.67)	(3.33,4,6)	(0.67,1.33,3.67)	(0.33,0.67,2.33)	(3,3.83,5.67)	(0.33,2.33,5.67)
(10.89,38.6,157)	(8.43,27.97,135.77)	(4.53,19.92,105.27)	(2.53,11.64,74.78)	(13.39,46.3,176.02)	(11.68,47.15,175.23)

Table 4.49 Relationship matrix between WHAT's and Evaluating factors (HOW's)

Step 8: Combined weight of evaluating criteria of supplier by the decision makers.

Evaluating criteria	D1	D 2	D 3	D 4	combined of weight criteria
	(0.27,0.47,0.67)	(0.13,0.33, 0.53)	(0.13,0.33, 0.53)	(0.27,0.47,0.67)	
H1	(1,4,7)	(1,4,7)	(5,6,9)	(1,4,7)	(0.33,1.77,4.47)
H2	(5,6,9)	(1,4,7)	(5,6,9)	(5,6,9)	(0.87,2.24,5.14)
H3	(1,4,7)	(1,4,7)	(5,6,9)	(1,4,7)	(0.33,1.77,4.47)
H4	(1,4,7)	(5,6,9)	(5,6,9)	(5,6,9)	(0.73,2.17,5.07)
H5	(0,1,3)	(0,1,3)	(1,4,7)	(1,4,7)	(0.1,1,3)
H6	(1,4,7)	(1,4,7)	(5,6,9)	(1,4,7)	(0.33,1.77,4.47)
H7	(5,6,9)	(5,6,9)	(5,6,9)	(1,4,7)	(0.73,2.17,5.07)
H8	(5,6,9)	(1,4,7)	(1,4,7)	(5,6,9)	(0.74,2.07,4.87)
H9	(1,4,7)	(1,4,7)	(5,6,9)	(1,4,7)	(0.33,1.77,4.47)
H10	(5,6,9)	(5,6,9)	(5,6,9)	(5,6,9)	(1,2.4,5.4)
H11	(5,6,9)	(5,6,9)	(5,6,9)	(5,6,9)	(1,2.4,5.4)
H12	(1,4,7)	(5,6,9)	(5,6,9)	(5,6,9)	(0.73,2.17,5.07)
H13	(1,4,7)	(1,4,7)	(1,4,7)	(5,6,9)	(0.47,1.84,4.54)
H14	(5,6,9)	(5,6,9)	(5,6,9)	(1,4,7)	(0.73,2.17,5.07)
H15	(0,1,3)	(1,4,7)	(5,6,9)	(5,6,9)	0.53,1.65,4.13)
H16	(1,4,7)	(0,1,3)	(1,4,7)	(5,6,9)	(0.44,1.59,4.01)
H17	(0,1,3)	(0,1,3)	(5,6,9)	(5,6,9)	(0.5,1.4,3.6)
H18	(1,4,7)	(1,4,7)	(5,6,9)	(1,4,7)	(0.33,1.77,4.47)
H19	(1,4,7)	(1,4,7)	(1,4,7)	(1,4,7)	(0.2,1.6,4.2)
H20	(0,1,3)	(1,4,7)	(1,4,7)	(1,4,7)	(0.13,1.25,3.53)
H21	(1,4,7)	(0,1,3)	(5,6,9)	(1,4,7)	(0.3,1.52,3.94)
H22	(0,1,3)	(0,1,3)	(1,4,7)	(1,4,7)	(0.1,1,3)
H23	(1,4,7)	(1,4,7)	(1,4,7)	(1,4,7)	(0.2,1.6,4.2)
H24	(1,4,7)	(0,1,3)	(5,6,9)	(5,6,9)	(0.57,1.75,4.27)
H25	(1,4,7)	(1,4,7)	(5,6,9)	(5,6,9)	(0.6,2,4.8)
H26	(1,4,7)	(1,4,7)	(1,4,7)	(5,6,9)	(0.47,1.84,4.54)

Table 4.50 Combined weight of evaluating factor of S1

Evaluating criteria	D1	D 2	D 3	D 4	combined of weight criteria
	(0.27,0.47,0.67)	(0.13,0.33, 0.53)	(0.13,0.33, 0.53)	(0.27,0.47,0.67)	
H1	(0,1,3)	(0,1,3)	(1,4,7)	(0,1,3)	(0.03,0.65,2.33)
H2	(0,1,3)	(0,1,3)	(1,4,7)	(1,4,7)	(0.1,1,3)
H3	(0,0,1)	(0,1,3)	(5,6,9)	(1,4,7)	(0.23,1.05,2.93)
H4	(1,4,7)	(1,4,7)	(5,6,9)	(0,1,3)	(0.26,1.41,3.8)
H5	(0,1,3)	(0,1,3)	(1,4,7)	(0,1,3)	(0.03,0.65,2.33)
H6	(0,1,3)	(0,1,3)	(5,6,9)	(5,6,9)	(0.5,1.4,3.6)
H7	(1,4,7)	(1,4,7)	(5,6,9)	(1,4,7)	(0.33,1.77,4.47)
H8	(0,1,3)	(0,1,3)	(1,4,7)	(0,1,3)	(0.03,0.65,2.33)
H9	(0,1,3)	(0,1,3)	(5,6,9)	(0,1,3)	(0.16,0.81,2.6)
H10	(0,1,3)	(0,1,3)	(5,6,9)	(0,1,3)	(0.16,0.81,2.6)
H11	(1,4,7)	(1,4,7)	(5,6,9)	(1,4,7)	(0.33,1.77,4.47)
H12	(0,1,3)	(1,4,7)	(5,6,9)	(1,4,7)	(0.26,1.41,3.8)
H13	(0,1,3)	(0,1,3)	(1,4,7)	(0,1,3)	(0.03,0.65,2.33)
H14	(0,1,3)	(0,1,3)	(5,6,9)	(1,4,7)	(0.23,1.17,3.27)
H15	(0,1,3)	(0,1,3)	(5,6,9)	(0,0,1)	(0.16,0.7,2.26)
H16	(0,1,3)	(0,1,3)	(5,6,9)	(0,0,1)	(0.16,0.7,2.26))
H17	(0,1,3)	(0,1,3)	(5,6,9)	(0,0,1)	(0.16,0.7,2.26)
H18	(1,4,7)	(1,4,7)	(5,6,9)	(1,4,7)	(0.33,1.77,4.47)
H19	(0,1,3)	(0,1,3)	(5,6,9)	(0,1,3)	(0.16,0.81,2.6)
H20	(0,1,3)	(0,1,3)	(1,4,7)	(0,1,3)	(0.03,0.65,2.33)
H21	(0,1,3)	(0,1,3)	(5,6,9)	(0,0,1)	(0.16,0.7,2.26)
H22	(1,4,7)	(1,4,7)	(1,4,7)	(0,1,3)	(0.13,1.25,3.53)
H23	(1,4,7)	(1,4,7)	(1,4,7)	(1,4,7)	(0.2,1.6,4.2)
H24	(0,1,3)	(0,1,3)	(5,6,9)	(0,1,3)	(0.16,0.81,2.6)
H25	(0,1,3)	(1,4,7)	(5,6,9)	(1,4,7)	(0.26,1.41,3.8)
H26	(0,1,3)	(0,1,3)	(1,4,7)	(0,1,3)	(0.03,0.65,2.33)

Table 4.51 Combined weight of evaluating factor of S2

Step 9: Construct phase II HOQ matrix of WHAT-HOW to find the weight of suppliers.

Evaluating criteria		WHAT	
HOW	Weight	S1	S2
H1	(9.42,38.96.148.13)	(0.33,1.77,4.47)	(0.03,0.65,2.33)
H2	(11.29.40.24,127.82)	(0.87,2.24,5.14)	(0.1,1,3)
H3	(15.84,51.9,193.71)	(0.33,1.77,4.47)	(0.23,1.05,2.93)
H4	(15.03,50.75,192.46)	(0.73,2.17,5.07)	(0.26,1.41,3.80)
H5	(12.25,42.76,171.64)	(0.1,1,3)	(0.03,0.65,2.33)
H6	10.56,35.16,162.74)	(0.33,1.77,4.47)	(0.5,1.4,3.6)
H7	(13.99,48.79,161.7)	(0.73,2.17,5.07)	(0.33,1.77,4.47)
H8	(14.2,48.63,186.42)	(0.74,2.07,4.87)	(0.03,0.65,2.33)
H9	(6.57,28.59,123.33)	(0.33,1.77,4.47)	(0.16,0.81,2.6)
H10	(14.31,50.34,179.92)	(1,2.4,5.4)	(0.16,0.81,2.6)
H11	(13.34,48.06,174.72)	(1,2.4,5.4)	(0.33,1.77,4.47)
H12	(6.5,29.53,125.52)	(0.73,2.17,5.07)	(0.26,1.41,3.8)
H13	(5.6,25.44,107.74)	(0.47,1.84,4.54)	(0.03,0.65,2.33)
H14	(6.5,29.53,125.52)	(0.73,2.17,5.07)	(0.23,1.17,3.27)
H15	(8.62,29.83,136.46)	(0.53,1.65,4.13)	(0.16,0.7,2.26)
H16	(12.22,43.48,167.73)	(0.44,1.59,4.01)	(0.16,0.7,2.26)
H17	(13.69,47.09,171.38)	(0.5,1.4,3.6)	(0.16,0.7,2.26)
H18	(9.55,30.26,145.78)	(0.33,1.77,4.47)	(0.33,1.77,4.47)
H19	(7.89,32.66,148.57)	(0.2,1.6,4.2)	(0.16,0.81,2.6)
H20	(11.11,42.27,164.98)	(0.13,1.25,3.53)	(0.03,0.65,2.33)
H21	(10.89,38.6,157)	(0.3,1.52,3.94)	(0.16,0.7,2.26)
H22	(8.43,27.97,135.77)	(0.1,1,3)	(0.13,1.25,3.53)
H23	(4.53,19.92,105.27)	(0.2,1.6,4.2)	(0.2,1.6,4.2)
H24	(2.53,11.64,74.78)	(0.57,1.75,4.27)	(0.16,0.81,2.6)
H25	(13.39,46.3,176.02)	(0.6,2,4.8)	(0.26,1.41,3.8)
H26	(11.68,47.15,175.23)	(0.47,1.84,4.54)	(0.03,0.65,2.33)
SUPPLIER WEIGHT		(139.43,1792.89,17487.5)	(49.46,1017.54,11915.2)

Table 4.52 Final supplier importance rating/weight

The assessment results gives the importance/weight of each supplier S1 and S2 and are shown in the last row in the above Table 4.52.

Step 10: Rank the suppliers on the score obtained.

supplier	supplier weights	crisp value	score	rank
S1	(139.43,1792.89,17487.5)	6473.27	1	1
S2	(49.46,1017.54,11915.2)	4327.4	0	2

Table 4.53 Rank of suppliers

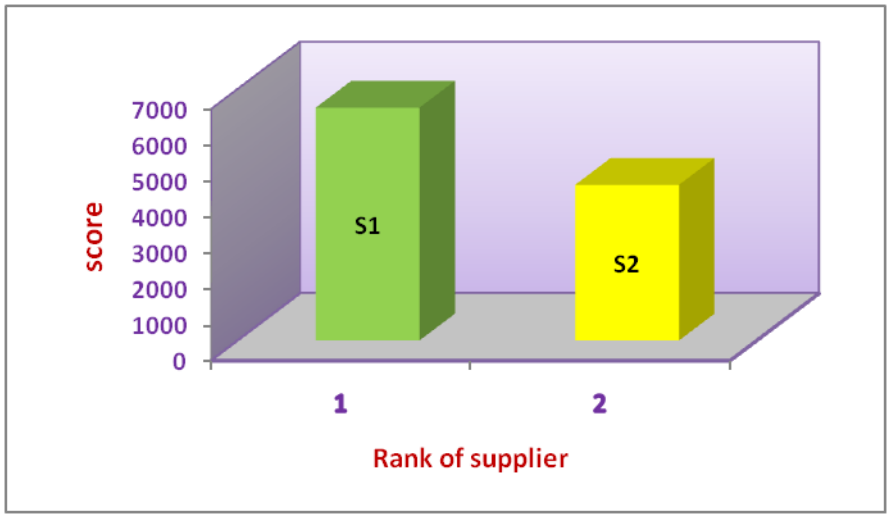


Figure 4.19 Rank of suppliers

The supplier 1 and supplier 2 has rank 1 and rank 2 respectively. Number of suppliers is only two for this product. This QFD method suggested will assist the company to periodically evaluate the suppliers and decide about the work allocation based on the performance of the supplier. Monitoring and control of the supplier is easy due to small numbers. Also suppliers are sure about the purchase order regularly. It generates healthy competition within suppliers. All three firms work as integrated unit. It is easy for the company to have long term relationship with these suppliers. It is concluded that the quality plays important role when the product is directly delivered at the project site or warehouse, which are at the far distance. This will avoid frequent maintenance, rework and service and protect the brand name of the buyer and supplier, maintaining and improving the competitive advantage in the market. The proposed method is tested in the company.

4.14.3: Single decision maker and multiple suppliers.

A small scale company is selected to apply the method in Pune, India. The company is preferred vendor of electrical components used by the multinational company in Pune, India The company need materials for the manufacturing of the electrical components. One of the parts required for the electrical component is purchased from five suppliers of the company. The purchase manager has full authority to take decision to select supplier. The proposed supplier selection method and supplier selection criteria are discussed with the purchase manager of the buying company. The supplier selection criteria are approved by the company and permission was granted to apply the proposed method for selection and evaluation of suppliers. The electrical part was purchased from five different suppliers is considered for this study. The supplier selection procedure is as per case 1 and case 2.

Step 1: Finalize the supplier selection criteria for the analysis.

Step 2: The purchase manager is only decision maker. The weight of the decision maker is calculated based on management position, authority, responsibility and field experience. Step3: Evaluate the importance of qualitative and quantitative criteria given by the company.

Step 4: Find weight of customer requirement (WHAT) as per decision maker.

Step 5: Build the phase I HOQ to find the importance of evaluating criteria.

Step 6: Find the relative weight of evaluating criteria of each supplier by the decision maker.

Step 7: Construct the phase II HOQ of evaluating factor and supplier matrix. Evaluate the importance of each supplier.

Step 8: Arrange the score obtained in descending order to find the rank of each supplier.

The steps are as follows:

Step 1: The supplier selection criteria are decided for supplier evaluation. The customer (buyer) requirement criteria and assessment criteria are shown in Table 4.6 and Table 4.9 above. The assessment (evaluating) criteria are explained in Table 4.9

Step 2: Assign weights to the decision maker based on field experience (FE), authority and responsibility (AR) and management position (MP) in the organization.

Decision Maker	Linguistic terms		
	FE	AR	MP
D1	H	V	H

Table 4.54 Linguistic matrix of decision maker

Decision Maker	Fuzzy number			weight
	FE	AR	MP	
D1	(0.4, 0.6, 0.8)	(0.6, 0.8, 1.0)	(0.4, 0.6, 0.8)	(0.47,0.67,0.87)

Table 4.55 Decision maker management position, authority, responsibility and field experience

Step 3: The organization give different importance to qualitative criteria and quantitative criteria. Find the degree of importance of qualitative criteria and quantitative criteria in terms of weight.

	Criteria	C_{QLT}	C_{QNT}	((0.47,0.67,0.87)	Weight
D1	C_{QLT}	(1,1,1)	(5,7,9)	(0.5,0.86,1.39)	(0.24,0.56,1.21)
	C_{QNT}	(1/7,1/5,1/3)	(1,1,1)	(0.1,0.14,0.28)	(0.05,0.09,0.24)

Table 4.56 Pair-wise comparison matrix for qualitative and quantitative criteria

Find the coefficient of preference of both criteria by decision makers.

Criteria	Weight	crisp value	Normalized Value
C_{QLT}	(0.24,0.56,1.21)	0.67	0.84
C_{QNT}	(0.05,0.09,0.24)	0.13	0.16

Table 4.57 Defuzzification of qualitative and quantitative weights

Coefficient of preference of quantitative and qualitative criteria shown in table below:

Criteria	Coefficient of preference
C_{QLT}	0..84
C_{QNT}	0.16

Table 4.58 Coefficient of preference

Qualitative criteria dominate in this case. The value of qualitative importance is 84% and quantitative 16%.

Step4: Find the combined weight of customer criteria.

Customer criteria	D1		Combined weight
	(0.47,0.67,0.87)		
Q	VSI	(5,7,9)	(2.35,4.69,7,83)
R	VSI	(5,7,9)	(2.35,4.69,7,83)
F	SI	(3,5,7)	(1.41,3.35,6.09)
S	SI	(3,5,7)	(1.41,3.35,6.09)
C	VSI	(5,7,9)	(2.35,4.69,7,83)
AS	VSI	(5,7,9)	(2.35,4.69,7,83)

Table4.59 combined weight of customer criteria

Step 5: The response from experts from different companies to develop relationship matrix. Find the importance of HOW

Build phase I HOQ matrix of customer requirement and technical assessment criteria of the suppliers.

WHAT \ HOW	Weights	H1	H2	H3	H4	H5	H6
Q	(2.35,4.69,7,83)	(4.5,8)	(6,7,9)	(3.33,4.33,7.67)	(4.67,5.67,8.33)	(4.67,5.67,8.33)	(3.67,4.5,7)
R	(2.35,4.69,7,83)	(4,5,8)	(4.33,5.17,3.33)	(4.67,5.67,8.33)	(4,5,8)	(3.33,4.17,6.33)	(2.67,3.67,7.33)
F	(1.41,3.35,6.09)	(1.67,2.5,5)	(0.67,1.33,3.6)	(3.67,4.5,7)	(4.67,5.67,8.33)	(2.67,3.5,6)	(2.33,3.17,6.33)
S	(1.41,3.35,6.09)	(3.67,4.5,7)	(2.33,3,5)	(5.33,6.33,8.67)	(4.67,5.67,8.33)	(3,3.83,6.67)	(2.67,3.5,6)
C	(2.35,4.69,7,83)	(2.67,3.5,6)	(3,3.67,5.33)	(6,7,8)	(4.67,5.67,8.33)	(4.67,5.67,8.33)	(3,3.83,6.67)
AS	(2.35,4.69,7,83)	(0.33,0.83,2.67)	(2,2.67,5.33)	(4.67,5.67,8.33)	(4,6,7)	(3,4,7)	(3.67,4.5,7)
Weights of How		(33.68,90.7,266.2)	(40.26,101,232.4)	(56.56,143,348.6)	53.92,143,349.4)	(44.82,116,132)	(37.62,99.7,294.3)

H7	H8	H9	H10	H11	H12	H13
(4.33,5.17,3.33)	(5.33,6.33,8.67)	(3,4,7)	(4.67,5.67,8.33)	(5.33,6.33,8.67)	(1.67,2.67,5.33)	(2,2.83,5.67)
(4.67,5.67,8.33)	(4.67,5.67,8.33)	(1.67,2.33,4.6)	(4.33,5.33,7.67)	(4.33,5.17.7.33)	(0.67,1.33,3.67)	(1.67,2.17,4.33)
(5.33,6.33,8.67)	(3.33,4.33,7.67)	(2.33,3.17,5.33)	(4.67,5.67,8.33)	(4,5,8)	(2.67,3.5,6)	(0.67,1.17,3.33)
(3.67,4.67,7.33)	(2.33,3.17,5.33)	(1.67,2.33,4.67)	(4,4.67,6.33)	(3.33,4,6)	(3.67,4.5,7)	(2.33,3,5)
(4.33,5.17,7.33)	(5.33,6.33,8.67)	(3.33,4.17,6.33)	(5.33,6.33,8.67)	(4.67,5.67,8.33)	(4.33,5.17,7.33)	(3.67,4.5,7)
(2.67,3.5,6)	(3.33,4.33,7.67)	(0.33,0.83,2.67)	(2.67,3.5,6)	(2,2.83,5.67)	(0.33,1,3)	(0,0.33,1.67)
(50.29,128,293.1)	(51.83,131,340.2)	(25.22,71.6,222.7)	(52.17,132,329.4)	(48.71,124,320.2)	(25.39,74.5,230.5)	(21.48,60.1,196.9)

H14	H15	H16	H17	H18	H19	H20
(1.67,2.67,5.33)	(2,2.83,5.67)	(4.67,5.67,8.33)	(5.33,6.33,8.67)	(2.33,3.33,6.67)	(0.33,1,3)	(4,5,8)
(0.67,1.33,3.67)	(2.67,3.5,6)	(2.67,3.33,5.67)	(4,4.67,6.33)	(2,2.67,5.33)	(3.33,4.33,7.67)	(4,5,8)
(2.67,3.5,6)	(2.67,3.33.5.67)	(3,4,7)	(2.33,3,5)	(3,3.83,6.67)	(2.33,3.17,6.33)	(3,3.67,5.33)
(3.67,4.5,7)	(3.33,4.17,6.33)	(4.33,5.17,7.33)	(4.33,5.17,7.33)	(2.67,3.5,6)	(2.67,3.67,7.33)	(3.67,4.5,7)
(4.33,5.17,7.33)	(1.67,2.33,4.67)	(4.67,5.67,8.33)	(4.67,5.67,8.33)	(2.67,3.33,5.67)	(4.67,5.67,8.33)	(3.67,4.5,7)
(0.33,1,3)	(2.67,3.33,5.67)	(2.67,3.33,5.67)	(3,3.83,6.67)	(4,4.67,6.33)	(1,1.83,4.67)	(1.33,2.17,5.33)
(25.39,74.5,230.5)	(29.63,81.4,245.4)	(44.83,115,306.5)	(49.34,124,310)	(33.84,90.2,265.1)	(28.98,83.1,268.5)	(39.95,106,296.9)

H21	H22	H23	H24	H25	H26
(4.67,5.67,8.33)	(0.67,1.33,3.67)	(0.67,1.33,3.67)	(1.67,2.33,4.67)	(4,5,8)	(1.67,2.33,4.67)
(2.67,3.5,6)	(1.67,2.5,5)	(3,4,7)	(0.67,1.5,4)	(3.67,4.5,7)	(4.67,5.67,8.33)
(2.33,3.17,5.33)	(4.33,5.17,7.33)	(0.33,0.83,2.67)	(0.33,0.83,2.67)	(5.33,6.33,8.67)	(4.67,5.67,8.33)
(2,2.67,5.33)	(2.67,3.5,6)	(1.67,2.33,4,67)	(0.83,1.33,2.67)	(3.67,4.5,7)	(6,7,9)
(4.67,5.67,8.33)	(3,3.83,6.67)	(0.67,1.33,3.67)	(0,0.5,2)	(4.67,5.67,8.33)	(4.67,5.67,8.33)
(2.67,3.33,5.67)	(3.33,4,6)	(0.67,1.33,3.67)	(0.33,0.67,2.33)	(3,3.83,5.67)	(0.33,2.33,5.67)
(40.6,105,286.7)	(30.24,83.7,248.3)	(14.59,48.1,185.7)	(7.91,30.7,134.3)	(48.74,125,322.5)	(41.69,117,316.9)

Table 4.60 .Relationship matrix between WHAT's and Evaluating factors (HOW's)

Step 6: Decision maker evaluate each supplier for each HOW (evaluating criteria).

Evaluating criteria	D1 (0.47,0.67,0.87)	combined of weight criteria S1
H1	(5,6,9)	(2.35,4.02,7.83)
H2	(5,6,9)	(2.35,4.02,7.83)
H3	(5,6,9)	(2.35,4.02,7.83)
H4	(5,6,9)	(2.35,4.02,7.83)
H5	(5,6,9)	(2.35,4.02,7.83)
H6	(5,6,9)	(2.35,4.02,7.83)
H7	(5,6,9)	(2.35,4.02,7.83)
H8	(5,6,9)	(2.35,4.02,7.83)
H9	(5,6,9)	(2.35,4.02,7.83)
H10	(5,6,9)	(2.35,4.02,7.83)
H11	(5,6,9)	(2.35,4.02,7.83)
H12	(5,6,9)	(2.35,4.02,7.83)
H13	(5,6,9)	(2.35,4.02,7.83)
H14	(5,6,9)	(2.35,4.02,7.83)
H15	(5,6,9)	(2.35,4.02,7.83)
H16	(5,6,9)	(2.35,4.02,7.83)
H17	(5,6,9)	(2.35,4.02,7.83)
H18	(5,6,9)	(2.35,4.02,7.83)
H19	(5,6,9)	(2.35,4.02,7.83)
H20	(5,6,9)	(2.35,4.02,7.83)
H21	(5,6,9)	(2.35,4.02,7.83)
H22	(5,6,9)	(2.35,4.02,7.83)
H23	(5,6,9)	(2.35,4.02,7.83)
H24	(5,6,9)	(2.35,4.02,7.83)
H25	(5,6,9)	(2.35,4.02,7.83)
H26	(5,6,9)	(2.35,4.02,7.83)

Table 4.61 Aggregate weight for the supplier (S1)

Evaluating criteria	D1 (0.47,0.67,0.87)	combined of weight criteria S2
H1	(1,4,7)	(0.47,2.68,6.09)
H2	(5,6,9)	(2.35,4.02,7.83)
H3	(5,6,9)	(2.35,4.02,7.83)
H4	(5,6,9)	(2.35,4.02,7.83)
H5	(5,6,9)	(2.35,4.02,7.83)
H6	(5,6,9)	(2.35,4.02,7.83)
H7	(5,6,9)	(2.35,4.02,7.83)
H8	(5,6,9)	(2.35,4.02,7.83)
H9	(5,6,9)	(2.35,4.02,7.83)
H10	(5,6,9)	(2.35,4.02,7.83)
H11	(5,6,9)	(2.35,4.02,7.83)
H12	(5,6,9)	(2.35,4.02,7.83)
H13	(5,6,9)	(2.35,4.02,7.83)
H14	(5,6,9)	(2.35,4.02,7.83)
H15	(5,6,9)	(2.35,4.02,7.83)
H16	(5,6,9)	(2.35,4.02,7.83)
H17	(5,6,9)	(2.35,4.02,7.83)
H18	(5,6,9)	(2.35,4.02,7.83)
H19	(5,6,9)	(2.35,4.02,7.83)
H20	(5,6,9)	(2.35,4.02,7.83)
H21	(5,6,9)	(2.35,4.02,7.83)
H22	(5,6,9)	(2.35,4.02,7.83)
H23	(5,6,9)	(2.35,4.02,7.83)
H24	(5,6,9)	(2.35,4.02,7.83)
H25	(5,6,9)	(2.35,4.02,7.83)
H26	(5,6,9)	(2.35,4.02,7.83)

Table 4.62 Aggregate weight for the supplier (S2)

Evaluating criteria	D1 (0.47,0.67,0.87)	combined of weight criteria S3
H1	(5,6,9)	(2.35,4.02,7.83)
H2	(5,6,9)	(2.35,4.02,7.83)
H3	(5,6,9)	(2.35,4.02,7.83)
H4	(5,6,9)	(2.35,4.02,7.83)
H5	(5,6,9)	(2.35,4.02,7.83)
H6	(5,6,9)	(2.35,4.02,7.83)
H7	(5,6,9)	(2.35,4.02,7.83)
H8	(5,6,9)	(2.35,4.02,7.83)
H9	(5,6,9)	(2.35,4.02,7.83)
H10	(5,6,9)	(2.35,4.02,7.83)
H11	(5,6,9)	(2.35,4.02,7.83)
H12	(5,6,9)	(2.35,4.02,7.83)
H13	(5,6,9)	(2.35,4.02,7.83)
H14	(5,6,9)	(2.35,4.02,7.83)
H15	(5,6,9)	(2.35,4.02,7.83)
H16	(5,6,9)	(2.35,4.02,7.83)
H17	(5,6,9)	(2.35,4.02,7.83)
H18	(5,6,9)	(2.35,4.02,7.83)
H19	(5,6,9)	(2.35,4.02,7.83)
H20	(5,6,9)	(2.35,4.02,7.83)
H21	(5,6,9)	(2.35,4.02,7.83)
H22	(5,6,9)	(2.35,4.02,7.83)
H23	(5,6,9)	(2.35,4.02,7.83)
H24	(5,6,9)	(2.35,4.02,7.83)
H25	(5,6,9)	(2.35,4.02,7.83)
H26	(5,6,9)	(2.35,4.02,7.83)

Table 4.63 Aggregate weight for the supplier (S3)

Evaluating criteria	D1 (0.47,0.67,0.87)	combined of weight criteria S4
H1	(1,4,7)	(0.47,2.68,6.09)
H2	(1,4,7)	(0.47,2.68,6.09)
H3	(5,6,9)	(2.35,4.02,7.83)
H4	(5,6,9)	(2.35,4.02,7.83)
H5	(5,6,9)	(2.35,4.02,7.83)
H6	(5,6,9)	(2.35,4.02,7.83)
H7	(5,6,9)	(2.35,4.02,7.83)
H8	(5,6,9)	(2.35,4.02,7.83)
H9	(5,6,9)	(2.35,4.02,7.83)
H10	(5,6,9)	(2.35,4.02,7.83)
H11	(5,6,9)	(2.35,4.02,7.83)
H12	(5,6,9)	(2.35,4.02,7.83)
H13	(5,6,9)	(2.35,4.02,7.83)
H14	(5,6,9)	(2.35,4.02,7.83)
H15	(1,4,7)	(0.47,2.68,6.09)
H16	(5,6,9)	(2.35,4.02,7.83)
H17	(5,6,9)	(2.35,4.02,7.83)
H18	(5,6,9)	(2.35,4.02,7.83)
H19	(5,6,9)	(2.35,4.02,7.83)
H20	(5,6,9)	(2.35,4.02,7.83)
H21	(5,6,9)	(2.35,4.02,7.83)
H22	(5,6,9)	(2.35,4.02,7.83)
H23	(5,6,9)	(2.35,4.02,7.83)
H24	(5,6,9)	(0.47,2.68,6.09)
H25	(5,6,9)	(0.47,2.68,6.09)
H26	(5,6,9)	(2.35,4.02,7.83)

Table 4.64 Aggregate weight for the supplier (S4)

Evaluating criteria	D1	combined of weight criteria
	(0.47,0.67,0.87)	
H1	(1,4,7)	(0.47,2.68,6.09)
H2	(5,6,9)	(2.35,4.02,7.83)
H3	(5,6,9)	(2.35,4.02,7.83)
H4	(5,6,9)	(2.35,4.02,7.83)
H5	(5,6,9)	(2.35,4.02,7.83)
H6	(5,6,9)	(2.35,4.02,7.83)
H7	(5,6,9)	(2.35,4.02,7.83)
H8	(5,6,9)	(2.35,4.02,7.83)
H9	(5,6,9)	(2.35,4.02,7.83)
H10	(5,6,9)	(2.35,4.02,7.83)
H11	(5,6,9)	(2.35,4.02,7.83)
H12	(5,6,9)	(2.35,4.02,7.83)
H13	(5,6,9)	(2.35,4.02,7.83)
H14	(5,6,9)	(2.35,4.02,7.83)
H15	(1,4,7)	(0.47,2.68,6.09)
H16	(5,6,9)	(2.35,4.02,7.83)
H17	(5,6,9)	(2.35,4.02,7.83)
H18	(5,6,9)	(2.35,4.02,7.83)
H19	(5,6,9)	(2.35,4.02,7.83)
H20	(5,6,9)	(2.35,4.02,7.83)
H21	(5,6,9)	(2.35,4.02,7.83)
H22	(5,6,9)	(2.35,4.02,7.83)
H23	(5,6,9)	(2.35,4.02,7.83)
H24	(1,4,7)	(0.47,2.68,6.09)
H25	(5,6,9)	(2.35,4.02,7.83)
H26	(5,6,9)	(2.35,4.02,7.83)

Table 4.65 Aggregate weight for the supplier (S5)

Step 7: Build phase II HOQ matrix of evaluating factor and supplier and find importance of supplier.

EVALUATING CRITERIA		SUPPLIER				
Weight		S1	S2	S3	S4	S5
H1	(33.68,90.7,266.2)	(2.35,4.02,7.83)	(0.47,2.68,6.09)	(2.35,4.02,7.83)	(0.47,2.68,6.09)	(0.47,2.68,6.09)
H2	(40.26,101,232.4)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(0.47,2.68,6.09)	(2.35,4.02,7.83)
H3	(56.56,143,348.6)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)
H4	53.92,143,349.4)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)
H5	(44.82,116,132)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)
H6	(37.62,99.7,294.3)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)
H7	(50.29,128,293.1)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)
H8	(51.83,131,340.2)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)
H9	(25.22,71.6,222.7)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)
H10	(52.17,132,329.4)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)
H11	(48.71,124,320.2)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)
H12	(25.39,74.5,230.5)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)
H13	(21.48,60.1,196.9)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)
H14	(25.39,74.5,230.5)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)
H15	(29.63,81.4,245.4)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(0.47,2.68,6.09)	(0.47,2.68,6.09)
H16	(44.83,115,306.5)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)
H17	(49.34,124,310)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)
H18	(33.84,90.2,265.1)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)
H19	(28.98,83.1,268.5)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)
H20	(39.95,106,296.9)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)
H21	(40.6,105,286.7)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)
H22	(30.24,83.7,248.3)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)
H23	(14.59,48.1,185.7)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)
H24	(7.91,30.7,134.3)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(0.47,2.68,6.09)	(0.47,2.68,6.09)
H25	(48.74,125,322.5)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(0.47,2.68,6.09)	(2.35,4.02,7.83)
H26	(41.69,117,316.9)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)	(2.35,4.02,7.83)
SUPPLIER WEIGHT		2297.6,10445.2,53034	2234.3,10348.7,52571	2297.6,,10445.2,53034.2	(1996.79,9870.3,50944.4)	2164.1,11663,51910

Table 4.66: Supplier weight matrix

The assessment results give the importance/weight of each supplier S1, S2, S3, S4 and S5 and are shown in the last row in the above Table 4.66.

Step 10: Find the score of each supplier and rank the suppliers..

supplier	supplier weights	crisp value	score	rank
S1	2297.6,10445.2,53034	21925	1	1
S2	2234.3,10348.7,52571	21716	.7884	3
S3	2297.6,,10445.2,53034.2	21925	1	1
S4	1996.79,9870.3,50944.4	20937.2	0	4
S5	2164.1,11663,51910	21912.4	.9872	2

Table 4.67 Score and rank of suppliers

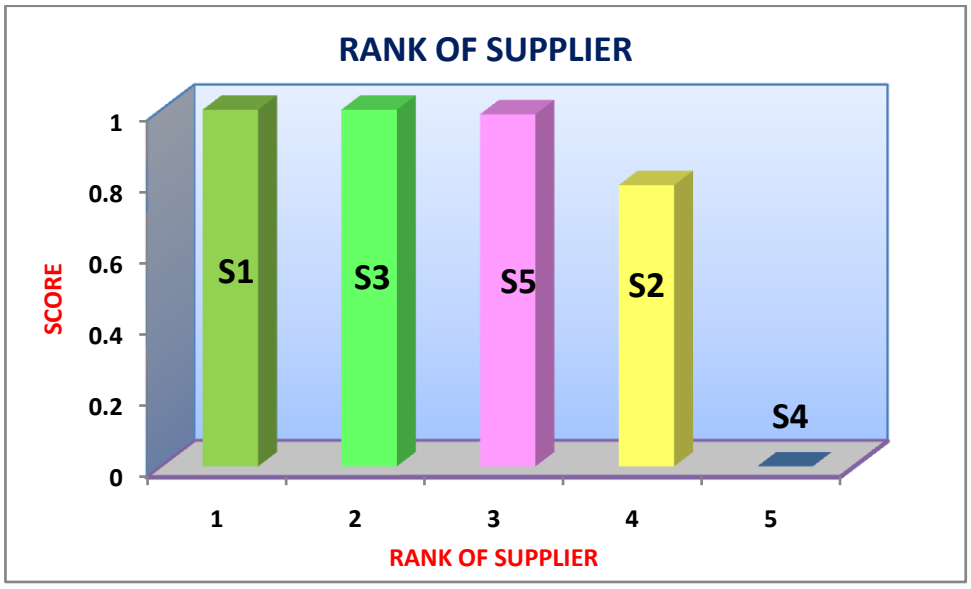


Figure 4.20 Rank of suppliers

The supplier ranks are shown in Table 4.67 and Figure 4.20 above. This evaluation is on qualitative criteria. Periodic evaluation by QFD method will alert all suppliers to regularly improve their evaluating parameters. In this case study, the performance of all five suppliers is almost same and thus evaluation of suppliers is difficult for decision maker. The purchase manager has difficulty in ranking suppliers accurately. The suppliers are instructed to follow the supply schedule and supply the components within specification with zero defects. The buyers assist in problem solving, training and extend support to the supplier. The buyer maintains the good relationship with the suppliers with mutual trust, respect and commitments. The buyer is satisfied with the performance of the

supplier, but finds difficulty to rate these suppliers. It is felt by the buyer that, the rating is essential to bring in the competitive spirit among the suppliers. It is decided to rank these suppliers and place the purchase order by varying quantity. The highest rank supplier will be given more volume order. The periodic evaluation will be done of all five suppliers. The suppliers focus on operation control and quality standard. The purchase managers' view is that the qualitative factors are responsible for quantitative factors. So purchase manager gives more stress on the qualitative criteria than the quantitative criteria. The proposed method is easy and gives output close to the real values. The company purchase manager applied the method in the company and was satisfied with the results.

4.15 Application of proposed Hybrid QFD-Entropy approach for supplier selection.

4.15.1 Introduction

The company under study is based in Goa and has domestic and foreign customers. The name of the company is kept confidential for the purpose of secrecy of the data. The company is in a process of selecting the supplier for its product requirement. The purchase head of the company is interested in selecting suppliers for uninterrupted supply of corrugated boxes to meet changing demand of its product in the market. The purchase committee members are referred as decision makers (D1, D2, D3 and D4).The decision makers prepare list of ten potential suppliers (S1, S2, S3, S4, S5, S6, S7, S8, S9, S10) for the corrugated boxes. Based on literature review study and open ended discussion with decision makers criteria (quantitative and qualitative) and evaluating criteria are listed in Table 4.6 and Table 4.9 above. The proposed method applies the entropy concept in the QFD process to rank the suppliers. The data of section 4.14.1 above is used after deffuzifiztion in this analysis. The QFD process has two HOQ matrices in two phases. The first relational matrix gives the initial HOW rating. The second matrix gives competitive priority for the supplier to decide for action based on the goal set by the buying organization. Each supplier has the degree of strength based on evaluating criteria The influence of the evaluating criteria depend on resources available with the organization. Hence each evaluating factor of each supplier has defined state and uncertainty associated with it called as entropy. The entropy, competitive priority and improvement ratio for each evaluating criteria guide the supplier for taking action for improvement and supplier selection.

4.15.2 Steps and analysis process of supplier selection

The steps in the proposed supplier selection method are illustrated below:

Step1. Find the relative weight of qualitative criteria by the decision makers.

Step2 Construct the relationship matrix of buyer (customer) requirement and evaluating factor with the help of experts from different organizations.

Step3. Build the house of quality using the relationship matrix and find the importance of each evaluating factor.

Step4. Find the relative weight of evaluating factor for each supplier by the decision makers as shown in below Table 4.68 Relative Weight is R_i i=1,2,….n

HOW	Relative rating of suppliers based on Evaluating Factors (HOW) by Decision Makers									
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
H1	2.1	2.56	2.98	0.74	0.74	0.74	0.88	0.74	2.01	2.01
H2	1.53	2.29	2.29	0.88	1.79	1.48	0.97	1.88	2.1	2.01
H3	2.71	2.2	1.75	1.87	2.01	1.85	0.97	1.22	2.01	2.01
H4	2.89	2.2	1.09	2.71	2.01	2.57	2.1	1.13	1.48	1.48
H5	2.56	2.29	2.1	0.74	1.52	0.74	0.74	0.74	1.66	1.41
H6	2.1	2.1	2.1	2.1	2.1	2.1	0.74	0.74	2.1	2.01
H7	2.2	1.36	1.5	0.98	1.52	1.66	0.88	0.88	1.85	1.85
H8	2.89	2.13	2.52	1.09	1.87	1.76	1.09	0.74	1.66	2.01
H9	2.2	2.2	2.2	2.01	2.2	2.01	2.01	1.76	2.2	1.76
H10	2.79	2.1	2.1	1.52	1.85	1.66	0.74	0.74	1.66	1.85
H11	2.98	2.1	2.52	1.48	2.01	1.76	0.74	0.74	2.01	2.98
H12	2.29	2.98	2.98	2.29	2.2	2.06	1.27	0.74	1.32	2.29
H13	2.79	2.79	1.19	0.74	1.87	1.27	0.88	0.74	2.06	2.37
H14	2.36	2.27	0.97	0.98	1.52	1.66	0.74	0.98	1.32	1.85
H15	2.01	2.62	1.23	0.74	1.27	1.76	0.74	0.74	1.32	2.01
H16	0.98	0.98	0.74	0.74	0.74	0.74	0.74	0.74	0.98	1.17
H17	2.43	2.08	1.41	1.27	1.27	1.27	0.74	0.74	1.66	1.41
H18	1.27	1.52	1.27	0.74	1.52	1.52	0.74	0.74	0.98	1.52
H19	1.76	1.41	1.76	1.27	1.41	1.76	0.74	1.27	1.17	1.62
H20	0.98	1.27	0.98	0.74	0.98	0.74	0.74	0.74	0.98	0.98
H21	2.18	2.52	2.27	1.69	1.41	1.41	1.27	0.74	0.88	2.03
H22	0.74	2.62	2.89	0.74	0.74	2	0.74	0.74	0.74	0.74
H23	1.13	1.27	0.74	0.74	0.74	0.74	0.74	0.74	0.74	1.66
H24	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74
H25	2.29	2.29	1.66	1.13	1.13	1.66	1.13	1.13	1.41	1.94
H26	2.08	2.08	1.09	1.09	1.48	1.27	1.09	0.74	0.74	2.01

Table 4.68 Relative weight of evaluating factor for each supplier by the decision makers

Step5. Calculate the entropy for each evaluating factor of supplier by using the formula and normalize the values.

$$H = -\theta \sum pi \; log \; pi \quad i = 1,2, \ldots . n$$

The entropy values are shown in entropy column in Table 4.69 below.

Step6. Calculate the Competitive priority for evaluating factor as shown in Table 4.69

$$Competitive\ Priority = \frac{H = -\theta \sum pi \; log \; pi \quad i = 1,2, \ldots . n}{\sum_{j=1}^{m} H \qquad j = 1,2, \ldots m}$$

Based on the rank of competitive priority supplier can decide on the action for competitiveness depending on evaluating factors. Table 4.69

Factor	Supplier										Entropy	Priority	Rank	Action for Competitiveness
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10				
H24	0.1355	0.1652	0.1923	0.0477	0.0477	0.0477	0.0568	0.0477	0.1297	0.1297	0.9376	0.037	1	Coding System
H9	0.0889	0.133	0.133	0.0511	0.1039	0.0859	0.0563	0.1092	0.122	0.1167	0.982	0.0388	2	Production Layout
H16	0.1457	0.1183	0.0941	0.1005	0.1081	0.0995	0.0522	0.0656	0.1081	0.1081	0.9859	0.0389	3	Problem Mitigation Techniques
H20	0.147	0.1119	0.0554	0.1378	0.1022	0.1307	0.1068	0.0575	0.0753	0.0753	0.9781	0.0386	4	Standard Practices
H19	0.1766	0.1579	0.1448	0.051	0.1048	0.051	0.051	0.051	0.1145	0.0972	0.9537	0.0377	5	Risk Management
H3	0.1154	0.1154	0.1154	0.1154	0.1154	0.1154	0.0407	0.0407	0.1154	0.1105	0.9766	0.0386	6	Organisational Structure &Mngt.
H2	0.1499	0.0926	0.1022	0.0668	0.1035	0.1131	0.0599	0.0599	0.126	0.126	0.9812	0.0388	7	Testing Facility and Inspection
H7	0.1627	0.1199	0.1419	0.0614	0.1053	0.0991	0.0614	0.0417	0.0935	0.1132	0.9711	0.0384	7	Planning and control
H18	0.1071	0.1071	0.1071	0.0978	0.1071	0.0978	0.0978	0.0856	0.1071	0.0856	0.9985	0.0394	7	Support Service
H25	0.164	0.1235	0.1235	0.0894	0.1088	0.0976	0.0435	0.0435	0.0976	0.1088	0.9721	0.0384	7	Compliance
H23	0.1542	0.1087	0.1304	0.0766	0.104	0.0911	0.0383	0.0383	0.104	0.1542	0.9639	0.0381	8	Security and Confidentiality
H4	0.1121	0.1459	0.1459	0.1121	0.1077	0.1009	0.0622	0.0362	0.0646	0.1121	0.9725	0.0384	9	Business Experience
H6	0.1671	0.1671	0.0713	0.0443	0.112	0.076	0.0527	0.0443	0.1234	0.1419	0.9527	0.0376	9	Enabling Technology
H17	0.1611	0.1549	0.0662	0.0669	0.1038	0.1133	0.0505	0.0669	0.0901	0.1263	0.9708	0.0384	10	R & D setup
H8	0.1392	0.1814	0.0852	0.0512	0.088	0.1219	0.0512	0.0512	0.0914	0.1392	0.9616	0.038	11	Latest Technology
H10	0.1146	0.1146	0.0865	0.0865	0.0865	0.0865	0.0865	0.0865	0.1146	0.1368	0.9936	0.0393	11	Production Facility
H12	0.1702	0.1457	0.0987	0.0889	0.0889	0.0889	0.0518	0.0518	0.1162	0.0987	0.9736	0.0385	11	Product Range
H14	0.1074	0.1286	0.1074	0.0626	0.1286	0.1286	0.0626	0.0626	0.0829	0.1286	0.9821	0.0388	11	Reputation
H21	0.1242	0.0995	0.1242	0.0896	0.0995	0.1242	0.0522	0.0896	0.0826	0.1143	0.9888	0.0391	11	Key Skills and Expertise
H26	0.1073	0.1391	0.1073	0.0811	0.1073	0.0811	0.0811	0.0811	0.1073	0.1073	0.9931	0.0392	11	Financial Position
H11	0.1329	0.1537	0.1384	0.103	0.086	0.086	0.0774	0.0451	0.0537	0.1238	0.9725	0.0384	12	Machinery and Equipments
H5	0.0583	0.2065	0.2277	0.0583	0.0583	0.1576	0.0583	0.0583	0.0583	0.0583	0.9181	0.0363	13	Human Resource
H13	0.1223	0.1374	0.0801	0.0801	0.0801	0.0801	0.0801	0.0801	0.0801	0.1797	0.9787	0.0387	14	Business Volume
H22	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	1	0.0395	15	Relationship
H15	0.1452	0.1452	0.1053	0.0717	0.0717	0.1053	0.0717	0.0717	0.0894	0.123	0.983	0.0388	16	innovation/Improvement Potential
H1	0.1522	0.1522	0.0797	0.0797	0.1083	0.0929	0.0797	0.0541	0.0541	0.147	0.9715	0.0384	17	Standard Quality Mgnt System

Table 4.69 Entropy related competitive priority of evaluating factors of supplier

Step6. Select the $H_{i\,max}$ i=1,2,…m from each evaluating factor Goal Gj= $H_{i\,max}$ j=1,2,…m

HOW	GOAL G_i	Improvement ratio for the suppliers										HOW Weight	Competitive Priority
		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10		
H1	2.98	1.42	1.16	1	4.03	4.03	4.03	3.39	4.03	1.48	1.48	82.91	0.037
H2	2.29	1.5	1	1	2.6	1.28	1.55	2.36	1.22	1.09	1.14	81.49	0.0388
H3	2.71	1	1.23	1.55	1.45	1.35	1.46	2.79	2.22	1.35	1.35	107.84	0.0389
H4	2.89	1	1.31	2.65	1.07	1.44	1.12	1.38	2.56	1.95	1.95	107.08	0.0386
H5	2.56	1	1.12	1.22	3.46	1.68	3.46	3.46	3.46	1.54	1.82	92.71	0.0377
H6	2.1	1	1	1	1	1	1	2.84	2.84	1	1.04	84.28	0.0386
H7	2.2	1	1.62	1.47	2.24	1.45	1.33	2.5	2.5	1.19	1.19	100.89	0.0388
H8	2.89	1	1.36	1.15	2.65	1.55	1.64	2.65	3.91	1.74	1.44	101.22	0.0384
H9	2.2	1	1	1	1.09	1	1.09	1.09	1.25	1	1.25	65.96	0.0394
H10	2.79	1	1.33	1.33	1.84	1.51	1.68	3.77	3.77	1.68	1.51	102	0.0384
H11	2.98	1	1.42	1.18	2.01	1.48	1.69	4.03	4.03	1.48	1	100.72	0.0381
H12	2.98	1.3	1	1	1.3	1.35	1.45	2.35	4.03	2.26	1.3	68.78	0.0384
H13	2.79	1	1	2.34	3.77	1.49	2.2	3.17	3.77	1.35	1.18	57.87	0.0376
H14	2.36	1	1.04	2.43	2.41	1.55	1.42	3.19	2.41	1.79	1.28	68.78	0.0384
H15	2.62	1.3	1	2.13	3.54	2.06	1.49	3.54	3.54	1.98	1.3	71.57	0.038
H16	0.98	1	1	1.32	1.32	1.32	1.32	1.32	1.32	1	0.84	93.79	0.0393
H17	2.43	1	1.17	1.72	1.91	1.91	1.91	3.28	3.28	1.46	1.72	95.79	0.0385
H18	1.52	1.2	1	1.2	2.05	1	1	2.05	2.05	1.55	1	75.98	0.0388
H19	1.76	1	1.25	1	1.39	1.25	1	2.38	1.39	1.5	1.09	75.69	0.0391
H20	1.27	1.3	1	1.3	1.72	1.3	1.72	1.72	1.72	1.3	1.3	90.1	0.0392
H21	2.52	1.16	1	1.11	1.49	1.79	1.79	1.98	3.41	2.86	1.24	84.59	0.0384
H22	2.89	3.91	1.1	1	3.91	3.91	1.45	3.91	3.91	3.91	3.91	70.02	0.0363
H23	1.66	1.47	1.31	2.24	2.24	2.24	2.24	2.24	2.24	2.24	1	50.67	0.0387
H24	0.74	1	1	1	1	1	1	1	1	1	1	39.81	0.0395
H25	2.29	1	1	1.38	2.03	2.03	1.38	2.03	2.03	1.62	1.18	99.02	0.0388
H26	2.08	1	1	1.91	1.91	1.41	1.64	1.91	2.81	2.81	1.03	97.38	0.0384
Sum		31.5	29.4	37.6	55.4	43.4	43.1	66.3	70.7	44.2	35.5	Improvement Ratio IR_{ij} i=1,2,…n, j=1,2,..m $IRij = \frac{Gj}{Ri}$	
Deviation=I N-Sum I		5.5	3.4	11.6	29.4	17.4	17.1	40.3	44.7	18.2	9.5		
Percentage Deviation		0.03	0.02	0.06	0.15	0.09	0.09	0.20	0.23	0.10	0.05		
Rank		2	1	4	8	6	5	9	10	7	3		
Supplier Order		S2	S1	S10	S3	S6	S5	S9	S4	S7	S8		

Table 4.70 Ranking of supplier using Goal, Improvement ratio and Initial weight of HOW

Step7. Find the improvement ratio of each supplier for evaluating factor as per formula in Table 4.70 above. Minimum improvement ratio for each supplier is 1 (one). Find $Sum = \sum_{j=1}^{m} IRij$ and normalize and calculate percentage deviation from the minimum value. Arrange the deviation in ascending order. Rank the supplier in ascending order of improvement ratio.

Step8. Compute the Final importance rating (FIR) of evaluating factors 'HOW'

Final Importance Rating FIR= IR X Initial HOW weight X CP_j

HOW	Final importance rating of HOW for each supplier for further improvement									
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
H1	4.353	3.57	3.068	12.35	12.35	12.35	10.4	12.35	4.55	4.548
H2	4.732	3.16	3.162	8.228	4.045	4.892	7.46	3.851	3.45	3.602
H3	4.195	5.17	6.496	6.079	5.656	6.145	11.7	9.318	5.66	5.656
H4	4.133	5.43	10.96	4.408	5.943	4.648	5.69	10.57	8.07	8.071
H5	3.495	3.91	4.261	12.09	5.887	12.09	12.1	12.09	5.39	6.346
H6	3.253	3.25	3.253	3.253	3.253	3.253	9.23	9.232	3.25	3.399
H7	3.915	6.33	5.741	8.788	5.666	5.188	9.79	9.786	4.66	4.655
H8	3.887	5.27	4.458	10.31	6.007	6.382	10.3	15.18	6.77	5.589
H9	2.599	2.6	2.599	2.844	2.599	2.844	2.84	3.249	2.6	3.249
H10	3.917	5.2	5.204	7.189	5.907	6.583	14.8	14.77	6.58	5.907
H11	3.837	5.45	4.538	7.727	5.689	6.497	15.5	15.45	5.69	3.837
H12	3.437	2.64	2.641	3.437	3.578	3.821	6.2	10.64	5.96	3.437
H13	2.176	2.18	5.102	8.204	3.246	4.78	6.9	8.204	2.95	2.562
H14	2.641	2.75	6.426	6.36	4.101	3.755	8.42	6.36	4.72	3.369
H15	3.545	2.72	5.793	9.629	5.611	4.049	9.63	9.629	5.4	3.545
16	3.686	3.69	4.881	4.881	4.881	4.881	4.88	4.881	3.69	3.087
H17	3.688	4.31	6.356	7.056	7.056	7.056	12.1	12.11	5.4	6.356
H18	3.528	2.95	3.528	6.055	2.948	2.948	6.06	6.055	4.57	2.948
H19	2.959	3.69	2.959	4.101	3.694	2.959	7.04	4.101	4.45	3.215
H20	4.577	3.53	4.577	6.062	4.577	6.062	6.06	6.062	4.58	4.577
H21	3.755	3.25	3.606	4.844	5.805	5.805	6.45	11.06	9.3	4.032
H22	9.926	2.8	2.542	9.926	9.926	3.673	9.93	9.926	9.93	9.926
H23	2.881	2.56	4.399	4.399	4.399	4.399	4.4	4.399	4.4	1.961
H24	1.572	1.57	1.572	1.572	1.572	1.572	1.57	1.572	1.57	1.572
H25	3.842	3.84	5.3	7.786	7.786	5.3	7.79	7.786	6.24	4.535
H26	3.739	3.74	7.136	7.136	5.255	6.124	7.14	10.51	10.5	3.87

Table 4.71 Final importance rating of HOW for each supplier for further improvement

Step9: Rank each HOW of each supplier for further improvement strategy by the supplier.

Ranking of HOW of each supplier for further improvement									
S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
H22	H7	H4	H1	H1	H1	H11	H11	H26	H22
H2	H11	H26	H5	H22	H5	H10	H8	H22	H4
H20	H4	H3	H8	H25	H17	H5	H10	H21	H17
H1	H8	H14	H22	H17	H10	H17	H1	H4	H5
H3	H10	H17	H15	H8	H11	H3	H5	H8	H10
H4	H3	H15	H7	H4	H8	H1	H17	H10	H3
H10	H17	H7	H2	H10	H3	H8	H21	H25	H8
H7	H5	H25	H13	H5	H26	H22	H4	H11	H7
H8	H25	H10	H25	H21	H20	H7	H12	H12	H20
H11	H26	H13	H11	H11	H21	H15	H26	H3	H1
H25	H16	H16	H10	H7	H25	H6	H22	H15	H25
H21	H19	H20	H26	H3	H7	H14	H7	H17	H21
H26	H1	H11	H17	H15	H2	H25	H15	H5	H26
H16	H20	H8	H14	H26	H16	H2	H3	H14	H11
H17	H6	H23	H3	H16	H13	H26	H6	H7	H2
H15	H21	H5	H18	H20	H4	H19	H13	H20	H15
H18	H2	H21	H20	H23	H23	H13	H25	H18	H12
H5	H18	H18	H16	H14	H15	H21	H14	H1	H6
H6	H22	H6	H21	H2	H12	H12	H18	H19	H14
H19	H14	H2	H4	H19	H14	H18	H20	H23	H9
H23	H15	H1	H23	H12	H22	H20	H16	H16	H19
H14	H12	H19	H19	H6	H6	H4	H23	H2	H16
H9	H9	H12	H12	H13	H19	H16	H19	H6	H18
H12	H23	H9	H6	H18	H18	H23	H2	H13	H13
H13	H13	H22	H9	H9	H9	H9	H9	H9	H23
H24	H24	H24	H24	H24	H24	H24	H24	H24	H24

Table 4.72 Ranking of HOW of each supplier for further improvement

Step10: Prioritise the evaluating factor on initial relative weight by the Decision maker

Priority Ranking of HOW by Decision Maker			
HOW		Initial Weight	Rank
H3	Management	107.84	1
H4	Experience	107.08	2
H10	Production Facility	102	3
H8	Modern Technology	101.22	4
H7	Material Planning and control	100.89	5
H11	Machinery	100.72	6
H25	Production Planning	99.02	7
H26	Financial Position	97.38	8
H17	R & D Facilities	95.79	9
H16	Modern Problem Solving Practices	93.79	10
H5	Human Resource	92.71	11
H20	Standard Practices	90.1	12
H21	Expertise Support	84.59	13
H6	Communication	84.28	14
H1	Quality Mgmt System	82.91	15
H2	Inspection system	81.49	16
H18	Support and Service	75.98	17
H19	Risk Management	75.69	18
H15	Innovation	71.57	19
H22	Reciprocal Arrangement	70.02	20
H12	Product Variety	68.78	21
H14	Reputation	68.78	22
H9	Production Layout	65.96	23
H13	Turnover	57.87	24
H23	Information Security	50.67	25
H24	Identification & Marking	39.81	26

Table 4.73 Priority Ranking of HOW by Decision Maker

Step11: Assess the difficulty level of implementation of the improvement strategy by the supplier with respect to the priority of the HOW by the decision maker. The difficulty level scale is as

Difficulty Level of action: High: >1.5 Medium: 1.25-1.50 Low: 1.0-1.25 Nil: ≤ 1.0

Tables 4.74 to Table 4.83 are difficulty tables for supplier S1 to S10

Priority for action for improvement by supplier S1				
Evaluating Factors		FIR	IR	Difficulty Level
H22	Relationship	9.93	3.91	HIGH
H2	Testing Facility and Inspection	4.73	1.5	MEDIUM
H20	Standard Practices	4.58	1.3	MEDIUM
H1	Standard Quality Mgnt System	4.35	1.42	MEDIUM
H3	Organisational Structure & Mngt.	4.19	1	NIL
H4	Business Experience	4.13	1	NIL
H10	Manufacturing Facility	3.92	1	NIL
H7	Planning and control	3.91	1	NIL
H8	Latest Technology	3.89	1	NIL
H11	Machinery and Equipments	3.84	1	NIL
H25	Compliance	3.84	1	NIL
H21	Key Skills and Expertise	3.75	1.16	LOW
H26	Financial Position	3.74	1	NIL
H16	Problem Mitigation Techniques	3.69	1	NIL
H17	R & D setup	3.69	1	NIL
H15	Innovation/Improvement Potential	3.55	1.3	MEDIUM
H18	Support Service	3.53	1.2	LOW
H5	Human Resource	3.5	1	NIL
H12	Product Range	3.44	1.3	MEDIUM
H6	Enabling Technology	3.25	1	NIL
H19	Risk Management	2.96	1	NIL
H23	Security and Confidentiality	2.88	1.47	MEDIUM
H14	Reputation	2.64	1	NIL
H9	Production Layout	2.6	1	NIL
H13	Business Volume	2.18	1	NIL
H24	Coding System	1.57	1	NIL

Table 4.74 Difficulty level of implementation by supplier S1

Priority for action for improvement by supplier S2			Ratio	Difficulty Level
H7	Planning and control	6.33	1.62	HIGH
H11	Machinery and Equipments	5.45	1.42	MEDIUM
H4	Business Experience	5.43	1.31	MEDIUM
H8	Latest Technology	5.27	1.36	MEDIUM
H10	Manufacturing Facility	5.2	1.33	MEDIUM
H3	Organisational Structure &Mngt.	5.17	1.23	LOW
H20	Standard Practices	4.58	1	NIL
H17	R & D setup	4.31	1.17	LOW
H5	Human Resource	3.91	1.12	LOW
H25	Compliance	3.84	1	NIL
H26	Financial Position	3.74	1	NIL
H16	Problem Mitigation Techniques	3.69	1	NIL
H19	Risk Management	3.69	1.25	LOW
H1	Standard Quality Mgnt System	3.57	1.16	LOW
H18	Support Service	3.53	1	NIL
H6	Enabling Technology	3.25	1	NIL
H21	Key Skills and Expertise	3.25	1	NIL
H2	Testing Facility and Inspection	3.16	1	NIL
H22	Relationship	2.8	1.1	LOW
H14	Reputation	2.75	1.04	LOW
H15	Innovation/Improvement Potential	2.72	1	NIL
H12	Product Range	2.64	1	NIL
H9	Production Layout	2.6	1	NIL
H23	Security and Confidentiality	2.56	1.31	MEDIUM
H13	Business Volume	2.18	1	NIL
H24	Coding System	1.57	1	NIL

Table 4.75 Difficulty level of implementation by supplier S2

Priority for action for improvement by supplier S3			Ratio	Difficulty Level
H4	Business Experience	11	2.65	HIGH
H26	Financial Position	7.14	1.91	HIGH
H3	Organisational Structure &Mngt.	6.5	1.55	HIGH
H14	Reputation	6.36	2.43	HIGH
H17	R & D setup	6.36	1.72	HIGH
H18	Support Service	6.06	1.2	LOW
H15	Innovation/Improvement Potential	5.79	2.13	HIGH
H7	Planning and control	5.74	1.47	MEDIUM
H25	Compliance	5.3	1.38	MEDIUM
H10	Manufacturing Facility	5.2	1.33	MEDIUM
H13	Business Volume	5.1	2.34	HIGH
H16	Problem Mitigation Techniques	4.88	1.32	MEDIUM
H20	Standard Practices	4.58	1.3	MEDIUM
H11	Machinery and Equipments	4.54	1.18	LOW
H8	Latest Technology	4.46	1.15	LOW
H23	Security and Confidentiality	4.4	2.24	HIGH
H5	Human Resource	4.26	1.22	LOW
H21	Key Skills and Expertise	3.61	1.11	LOW
H6	Enabling Technology	3.25	1	NIL
H2	Testing Facility and Inspection	3.16	1	NIL
H1	Standard Quality Mgnt System	3.07	1	NIL
H19	Risk Management	2.96	1	NIL
H12	Product Range	2.64	1	NIL
H9	Production Layout	2.6	1	NIL
H22	Relationship	2.54	1	NIL
H24	Coding System	1.57	1	NIL

Table 4.76 Difficulty level of implementation by supplier S3

Priority for action for improvement by supplier S4			Ratio	Difficulty Level
H1	Standard Quality Mgnt System	12.4	4.03	HIGH
H5	Human Resource	12.1	3.46	HIGH
H8	Latest Technology	10.3	2.65	HIGH
H22	Relationship	9.93	3.91	HIGH
H15	Innovation/Improvement Potential	9.63	3.54	HIGH
H7	Planning and control	8.79	2.24	HIGH
H2	Testing Facility and Inspection	8.23	2.6	HIGH
H13	Business Volume	8.2	3.77	HIGH
H25	Compliance	7.79	2.03	HIGH
H11	Machinery and Equipments	7.73	2.01	HIGH
H10	Manufacturing Facility	7.19	1.84	HIGH
H26	Financial Position	7.14	1.91	HIGH
H17	R & D setup	7.06	1.91	HIGH
H14	Reputation	6.36	2.41	HIGH
H3	Organisational Structure &Mngt.	6.08	1.45	MEDIUM
H18	Support Service	6.06	2.05	HIGH
H20	Standard Practices	6.06	1.72	HIGH
H16	Problem Mitigation Techniques	4.88	1.32	MEDIUM
H21	Key Skills and Expertise	4.84	1.49	MEDIUM
H4	Business Experience	4.41	1.07	LOW
H23	Security and Confidentiality	4.4	2.24	HIGH
H19	Risk Management	4.1	1.39	MEDIUM
H12	Product Range	3.44	1.3	MEDIUM
H6	Enabling Technology	3.25	1	NIL
H9	Production Layout	2.84	1.09	LOW
H24	Coding System	1.57	1	NIL

Table 4.77 Difficulty level of implementation by supplier S4

Priority for action for improvement by supplier S5			Ratio	Difficulty Level
H1	Standard Quality Mgnt System	12.4	4.03	HIGH
H22	Relationship	9.93	3.91	HIGH
H25	Compliance	7.79	2.03	HIGH
H17	R & D setup	7.06	1.91	HIGH
H8	Latest Technology	6.01	1.55	HIGH
H4	Business Experience	5.94	1.44	MEDIUM
H10	Manufacturing Facility	5.91	1.51	HIGH
H5	Human Resource	5.89	1.68	HIGH
H21	Key Skills and Expertise	5.81	1.79	HIGH
H11	Machinery and Equipments	5.69	1.48	MEDIUM
H7	Planning and control	5.67	1.45	MEDIUM
H3	Organisational Structure &Mngt.	5.66	1.35	MEDIUM
H15	Innovation/Improvement Potential	5.61	2.06	HIGH
H26	Financial Position	5.26	1.41	MEDIUM
H16	Problem Mitigation Techniques	4.88	1.32	MEDIUM
H20	Standard Practices	4.58	1.3	MEDIUM
H23	Security and Confidentiality	4.4	2.24	HIGH
H14	Reputation	4.1	1.55	HIGH
H2	Testing Facility and Inspection	4.04	1.28	MEDIUM
H19	Risk Management	3.69	1.25	LOW
H12	Product Range	3.58	1.35	MEDIUM
H6	Enabling Technology	3.25	1	NIL
H13	Business Volume	3.25	1.49	MEDIUM
H18	Support Service	2.95	1	NIL
H9	Production Layout	2.6	1	NIL
H24	Coding System	1.57	1	NIL

Table 4.78 Difficulty level of implementation by supplier S5

Priority for action for improvement by supplier S6			Ratio	Difficulty Level
H1	Standard Quality Mgnt System	12.4	4.03	HIGH
H5	Human Resource	12.1	3.46	HIGH
H17	R & D setup	7.06	1.91	HIGH
H10	Manufacturing Facility	6.58	1.68	HIGH
H11	Machinery and Equipments	6.5	1.69	HIGH
H8	Latest Technology	6.38	1.64	HIGH
H3	Organisational Structure &Mngt.	6.15	1.46	MEDIUM
H26	Financial Position	6.12	1.64	HIGH
H20	Standard Practices	6.06	1.72	HIGH
H21	Key Skills and Expertise	5.81	1.79	HIGH
H25	Compliance	5.3	1.38	MEDIUM
H7	Planning and control	5.19	1.33	MEDIUM
H2	Testing Facility and Inspection	4.89	1.55	HIGH
H16	Problem Mitigation Techniques	4.88	1.32	MEDIUM
H13	Business Volume	4.78	2.2	HIGH
H4	Business Experience	4.65	1.12	LOW
H23	Security and Confidentiality	4.4	2.24	HIGH
H15	Innovation/Improvement Potential	4.05	1.49	MEDIUM
H12	Product Range	3.82	1.45	MEDIUM
H14	Reputation	3.75	1.42	MEDIUM
H22	Relationship	3.67	1.45	MEDIUM
H6	Enabling Technology	3.25	1	NIL
H19	Risk Management	2.96	1	NIL
H18	Support Service	2.95	1	NIL
H9	Production Layout	2.84	1.09	LOW
H24	Coding System	1.57	1	NIL

Table 4.79 Difficulty level of implementation by supplier S6

Priority for action for improvement by supplier S7			Ratio	Difficulty Level
H11	Machinery and Equipments	15.5	4.03	HIGH
H10	Manufacturing Facility	14.8	3.77	HIGH
H5	Human Resource	12.1	3.46	HIGH
H17	R & D setup	12.1	3.28	HIGH
H3	Organisational Structure &Mngt.	11.7	2.79	HIGH
H1	Standard Quality Mgnt System	10.4	3.39	HIGH
H8	Latest Technology	10.3	2.65	HIGH
H22	Relationship	9.93	3.91	HIGH
H7	Planning and control	9.79	2.5	HIGH
H15	Innovation/Improvement Potential	9.63	3.54	HIGH
H6	Enabling Technology	9.23	2.84	HIGH
H14	Reputation	8.42	3.19	HIGH
H25	Compliance	7.79	2.03	HIGH
H2	Testing Facility and Inspection	7.46	2.36	HIGH
H26	Financial Position	7.14	1.91	HIGH
H19	Risk Management	7.04	2.38	HIGH
H13	Business Volume	6.9	3.17	HIGH
H21	Key Skills and Expertise	6.45	1.98	HIGH
H12	Product Range	6.2	2.35	HIGH
H18	Support Service	6.06	2.05	HIGH
H20	Standard Practices	6.06	1.72	HIGH
H4	Business Experience	5.69	1.38	MEDIUM
H16	Problem Mitigation Techniques	4.88	1.32	MEDIUM
H23	Security and Confidentiality	4.4	2.24	HIGH
H9	Production Layout	2.84	1.09	LOW
H24	Coding System	1.57	1	NIL

Table 4.80 Difficulty level of implementation by supplier S7

Priority for action for improvement by supplier S8			Ratio	Difficulty Level
H11	Machinery and Equipments	15.5	4.03	HIGH
H8	Latest Technology	15.2	3.91	HIGH
H10	Manufacturing Facility	14.8	3.77	HIGH
H1	Standard Quality Mgnt System	12.4	4.03	HIGH
H5	Human Resource	12.1	3.46	HIGH
H17	R & D setup	12.1	3.28	HIGH
H21	Key Skills and Expertise	11.1	3.41	HIGH
H4	Business Experience	10.6	2.56	HIGH
H12	Product Range	10.6	4.03	HIGH
H26	Financial Position	10.5	2.81	HIGH
H22	Relationship	9.93	3.91	HIGH
H7	Planning and control	9.79	2.5	HIGH
H15	Innovation/Improvement Potential	9.63	3.54	HIGH
H3	Organisational Structure &Mngt.	9.32	2.22	HIGH
H6	Enabling Technology	9.23	2.84	HIGH
H13	Business Volume	8.2	3.77	HIGH
H25	Compliance	7.79	2.03	HIGH
H14	Reputation	6.36	2.41	HIGH
H18	Support Service	6.06	2.05	HIGH
H20	Standard Practices	6.06	1.72	HIGH
H16	Problem Mitigation Techniques	4.88	1.32	MEDIUM
H23	Security and Confidentiality	4.4	2.24	HIGH
H19	Risk Management	4.1	1.39	MEDIUM
H2	Testing Facility and Inspection	3.85	1.22	LOW
H9	Production Layout	3.25	1.25	LOW
H24	Coding System	1.57	1	NIL

Table 4.81 Difficulty level of implementation by supplier S8

Priority for action for improvement by supplier S9			Ratio	Difficulty Level
H26	Financial Position	10.5	2.81	HIGH
H22	Relationship	9.93	3.91	HIGH
H21	Key Skills and Expertise	9.3	2.86	HIGH
H4	Business Experience	8.07	1.95	HIGH
H8	Latest Technology	6.77	1.74	HIGH
H10	Manufacturing Facility	6.58	1.68	HIGH
H25	Compliance	6.24	1.62	HIGH
H12	Product Range	5.96	2.26	HIGH
H11	Machinery and Equipments	5.69	1.48	MEDIUM
H3	Organisational Structure &Mngt.	5.66	1.35	MEDIUM
H15	Innovation/Improvement Potential	5.4	1.98	HIGH
H17	R & D setup	5.4	1.46	MEDIUM
H5	Human Resource	5.39	1.54	HIGH
H14	Reputation	4.72	1.79	HIGH
H7	Planning and control	4.66	1.19	LOW
H20	Standard Practices	4.58	1.3	MEDIUM
H18	Support Service	4.57	1.55	HIGH
H1	Standard Quality Mgnt System	4.55	1.48	MEDIUM
H19	Risk Management	4.45	1.5	MEDIUM
H23	Security and Confidentiality	4.4	2.24	HIGH
H16	Problem Mitigation Techniques	3.69	1	NIL
H2	Testing Facility and Inspection	3.45	1.09	LOW
H6	Enabling Technology	3.25	1	NIL
H13	Business Volume	2.95	1.35	MEDIUM
H9	Production Layout	2.6	1	NIL
H24	Coding System	1.57	1	NIL

Table 4.82 Difficulty level of implementation by supplier S9

Priority for action for improvement by supplier S10			Ratio	Difficulty Level
H22	Relationship	9.93	3.91	HIGH
H4	Business Experience	8.07	1.95	HIGH
H17	R & D setup	6.36	1.72	HIGH
H5	Human Resource	6.35	1.82	HIGH
H10	Manufacturing Facility	5.91	1.51	HIGH
H3	Organisational Structure & Mngt.	5.66	1.35	MEDIUM
H8	Latest Technology	5.59	1.44	MEDIUM
H7	Planning and control	4.66	1.19	LOW
H20	Standard Practices	4.58	1.3	MEDIUM
H1	Standard Quality Mgnt System	4.55	1.48	MEDIUM
H25	Compliance	4.54	1.18	LOW
H21	Key Skills and Expertise	4.03	1.24	LOW
H26	Financial Position	3.89	1.03	LOW
H11	Machinery and Equipments	3.84	1	NIL
H2	Testing Facility and Inspection	3.6	1.14	LOW
H15	Innovation/Improvement Potential	3.55	1.3	MEDIUM
H12	Product Range	3.44	1.3	MEDIUM
H6	Enabling Technology	3.4	1.04	LOW
H14	Reputation	3.37	1.28	MEDIUM
H9	Production Layout	3.25	1.25	LOW
H19	Risk Management	3.22	1.09	LOW
H16	Problem Mitigation Techniques	3.09	0.84	LOW
H18	Support Service	2.95	1	NIL
H13	Business Volume	2.56	1.18	LOW
H23	Security and Confidentiality	1.96	1	NIL
H24	Coding System	1.57	1	NIL

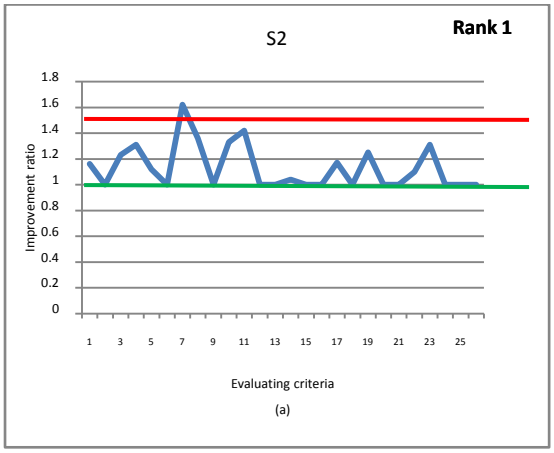
Table 4.83 Difficulty level of implementation by supplier S10

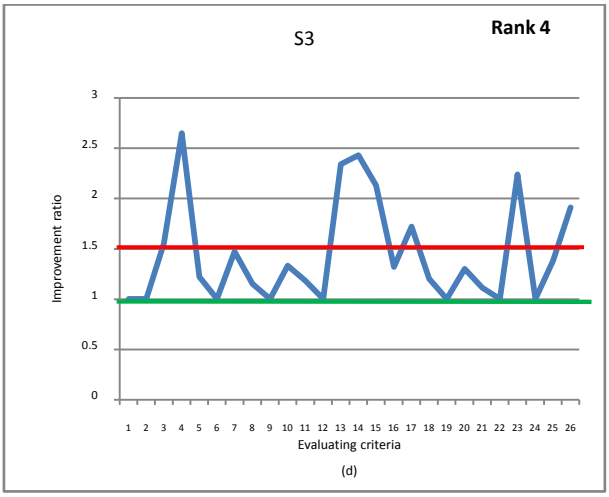
Step 12: Consolidate the difficulty levels of each supplier along with the supplier order in Table 4.84 for the easy reference of the decision maker. This method is easy and efficient for implementation takes care of uncertainties in the supplier selection process.

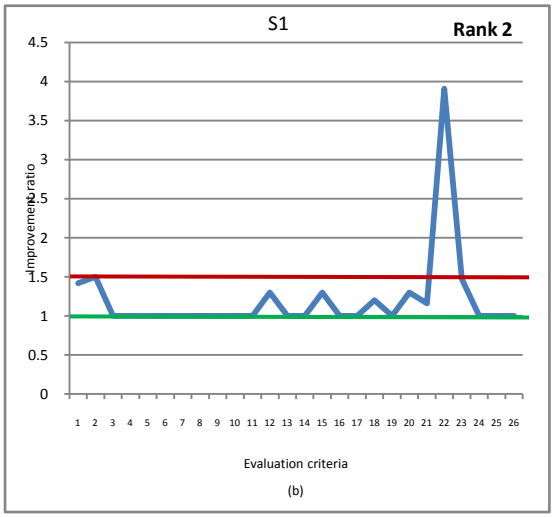
Rank	1	2	3	4	5	6	7	8	9	10
Supplier Order	S2	S1	S10	S3	S6	S5	S9	S4	S7	S8
HIGH	1	1	5	8	12	11	13	17	22	21
MEDIUM	5	6	7	5	8	10	7	5	2	2
LOW	7	2	10	5	2	1	2	2	1	2
NIL	13	17	4	8e	4	4	4	2	1	1

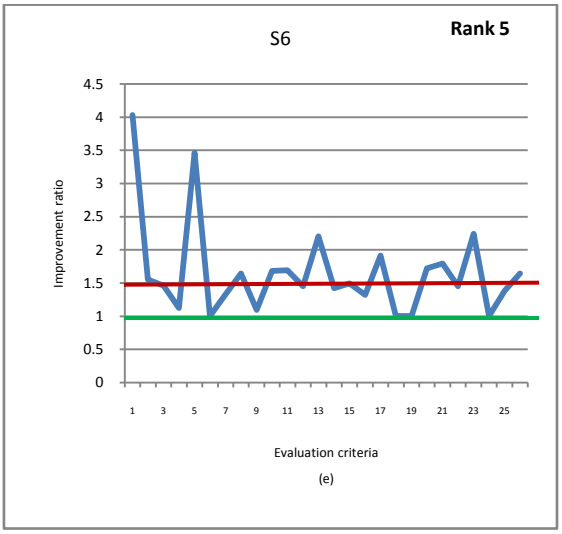
Table 4.84 Supplier selection order with level of difficulty of strategy implementation

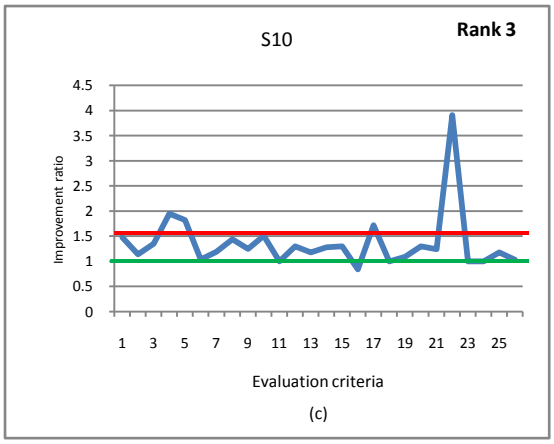
The suppliers are grouped into three categories. The group 1 comprises of suppliers S2, S1, S10 and S3 and graphs a, b, c, and d corresponds to these suppliers. The supplier S2 variations are within the limit of 1-1.5 range. The supplier S1 has high difficulty above 3.5 and supplier S2 has high difficulty up to 1.6. Though the supplier S1 has 17 NIL and 2 LOW difficulties, its rank is 2 instead of rank 1. In case of suppliers S10 and S3, supplier S3 has 8 high difficulties with majority of more than 2 and above and for supplier S10 only 2 difficulties cross the limit 2 also other low difficulties are within the range of 1-1.5 but S3 has more variations. So here S10 is at rank 3 and S3 at rank 4. The group 2 includes S6, S5 and S9 corresponds to graph e, f, & g. The suppliers S6, S5 and S9 have the high difficulty level in ascending order. Supplier S6 has two peaks of 4 and 3.5, but supplier S5 has two peaks touching range 4. The supplier S9 has higher variation compared to S^ and S5. Hence the Suppliers S6, S5 and S9 are placed at the ran 5,6, and 7 respectively. Suppliers S6, S5 and S9 variations are controllable and can be considered for supplier development. Suppliers S4, S7 & S8 in group 3 corresponds to the graph h, i and j respectively are knocked out due to unmanageable high variations. QFD entropy method gives more information during analysis. The graph (a) to (j) shows rank and difficulty level of the suppliers from S1 to S10 as shown in Figure 4.21.

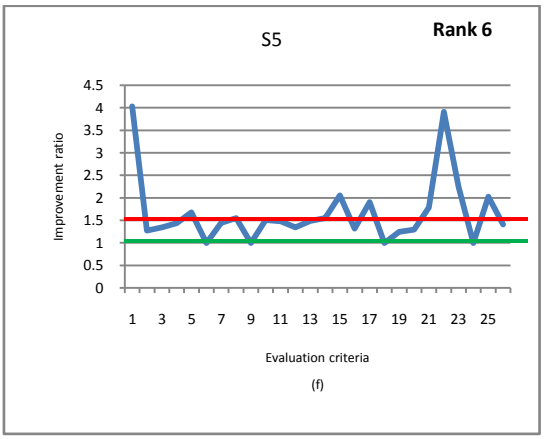

S2
Rank 1
Improvement ratio
Evaluating criteria
(a)

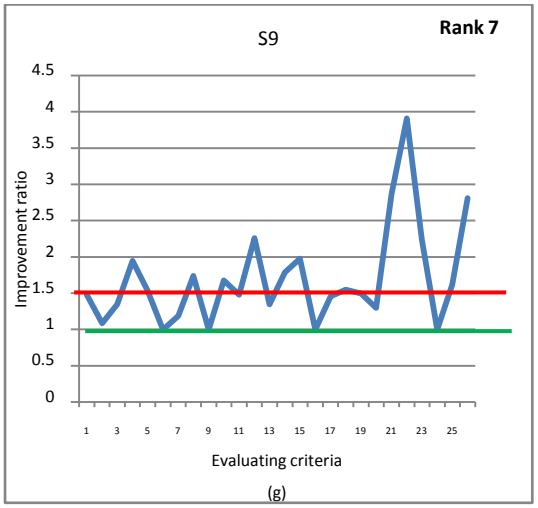

S3
Rank 4
Improvement ratio
Evaluating criteria
(d)

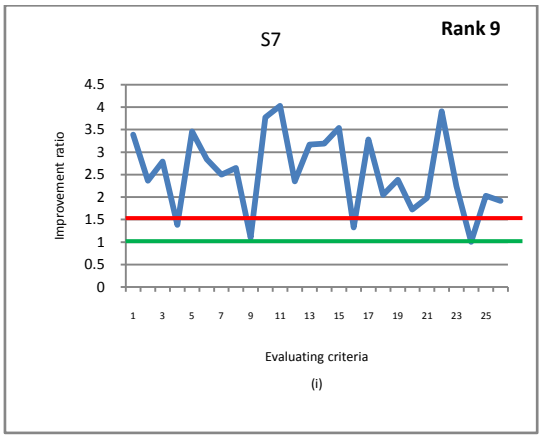

S1
Rank 2
Improvement ratio
Evaluation criteria
(b)

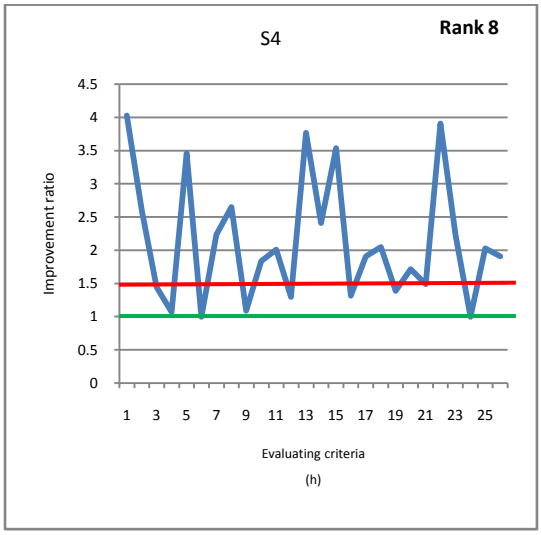

S6
Rank 5
Improvement ratio
Evaluation criteria
(e)


S10
Rank 3
Improvement ratio
Evaluation criteria
(c)


S5
Rank 6
Improvement ratio
Evaluation criteria
(f)







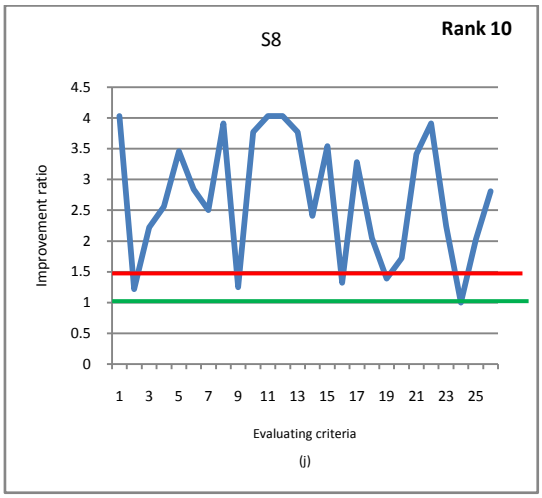


Figure 4.21 Graph (a) to (j) show rank and difficulty level of the suppliers

CHAPTER 5

DISCUSSION AND CONCLUSION

5.1 Discussion

The research intent was to develop a decision tool for supplier selection considering strategic outsourcing in dynamic environment. The research study also focus on, outsourcing, supplier selection process, to identify the supplier selection criteria in today's business environment based on the literature review and industry expert opinions and to know existing supplier selection methods in practice.

The aim is achieved successfully, first, developing a heuristic method using decision tree to decide on outsourcing or in-sourcing and identify the number of suppliers essential if outsourcing decision is taken. The other intent is to develop supplier selection method to select the suppliers from pool of suppliers to meet the need of organisation. The methods developed are, 1.Hybrid fuzzy QFD method 2.QFD-entropy method. The developed methods are tested in the organisation for its effectiveness.

(a) The hybrid fuzzy QFD method is applied in three organizations. The Firm 1 and Firm 2 are based in Goa while Firm 3 is in Pune. The details are below:

Variable	Organisation		
	Firm1	Firm 2	Firm 3
Decision Making	Group	Group	Single
No. of suppliers	10	2	5
Criteria	Multiple	Multiple	Multiple
	Quantitative & Qualitative	Qualitative	Qualitative

Table 5.1 Organisation variables

In case of Firm 1 both criteria are considered. The decision makers assign importance to the qualitative and quantitative criteria. The table 4.41 shows the rank of suppliers and sensitivity analysis for various range of coefficient of preference. The decision makers importance to the criteria play major role in deciding the ranking of suppliers. As per section 4.14.1, decision maker give more importance to quantitative factor Table 4.27. The decision maker's preference for criteria play major role in the

ranking of suppliers. The quantitative factor has more weight means the quantitative parameters are important in supplier selection in Firm 1. Out of five quantitative factors price is dominating factor since other factors have influence on the price determination by the supplier. The sensitivity analysis is shown in the Table 4.41 for different values of 'α'.

As per Firm 2, the supplier 1 and supplier 2 has rank 1 and rank 2 respectively. Number of suppliers is only two for this product. This QFD method suggested will assist the company to periodically evaluate the suppliers and decide about the work allocation based on the performance of the supplier. Monitoring and control of the supplier is easy due to small numbers. Also suppliers are sure about the purchase order regularly. It generates healthy competition within suppliers. All three firms work as integrated unit. It is easy for the company to have long term relationship with these suppliers. It is concluded that the quality plays important role when the product is directly delivered at the project site or warehouse, which are at the far distance. This will avoid frequent maintenance, rework and service and protect the brand name of the buyer and supplier, maintaining and improving the competitive advantage in the market. The proposed method is tested in the company.

Regarding Firm3, the supplier ranks are shown in Table 4.67 above. The evaluation of supplier is on qualitative criteria. The periodic evaluation using QFD method will alert all suppliers to regularly improve their evaluating parameters. In this study of Firm 3, the performance of all five suppliers is almost same and thus evaluation of suppliers is difficult for decision maker. The purchase manager has difficulty in ranking suppliers accurately. The suppliers are instructed to follow the supply schedule and supply the components within specification with zero defects. The buyers assist in problem solving, training and extend support to the supplier. The buyer maintains the good relationship with the suppliers with mutual trust, respect and commitments. The buyer is satisfied with the performance of the supplier, but finds difficulty to rate these suppliers. It is felt by the buyer that, the rating is essential to bring in the competitive spirit among the suppliers. It is decided to rank these suppliers and place the purchase order by varying quantity. The highest rank supplier will be given more volume order. The periodic evaluation will be done of all five suppliers. The suppliers focus on operation control and quality standard. The purchase managers' view is that the qualitative factors are responsible for quantitative factors. So purchase manager gives more stress on the qualitative criteria than the quantitative criteria. The proposed method is easy and gives

output close to the real values. The company purchase manager applied the method in the company and was satisfied with the results.

(b) The QFD-entropy method: The data of Firm 1 is analysed applying .QFD-entropy method. This method is suitable for qualitative data only. The qualitative data of Firm 1 is employed for analysis. The group 1 comprises of suppliers S2, S1, S10 and S3 and graphs a, b, c, and d corresponds to these suppliers. The supplier S2 variations are within the limit of 1-1.5 range. The supplier S1 has high difficulty above 3.5 and supplier S2 has high difficulty up to 1.6. Though the supplier S1 has 17 NIL and 2 LOW difficulties, its rank is 2 instead of rank 1. In case of suppliers S10 and S3, supplier S3 has 8 high difficulties with majority of more than 2 and above and for supplier S10 only 2 difficulties cross the limit 2 also other low difficulties are within the range of 1-1.5 but S3 has more variations. So here S10 is at rank 3 and S3 at rank 4. The group 2 includes S6, S5 and S9 corresponds to graph e, f, & g. The suppliers S6, S5 and S9 have the high difficulty level in ascending order. Supplier S6 has two peaks of 4 and 3.5, but supplier S5 has two peaks touching range 4. The supplier S9 has higher variation compared to S^ and S5. Hence the Suppliers S6, S5 and S9 are placed at the rank 5, 6, and 7 respectively. Suppliers S6, S5 and S9 variations are controllable and can be considered for supplier development. Suppliers S4, S7 & S8 in group 3 corresponds to the graph h, i and j respectively are knocked out due to unmanageable high variations. QFD entropy method gives more information during analysis. The graphs are shown in Figure 4.21.

5.1.1 Comparison of Hybrid Fuzzy QFD and Hybrid Entropy QFD method

A. Hybrid QFD Entropy method

Rank	1	2	3	4	5	6	7	8	9	10
Supplier Order	S2	S1	S10	S3	S6	S5	S9	S4	S7	S8
HIGH	1	1	5	8	12	11	13	17	22	21
MEDIUM	5	6	7	5	8	10	7	5	2	2
LOW	7	2	10	5	2	1	2	2	1	2
NIL	13	17	4	8	4	4	4	2	1	1

Table 4.84 Supplier selection order with level of difficulty of strategy implementation

B. **Hybrid Fuzzy QFD method**.

Rank	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Supplier Order	S1	S2	S3	S10	S5	S9	S6	S4	S7	S8

Table 4.33 Rank of supplier on qualitative criteria

It is observed on comparing both proposed methods that,

1. The results of both methods are shown in Table 4.33 and Table 4.84. The suppliers are arranged in the descending order of ranking in both the tables above. The result obtained is divided into three groups. The first group is the acceptable supplier base by the organisation. Second group of suppliers can be considered for the SDI by the organisation. The last group fall in supplier pruning category.

(a) The first group comprises of first four suppliers out of ten suppliers are S1, S2, S10 and S3. In this group the order of S1 and S2 is interchanged in both methods, however there is no change in the order of S10 and S3. This change does not have effect on acceptable supplier set of the organisation.

(b) The second group of supplier set is S5, S6, and S9. There exists change in the ranking order of suppliers in this group by both methods. However there is no change in the group elements. This group is for SDI decision by the organisation and does not have any effect on first group.

(c) The last group comprise of S4, S7 and S8 retaining the same ranking order in both methods. The suppliers in this group are pruned by the organisation, since the difficulty level of implementation of improvement strategy is high for these suppliers. This group will also dictate difficulties to the buyer for monitoring and control of their operations and processes.

The proper coordination between buyer and supplier is required for efficient control on operations and processes for systematic implementation of SDI decision in second group and for supplier evaluation in the first group.

2. The hybrid fuzzy QFD method only ranks the supplier; however hybrid entropy method ranks the supplier and assesses the level of difficulty faced by each supplier. The decision maker can choose any method of his choice as per his suitability.

3. The hybrid fuzzy QFD method can consider both qualitative and quantitative criteria, but QFD Entropy method is suitable for qualitative criteria only.

5.2 Conclusion

In the competitive environment organizations struggle to survive and grow. The activities having potential for competitive advantage are protected and controlled and other non core activities are outsourced, so that resources can be concentrated on core activities to get competitive edge in the market. By outsourcing, organization's capacities and capabilities are supplemented by the supplier's skill, knowledge, expertise and resources. This benefit is derived by developing a strong association of the buyer and supplier with proper cooperation, coordination, collaboration and integration with appropriate strategy (low cost strategy, response strategy or differentiation strategy) in the market. Hence supplier selection is crucial for the organisation. The supplier selection methods in the literature consider the final selection phase in the supplier selection process.

In today's context, supplier selection phase starts at outsourcing stage. The supplier selection decision depends on the outsourcing decision, buyer-supplier relationship and supplier selection criteria. A heuristic methodology using decision theory is suggested to assist the decision maker for taking outsourcing decision. Based on the decision the rganisation either perform the activities internally or outsource the activities to maintain competitive position in the market. The outsourcing decisions pull the suppliers from the intermediate market to supplement the resources of the buyer to derive competitive advantage and customer satisfaction in the dynamic business environment. The buyer develops long term relationship with the selected suppliers for mutual benefits Ghodsypour S.H. et al.(1998),Chan(2003), Perona (2004), S. Sen et al.(2008). The right supplier selection is essential and critical task of the decision maker. This research study proposed two supplier selection methods 1.Hybrid fuzzy-QFD method 2.Hybrid QFD-Entropy method. A QFD process is proposed with two house of quality phases performed sequentially to get the final score of the supplier. Relationship matrix is developed between buyer requirement and supplier influencing evaluating criteria. AHP assist in maintaining the consistency in the decision maker's judgment. The fuzzy set theory is applied due to vagueness, imprecise data and human judgment for realistic results in fuzzy environment. The linguistic assessment of decisions maker in the fuzzy environment is represented by TFN to reduce the fuzziness in the supplier selection process. Quantitative

evaluation of supplier is done by linear weighted method to obtain quantitative supplier score. The results of qualitative and quantitative evaluation are aggregated to rank the suppliers. Second method proposed uses entropy (dispersion) to incorporate uncertainty and variations in the selection process. The entropy, competitive priority and improvement ratio is calculated. The suppliers are ranked based on the improvement ratio and the difficulty of strategy implementation is assessed for each supplier. .

The both proposed methods are compared for superiority. The hybrid FQFD method rank the suppliers on score obtained using qualitative and quantitative criteria., however QFD-entropy method rank the supplier on improvement strength and assess the level of difficulty faced by each supplier in strategy implementation. The decision maker can choose any one method for supplier selection.

5.3 Limitations and Managerial implications

1. The proposed methods can be used by single decision maker or for group decision making to solve MCDM problem with multiple criteria, vagueness and imprecise data, human judgment, decision makers' intuition, insight, experience, skill, knowledge of linguistic assessment.
2. The proposed hybrid QFD method incorporates qualitative and quantitative data, traditional and strategic criteria, fuzzy environment and group decision.
3. The methods have flexibility in criteria selection. The decision maker can choose criteria as per organisation requirement.
4. The information loss is minimized by the use of fuzzy number.
5. The involvement of experts from different functional areas assists in taking holistic decision of customer requirements.
6. If the suppliers are having tough competition, than it is difficult for the decision makers to evaluate and select the right supplier/suppliers. The proposed methods are effective in supplier competitive environment.
7. The entropy method proposed assist decision makers to evaluate the improvement strength of each supplier, asses the level of difficulty in strategy implementation based on the competitive priority of evaluating criteria and also rank the suppliers.
8. The methods proposed are simple, effective, efficient and easy to use.
9. The methods can be used by the decision managers, senior managers, or purchase mangers involved in supplier selection process.
10. Hybrid entropy is suitable for qualitative criteria only.
11. Methods are suitable and effective in medium and large scale organisations.

5.4 Future work

A diversified range for future work of research is available for the presented methodology. Future research is to compare the outcome of proposed methods with other group decision methods for supplier selection. The QFD relationship matrix is built for 'WHAT' and 'HOW' by six experts. The more reliable relationship (WHAT-HOW) matrix can be built by increasing the number of experts from different industry verticals. The limited use of six qualitative and five quantitative criteria's is done in the analysis. However more addition of the criteria is required to study the behavior of proposed model. The models developed could be applied in material management, construction industry, pharmaceutical industry, projects, manufacturing sector, other management problems such as human resource selection, site selection, marketing, etc. It is suggested to employ fuzzy numbers in QFD-entropy and compare the results obtained by the proposed methods. Further work is to develop user friendly application software based on proposed algorithm using Visual Basic 6.0, Microsoft Excel, .net to make model easy to use by the decision makers.

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ANNEXURE A

Questionnaire

!.A. Name of the organization:

B. Type of Organization: a. Small Scale O b. Medium Scale O c. Large Scale O d. MNC O

2. Name of the Department/Section

3. Designation:

4. Experience (no. of years): a. 0 ≤ 5 b. 5 ≤ 10 c. 10 ≤ 20 d. 20 > above

5. Decision Authority: a. Low b. Average c. High d. Very High

7. Give importance of Qualitative criteria over Quantitative Criteria:

qualitative criteria	quality, reliability, flexibility, stability, capability, availability & sustainability,
quantitative criteria	price, quantity, proximity, credit time, delivery time

a. Just Equal O b. Equally Important O c. Weakly Important O
d. Strong Important O e Very Strong Important. O f. Immense Important O

7. Please give importance of Qualitative criteria. Please tick √ mark in the cell

Criteria	Equally Strong	Equally Preferred	Moderate	Strong	Very Strong	Extremely
Quality						
Reliability						
Flexibility						
Stability						
Capability						
Availability						

8. Comparison of Decision makers by Head of Organisation / / Decision Team

Ex: Team(5 members) Please enter the appropriate number in column 2 below

Importance	Equally strong 1	Equally Preferred 2	Moderate 3	Strong 4	Very Strong 5	Extremely 6

Decision maker is	Importance	than Decision maker
DM 1		DM 2
DM 1		DM 3
DM 1		DM 4
DM 1		DM 5
DM 2		DM 3
DM 2		DM 4
DM 2		DM 5
DM 3		DM 4
DM 3		DM 5
DM 4		DM 5

9. Rate the Supplier based on following Evaluating factors: Decision Maker:_____
Please enter in cell either No/Weak/Moderate/Strong in reference to supplier **N / W / M / S**

Evaluation Factor	Suppliers									
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Standard Quality Management System										
Testing Facility and Inspection										
Organisational Structure and Management										
Business Experience										
Human Resource										
Enabling Technology										
Planning and Control										
Latest Technology										
Production Layout										
Manufacturing Facilities										
Machinery and Equipments										
Product range										
Business volume										
Reputation										
Innovation/Improvement Potential										
Problem Mitigation Techniques										
Research and Development setup										
Service support										
Risk Management										
Standard practise										
Key skills and Expertise										
Relationship										
Security and Confidentiality										
Coding system										
Compliance and Response										
Financial Position										

ANNEXURE B

Relationship Matrix

Customer (Buyer) requirements WHAT	**Technical evaluation criteria of supplier HOW**																								
	Standard Quality Management System	Testing Facility and Inspection	Organisational Structure and Management	Business Experience	Human Resource	Enabling Technology	Planning and Control	Latest Technology	Production Layout	Manufacturing Facilities	Machinery and Equipments	Product Range	Business Volume	Reputation	Innovation/Improvement Potential	Problem Mitigation Techniques	Research and Development setup	Service support	Risk Management	Standard Practices	Key skills and Expertise	Relationship	Security and Confidentiality	Coding system	Compliance and Response	Financial Position
	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	H11	H12	H13	H14	H15	H16	H17	H18	H19	H20	H21	H22	H23	H24	H25	H26
Quality W1																										
Reliability W2																										
Flexibility W3																										
Stability W4																										
Capability W5																										
Availability & Sustainability W6																										

ANNEXURE C

Questions for assessing the supplier selection process, methods and criteria

1. Which are the products manufactured by organization?
2. Give the importance to these products.
3. Product Importance is based on which characteristic?
4. How you classify the end products? Market share (Customer product/own product) / Manufacturing cost /Quality standards? Domestic market, Int. Market, Low/High accuracy,
5. Which is the main product manufactured based on schedule?
6. Where this product is used by the customer?
7. What is mode of payment from customer? Which mode do you accept?
8. What are the requirements of Customer?
9. How does customer get assurance of fulfillment of their requirements?
10. Does customer conduct any audit or check?
11. What customer checks at buyers place during the audit?
12. Product quantity manufactured is constant or varies during the period?
13. Whether variation in the product quantity has impact on the functioning of the organization?
14. What is % of purchase as compared to sales?
15. What type of efforts taken by you to improve the purchase by sales ratio?
16. What steps are initiated by buyer to reduce the purchase cost?
17. How joint cost reduction approach is adopted by the buyer and seller in your case?
18. Which raw material or purchase product has opportunity to reduce cost? How? (location(Transportation cost), mass requirement(quantity discount), assured business, substitute product, alternative supplier
19. How customer requirements are fulfilled by supplier?
20. How buyer dictates the criteria to the supplier in relation to the customer requirement?
21. How frequently orders are placed with the supplier?
22. What are the various reasons for the delay in deliveries from the supplier?
23. What actions are taken to minimize the delay in deliveries from the supplier?
24. What are the controllable factors to minimize the lateness?
25. List of customers of the product manufactured by the buyer? Major, regular, custom specific

26. Which quality standards/ Norms/ marking for product used?
27. Which process is followed to manufacture the product by the organization? Manufacturing /Assembly
28. What is outsourced by the organization? Give the list. Product/Service
29. What are the reasons for the purchasing the raw material, product components, sub assemblies from the suppliers?
30. Is the organization is bound to purchase from the specific supplier? If yes what is the reason for it?
31. How you classify the raw material during purchase?
32. How you classify the product during purchase?
33. Which type of classification system is used for the raw material? Eg. ABC system
34. Which type of classification system is used for the Product? Eg. ABC system
35. How purchase orders are placed with the supplier? On regular interval or as and when required.
36. List of suppliers of the organization.
37. Where the suppliers are are located? Within Goa, Within India, Outside India
38. What type of supplier organization is? Single Owner, Artisian, SSI, MSI, LSI, MNC.
39. Who are major suppliers of raw material/Components/Semi Assembly?
40. Do the suppliers of raw material are approved?
41. What are benefits of approving the supplier?
42. What is procedure adapted for approval of supplier?
43. How you select supplier for new product?
44. How existing suppliers are evaluated and monitored?
45. How new suppliers are selected and monitored?
46. How suppliers are selected for the existing product/components?
47. What is the contribution of supplier in product development?
48. How you solve the technical difficulties of the supplier?
49. What is the contribution of the supplier in technical discussion?
50. How suppliers help in problem solving?

51. How frequently you visit the supplier premises?
52. How frequently supplier visit your organisation?
53. What you check or verify during the visit at supplier premises?
54. What supplier check at buyers place?
55. Which facilities are shared by the supplier with the buyer?
56. Which facilities are shared by the buyer with the supplier?
57. Which parameters are checked while selecting the supplier?
58. How supplier assure for supply of material according to specification? Product Quality, quantity, delivery time, customer service, after sales service etc.
59. What role does Quality, Production and Purchase department plays while selection of supplier?
60. What is the expectation of finance department that puts constraint on selection of supplier? Credit facility (number of days), advance payment etc.
61. What mode of payment preferred by buyer to supplier? COD, Cheque, DD, RTGS, LC
62. What is the mode of payment by supplier to buyer? COD, Cheque, DD, RTGS, LC
63. Which mode is preferred (State reason) (ECS clearance may reduce cost)
64. How does organization background influence on supplier selection?
65. Who dominates on supplier selection process? Why and How?
66. What do you mean by supplier background?
67. How does supplier's background influence on selection process?
68. How pre delivery inspection is done?
69. Who does pre delivery inspection at the supplier premises? State the reason. (Seller himself, buyer personnel, third party on behalf of buyer).
70. Who has control over supply? Supplier or Buyer.
71. How you control your suppliers? List the methods of control.
72. What are the checks that are performed on the raw material received from supplier?
73. Which department are involved in verifying raw material and other product components?
74. Which department decision influence on acceptance/rejection of raw material/product components?
75. How the loss due to raw material/product component rejection is quantified?

76. Who is responsible for the loss?
77. How the losses due to rejection of raw matrial are recovered?
78. Which are the probable reasons identified for the rejection of material from the supplier?
79. What are corrective actions taken to prevent further reoccurrence of such rejections?
80. What steps are initiated by the supplier fro reduction of rejection rate?
81. How the action taken by the supplier for improvement is verified?
82. Is there any item/items sourced from single supplier ?Why?
83. Is there any item/items sourced from multiple suppliers ?Why?
84. Which are the products that give maximum profit to the organisation?
85. Which type of supplier does organisation have? domestic, local, foreign
86. What are the circumstances that forces organisation to select domestic and foreign supplier? Non availability, Monopoly, Quality, Cost, Duty Benefits, any other.
87 Who are involved in supplier selection process, approval and decision?
88. What are parameters /points considered during selection/approval of supplier?
89. Which are the products/raw material that require group decision?
90. On which aspect organisation focus much during selection of supplier?
91. Which are the areas you concentrate on cost reduction while supplier selection?
92. How supplier help in the cost reduction?
93. How does geographical location of supplier have impact on selection process?
94. What are important aspect in delivery of product/material/components?
95. How you define the quality requirements for items to purchase? Drawings, data sheets, part specification, quality plan (material, manufacturing processes, test and testing processes, verbal information)
96. What are service expectations from suppliers?
97. What are important costs included when you define product cost?
98. What will make one supplier strong as compared to other suppliers? (Supply network, product range, quality standards, etc.)
99. How you evaluate supplier strength?
100. How do you asses QMS of supplier? (Check sheet, Check list)

101. Who are involved in verifying QMS system of supplier?
102. What do you check during assessing QMS system of supplier?
103. How does buyer gets an assurance from supplier about fulfillment of requirements?
104. How does supplier employee contribute towards fulfillment of buyer requirements?
105. How do you define product quality?
106. How you monitor or evaluate suppliers manufacturing quality?
107. What do you mean by Management/Employee/Process/Technological capability of supplier?
108. How do you asses Management/Employee/Process/Technological capability of supplier?
109. What do you mean by the financial stability of supplier organization?
110. How do you check financial stability?
111. In which manner financial stability will impact on supplier selection process?
112. How you differentiate between reliable and unreliable supplier?
113. What are checks that you carry out to know reliability of your supplier?
114. What importance you give to test and inspection management?
115. What quality check you perform on incoming material from supplier? Why?
116. As a buyer what are your expectation in respect to product packing?
117. What impact packaging and marking will have on quality of product? Why packaging and marking is important?
118. Who gives the specification for packaging and coding(Marking), Customer or you.?
119. How should be the approach of supplier that will make supplier selection process easy?
120. In which respect supplier should be flexible that will give advantage to buyer?
121. What are advantages of supplier being flexible?
122. As part of discipline, what is your expectation from supplier?
123. What will be consequence on the raw material/product if supplier is not disciplined?
124. How you measure the supplier competency?
125. How much supplier is dependent on your purchase order?

126. How much quantum of business is given to the supplier?
127. Is your supplier also supplies to other organisation?
128. Other organisation to whom supplier supplies is your competitor?
129. How you checked the maintaining the confidentiality by your supplier?
130. What method is adapted to check the confidentiality?
131. What type of ICT you prefer?
132. What type of ICT your supplier is having?
133. Are your supplier open for communication?
134. What type of opportunistic approach noticed by you in supplier?
135. How you deal with unethical methods by the supplier?
136. How prompt the communication is, so that further work can be planned?
137. Does attitude, responsiveness will be considered during supplier selection? What impact it will have on product quality?
138. How should be the information flow system for quick processing?
139. What information system you prefer organization should use?
140. What are your perception regarding flexibility of supplier's organization?
141. How you measure supplier's flexibility in terms of manufacturing, operations, design,
142. What are the quality systems that organization needs to have to meet customer requirements?
143. How do supplier's competent employee will contribute towards quality and delivery of product?
144. How much employee competency, skill of employee, culture of organization will influence towards organization growth? How do you quantify the same?
145. How do product variety, machinery, layout, turnover of organization influence on supplier selection process? What approach you adapt to get details of same?

ANNEXURE D

Feedback given by the organisations on the research work done in their plant.

LIFT CONTROLS PVT. LTD.

CIN NO. U31200GA2001PTC002956

Date :

Our Ref. :

Your Ref. :

LIFT CONTROLS PVT. LTD.

28/06/2016

TO WHOMSOEVER IT MAY CONCERN

This is to mention that, Mr. Mahesh Dani, carried out his research study in our company. During his research study he was associated with our official for understanding the supplier selection process of our company. The supplier selection is critical to our company. The method discussed and suggested by Mr. Dani covers all the supplier parameters necessary for the company. The method involves all persons connected with supplier selection. The method includes stages, which are easier to understand for the company persons involved in selection process. The trial result obtained by this method is better compared to earlier result. The difficulty of selecting multiple suppliers can be overcome by this simplified method. The company plans to use this method for supplier selection of material. We congratulate Mr. Dani for new method suggested to us which will make our task easier for supplier selection. Mr.Mahesh Dani was sincere and hardworking during his study period in our company.

FOR LIFT CONTROLS PVT LTD

MAHENDRA KHANDEPARKAR
DIRECTOR
DIN NO: 00095704

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DATE :JUNE 30, 2016

TO WHOM SO EVER IT MAY CONCERN

WE WOULD LIKE TO MENTION THAT MR. MAHESH DANI COMPLETED PART OF HIS RESEARCH WORK IN OUR ORGANISATION ON SUPPLIER SELECTION CRITERIA, PROCESS, METHODS WHICH IS IMPORTANT TO ANY ORGANISATION TO SELECT RIGHT SUPPLIER AT RIGHT TIME FOR RIGHT PRODUCT.

OUR ORGANISATION FOCUSED & CONSIDER PRICE/COST, QUANTITY, DELIVERY TIME ETC DURING SUPPLIER SELECTION, NO SPECIFIC METHOD OR TECHNIQUE IS USED FOR SUPPLIER SELECTION. THE PROPOSED METHOD BY MR. DANI IS SCIENTIFIC WITH SYSTEMATIC PROCEDURE AND TAKE INTO ACCOUNT WIDE RANGE OF CRITERIA ESSENTIAL FOR SUPPLIER SELECTION IN TODAY'S COMPETITIVE ENVIRONMENT, THE PROPOSED METHOD CAN BE APPLIED IN ORGANISATION FOR ACCURATE SUPPLIER SELECTION THE OUTPUT OF WHICH SIGNIFICANTLY VARY WITH AND WITHOUT PROPOSED METHOD UNDER THE SAME ENVIRONMENTAL CONDITIONS. THE PROPOSED METHOD IS SIMPLE, EASY TO UNDERSTAND AND EASY TO USE BY THE PURCHASE MANAGER.

WE APPRECIATE THE EFFORTS OF MR. DANI FOR DEVELOPING THE SUPPLIER SELECTION METHOD APPLICABLE IN MOST OF THE ORGANISATIONS. WE MAY BE APPLYING THIS SUPPLIER SELECTION METHOD IN OUR ORGANISATION TO REDUCE TIME AND EFFORTS OF THE PERSONNEL INVOLVED IN SUPPLIER SELECTION PROCESS.

FOR ADVANCED COMPOSITES PVT LTD

(MOHAN IYER)
MANAGING DIRECTOR

ADVANCED COMPOSITES PVT. LTD. BICHOLIM, GOA

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Tel.: 020 - 65295556 / 7 / 8 E-mail: info@htswitchgears.com www.htswitchgears.co.in

Date – 10th August 2016

TO WHOMSOEVER IT MAY CONCERN

This is to mention that, **Mr. Mahesh H. Dani** carried out his research work in our company. He was associated with our personnel to understand the supplier selection process of our company. The suppliers are important for the company and hence supplier selection is crucial function to our company. The method discussed and suggested by **Mr. Dani** includes supplier parameters essential for the company and business environmental conditions. The method involves all persons responsible for supplier selection. The method includes simple steps which are easier to understand for the company persons involved in the supplier selection process. The suggested method is structured and simple. The method is tested for its suitability. The test result is superior compared to earlier result. The difficulty of selecting and ranking multiple suppliers can be overcome by this simplified method. The company plans to use this method for supplier selection of material. We appreciate the efforts taken by **Mr. Dani** for developing the new supplier selection method suitable for any manufacturing company. The new method suggested to us will make our task of supplier selection simple and easier. **Mr. Mahesh Dani** was sincere and hardworking during his study period in our company.

Thanking You,
Yours faithfully,
For H.T. Switchgears

(Authorised signatory)

H.T. SWITCHGEARS Authorised Signatory PUNE-411023

ANNEXURE E

Research publications

1. Mahesh Dani and Dayanand M.S.,(2011), Need and Importance of Strategic Outsourcing – An Overview, Proceeding of the 1st National Doctoral Conference , VIM, Pune , page 37

2. Mahesh Dani and Dayanand M.S.,(2011), Impact of Outsourcing on Industry Performance, Proceeding of the 2nd International Conference on- Recent Trends in Business, Management & IT, Poona College of Arts, Science &Commerce in association with University of Pune,44-47

3. Mahesh Dani and Dayanand M.S. (2011), Strategic Role of Vendor in SCM Structure, Proceeding of the International Conference on Competency Building Strategies in Business and Technology for sustainable development at SIM, Chennai. 593-596

4. Mahesh Dani and Dayanand M.S. ,(2012), Decision Tree and Heuristic approach for Outsourcing and supplier base in multi period business environment, International Journal of Advances in Management, Technology and Engineering Sciences, Vol. I, issue 9(1), 9-14

5. Mahesh Dani and Dayanand M.S.,(2013), Factors affecting supplier selection process in manufacturing industry, Annamalai Journal Of Management, Vol. 6, special issue 2, 66-69.

6. Mahesh Dani and Dayanand M.S.,(2013),A review on supplier selection process, criteria and methods, International journal of business, management & social sciences,vol II,issue12(1), 24-27

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8. Mahesh Dani, Dr. Dayanand M.S, Amol Patil, Dr. V. N. Gaitonde,(2014), Integrated Fuzzy QFD-AHP-WLM approach for supplier selection, International Journal of Advances in Management, Technology & Engineering Sciences. Vol III, issue 10, 38-43