Review of existing methods, models and tools for supplier evaluation

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ABSTRACT

The objective of this dissertation is to reflect the importance of supplier evaluation process, analyzing criteria that can be used to determinate the best supplier and developing different methods that help to make this decision.

The market is changing and supplier selection approach has evolved from multiple suppliers to single supplier approach. In the past, the traditional approach used to consider multiple suppliers and one main criterion, the price. However, the market has moved towards contracting a single supplier selected by means of a multiple criteria. In 1960, Dickson created an exhaustive criteria list, which has been the reference for decades as the criteria to evaluate suppliers.

This project has investigated the work carried out not only by Dickson but also by different authors that progressed in this area later on. Based on the research carried out, a new list has been developed. According to this investigation, quality, delivery, service and cost are the four most important criteria to evaluate suppliers. Furthermore, this investigation has identified that multi-criteria approach has some problems, since it is not easy to evaluate some of the criteria and sometimes they contradict each other. Therefore it is essential to record in advance what the company is looking for, and what the importance of each of the requirements is.

Supplier selection process, which is described in Section 2, starts with the evaluation of the company needs, development of the requirements and selection criteria. Then, a market survey is carried out to identify a limited numbers of suppliers which will participate in the request for quotation (RFQ.) Once the bids are received, they are evaluated involving all company's stakeholders. Finally, one or more companies are awarded as suppliers based on the final result. Section 3 depicts the evaluation criteria.

There are plenty of methods to make the selection. This dissertation has focused on the following methods: Analytical Hierarchic Process (AHP), Analytic Network Process (ANP), Techniques for Order Preference by Similarity to an Ideal Solution (TOPSIS), Data Envelopment Analysis (DEA), Case-Based Reasoning (CBR) and Decision-Matrix Method. All of them are described in Section 4. Besides to explain the main important concept of each method, the methodology and the advantages and limitations, a review of authors, who propose extensions of this method, is carried out. Additionally this section includes a summary that was developed to include other existing methods for supplier evaluation.

Finally, Section 5 provides a practical approach of these concepts, analyzing an existing real case of supplier selection in a successful energy sector company. It describes the company´s supplier selection process, the main criteria that are considered and an example of the technical evaluation of metallic structures to know with more detail tools that are used for that company.

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1. INTRODUCTION

1.1. BACKGROUND

Supplier selection represents one of the most important decisions in a company to remain competitive, especially nowadays, where markets are changing very fast.

The purchasing activity determines the most important part of the final cost of the product, for this reason this selection is one of the decisions which determine the long-term viability of the company. Gencer and Gürpinar [1] point out that the costs of the purchased goods and services account for more than 60% of the cost of goods sold in many firms and over 50% of all quality defects can be traced back to purchase material.

Consequently, a good purchasing and supply chain can make an important contribution to a company's result and to be successful in nowadays competition conditions. Furthermore, continuous improvement programmes in engineering, logistics and manufacturing management require improving relationships with suppliers that result in lead-time reductions, just-in-time deliveries and zero defects on components. These relationships shall also result in improved value to the end customer. [2]

The supplier selection is a multi-criterion problem which includes both qualitative and quantitative factors (criteria). In order to select the best suppliers it is necessary to make a trade-off between these tangible and intangible factors some of which may conflict. It is not easy to make a decision about which the best supplier is, so methods to help in this process are developed.

1.2. PURPOSE

The goal of this investigation is not to find the best supplier evaluation method, because it does not exist one method that fits all. This dissertation tries to find the key elements of a successful supplier performance evaluation. To achieve this goal, the investigation has three main objectives:

1. To understand the importance of the supplier evaluation, studying its evolution in the last years, the main steps of the process and any other important aspects which are necessaries to consider.
2. To investigate the criteria that are important in supplier selection process, developing a list of the most important criteria according with the authors studied. Furthermore, to carry out a review of the existing supplier selection methods.
3. To study a practical example of supplier selection in a company to know more about how the theory is applied at work.

1.3. METHODOLOGY

Diverse literature such as books and journal articles, searched via Emerald or ScienceDirect, has been used to gather the information to get the background information to achieve the goals of this dissertation. Several papers from the last years have been reviewed to know the state of the art supplier evaluation methods. Furthermore, an interview with a manager of the company studied is carries out, in order to understand the supplier evaluation processes is in his company and the tools that they use for it.

1.4. *DISPOSITION*

The organization of this Master Thesis is as follows.

Chapter 1. Introduction. The background leading to the purpose of this master thesis, the main objectives and the methodology used are revealed.

Chapter 2. Supplier Selection. It provides a substantial presentation of supplier selection evolution, the main process' steps and other important aspects that can be found there.

Chapter 3. Supplier Evaluation Criteria. It introduces the main criteria to evaluate suppliers and carries out a study about the priority of these criteria with the opinion of different authors. Consequently, a criteria list is developed and the main criteria (quality, performance delivery, service and cost) are explained.

Chapter 4. Supplier Evaluation Methods. It presents some of the supplier selection methods, the main characteristics, their methodology, the advantages and limitations and the approach of some authors.

Chapter 5. An Energy Sector Company Supplier Evaluation. It analyzes an energy sector company supplier selection process with an example in the technical evaluation of metallic structures.

Chapter 6. Analysis. It compares the company studied in the last section with the theory developed in the first sections.

Chapter 7. Conclusion. The investigation is concluded.

2. SUPPLIER SELECTION.

2.1. TRADITIONAL AND NEW PROCUREMENT MANAGEMENT

Supplier selection approach is changing since the market requirements have evolved. The market research for new suppliers is an on-going activity of high priority for all companies in order to optimize costs, and upgrade the variety and typology of their products range to match the market needs. Particularly nowadays, where product life cycle is generally very short (3 to 4 years) and new designs often require new materials or new technologies. [3]

Procurement department's traditional purchasing strategy considers price as the most important attribute. It also prefers a multi-supplier strategy assigning not more than 15% to 25% of the purchase orders to the same supplier, which provides the company more negotiating power, and protects the company against sudden price increases, or modifications in the delivery time. Only in exceptional cases, when there are no other alternative (monopoly market) or when time and resources to find and negotiate alternative suppliers are not available, it is approved to assign the 100% of the articles to the same supplier. Therefore, to follow this strategy, the main effort is to find suppliers that comply with all requirements, and then select the provider based on the price (the only selection criteria). If there are mistakes in this decision, it can be solved by changing provider (which is considered feasible in an open competitive market), as the price of change the supply is relatively low. [4]

However, new Procurement Management approaches are moving towards the usefulness of building up a stable relationship with specific suppliers closing strategic agreements bringing benefits of closer collaboration or finding sinergies. [3] Ansari and Modarress [5] show that in Just In Time (JIT) enviroment, the majority of the companies prefer to follow a strategy of usinig as few as possible number of suppliers, and if possible use a single supplier. Quarly [6] presents the factors which determine the policy of a single or multi suppliers selection. An area of current research focuses on the classification of components or parts or process to externalise in order to establish a suitable relationship with the supplier of each category. For example, the company can consider a relation of partnership or even a strategic alliance with a supplier who provides a part or a component and with which it wishes to have a durable cooperation. On the other hand, this company can have a hierarchical relation and a significant number of suppliers for the standard parts in order to establish a competition between them and therefore reduce the purchasing costs. [3]

This new approach has clear advantages, as shown in Table 1, although the supplier selection process can be very different.

Multiple Suppliers	Single Supplier
Ensure continuity of supply in case of problems.	Easier to coordinate the relationship and manage the flow of materials and information.
Avoid the risk of excessive dependence of the provider if we become their only customer.	Less time and effort to promote closer relations with the supplier and to evaluate their performance.
Lower cost of change the supplier.	Quality, deadlines and service more uniform.
Be able to use smaller suppliers whose capacity could not take all the demand.	To improve supplier responsibility. To use better the supplier capacity.
	Lower costs of transport and distribution, and the possibility of reducing the total stock in the process.
	Higher purschase volume allows the use economies of scale and price reduction
	Possibility of concentrating equipments, tools or expensive specific installations in a single source.

Table 1. Advantages some supplier versus single supplier.
Source: [4]

The difference of the new approaches is to apply a policy of using a single supplier (or a few), for a relatively long term, with agreement of continuous improvement and to maintain this relationship as long as there are no problems in the relationship with the supplier. These policies not only reduce the costs of finding new suppliers but bring other advantages such as obtain a more uniform quality or achieve economies of scale, gather lessons learnt through the continuity of supply, and provide estability to the supplier which allow it to make specific investments to improve his level of service and be more competitive. [4]

Reduce the number of suppliers increases the company dependence on them. Confidence on the supplier becomes a major issue. The supplier selection process becomes more complex. It is a multi-criteria decision-making process, where there are quantitative and qualitative criteria. Therefore, it is not enough to develop a standard selection criteria and apply it indiscriminately in any situation, it is necessary to identify the criteria to be used as obtain reliable information of the suppliers (See Section 3). All this leads to increased the cost associated with switching supplier. [4]

2.2. SUPPLIER SELECTION PROCESS

This section explains the four important steps in the Supplier Selection Process which are represented in Figure 1.

Figure 1. The important steps in the Supplier Selection Process.
Source: Author's own.

The first step is to evaluate the company needs to define the business, technical and usability requirements in order to contact the right vendors. After creating the list of requirements, then selection criteria is developed to evaluate the suppliers, including the way to score the different criteria. [2]

The second step is to gather a limited group of suppliers. First, it makes an initial bidders' list (so-called bidders' long list) with the suppliers which satisfy the requirements and it is sent to each one a request for information (RFI) to get more information about these suppliers. The aim of the RFI is to know if the company is interested and to gather enough information to make a rough evaluation. Large companies generally work with "approved vendors' lists" in order to select the suppliers for the long list because it is not possible to evaluate all of them. Long list of suppliers is then reduced to a supplier short list with the most promising suppliers. In this list there are usually three to five suppliers. These companies which are in the short list are contacted through a request for quotation (RFQ) so they should send their bids. These activities are called tendering process. Sometimes there are not enough number of approved suppliers available, thus it is necessary to find new suppliers through supply market research. [2]

After receiving the quotations, the Procurement department make a preliminary technical and commercial evaluation, in which all relevant aspects are reviewed. [2] Companies use different methods to evaluate and select the supplier as it is explained in Section 5.

Finally, one supplier is selected with whom the delivery of the product or service is negotiated. The suppliers who are not selected are informed about the reasons for rejecting their proposals. [2]

The purchasing process is not limited to the purchasing department. Many levels in the organization are usually involved. The tasks, responsibilities and authority of each department should be indicated in each phase, to prevent misunderstandings and role conflicts. Consequently, before to start the supplier selection process, it has to indicate who the person responsible for each task is. [2]

2.3. *ASPECTS TO CONSIDER OF THE SUPPLIER SELECTION PROCESS*

In a supplier selection process there are some aspects to be aware and consider.

All relevant company´s stakeholders (Procurement, Engineering, logistics, Production…) must be involved in the supplier selection decision.

Selection criteria must be agreed among the stakeholders ensuring the right weight is allocated to each criteria based on the overall importance, and always aligned to the main objective of the company. The members of this group must consider the interest of all the services, and thus the representative of each service must know well the needs or the other departments of the company. [3]

Section 3 describes the different criteria that can be used to select the supplier. Sometimes these criteria are contradictory, for example, many times cost and quality do not come together. The product can be very cheap but with a poor quality so it is necessary to decide which criteria are considered more important (allocate more weight to that criteria) and how to evaluate them. The supplier that provides the best trade-off of all criteria is selected.

In addition, some criteria are difficult to evaluate since they can only be measured in a qualitative way (and not quantitative). These criteria are more subjective and more people dependent. Examples of objective or quantitative criteria are those that can be measured by a concrete quantitative dimension (like cost). For example the criterion “price” of the product is easy to measure, it can be obtained directly. Examples of qualitative or subjective criteria are the quality of products and services. They cannot be measured them directly. It should take into account the cost of rejection of the product, the cost of the services after sale and so on. [3]

In many cases the company faces a multi-supplier choice or situation, when more than one supplier is selected. Indeed when, for example, the best supplier cannot satisfy all of the customer demand or order (capacity limitation constraint), the customer must satisfy its demand with several suppliers. In a multi supplier case, the company is interested by the two following questions. Which suppliers to choose and how much is it necessary to order from each one? In certain cases, even if the supplier can satisfy the total demand, the company prefers to have more than one supplier. Even if this choice requires more effort and workload from the company, it is worthwhile when one of the suppliers, for any reason, cannot satisfy the assigned demand, and it can be requested to an alternative supplier within the list of preferred options. [7]

Today, we are involved in a “co-operative logistics” environment. The company seeks a strong co-operation with its principal suppliers. This co-operation requires a low number of suppliers. A strong co-operation with high number of suppliers is very difficult to manage. [3]

3. SUPPLIER EVALUATION CRITERIA

Supplier or vendor selection decisions are complicated by the fact that various criteria must be considered in decisions making process. The analysis of criteria for selecting and measuring the performance of suppliers has been the focus of many scientists and purchasing practitioners since the 1960's. [3]

The majority of research about supplier selection problem mentions Dickson's study [8]. It is based on a questionnaire sent to 273 purchasing agents and managers selected from the membership list of the National Association of Purchasing Managers, which include agents and managers from the United States and Canada. Dickson's study describes the importance of 23 criteria for supplier selection which are classified with respect to their importance observed in the beginning of the sixties. At that time (1966), the most significant criteria are quality of the product, the on-time delivery, the performance history of the supplier and the warranty policy used by the supplier (See Table 2).

Rank	Criteria
1	Quality
2	Delivery
3	Performance history
4	Warranties and claim policies
5	Production facilities and capacity
6	Price
7	Technical capability
8	Financial position
9	Procedural compliance
10	Communication system
11	Reputation and position in industry
12	Desire of business
13	Management and organization
14	Operating controls
15	Repair service
16	Attitude
17	Impression
18	Packaging ability
19	Labor relations record
20	Geographical location
21	Amount of past business
22	Training aids
23	Reciprocal arrangements

Table 2. Dickson's Supplier selection criteria.
Source: [8]

The 23 criteria presented by Dickson still covers the majority of the criteria presented in the literature nowadays, but the evolution of the industrial environment modifies the ranking of these criteria or adds others criteria that are considered important too.[3] Furthermore, there are criteria more important than others depending on the process, so it is not easy to define one exclusive list. Table 3 summaries the criteria that different sources considered in the supplier selection process.

Criteria/ Source	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Total
Quality	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	19
Price/Cost	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X		17
Performance Delivery	X	X	X		X	X	X	X	X	X			X	X	X	X	X	X		15
Service	X			X	X	X		X		X	X		X		X		X	X		11
Financial strength	X	X		X				X				X		X	X		X		X	9
Lead-time			X		X	X	X			X		X				X	X			8
Technical ability	X	X		X										X	X	X		X	X	8
Flexibility	X		X			X	X					X				X				6
Production Capacity		X										X			X	X	X		X	6
Development				X		X	X				X				X					5
Management attitude				X										X			X		X	4
Fill rate		X				X														2
Geographic location		X													X					2

Table 3. A compilation of criteria that different authors consider important.

1. Muralidharan et al. [9]
2. Barla [10]
3. Jain et al. [11]
4. Kahraman et al. [12]
5. Lasch and Janker. [13]
6. Christopher. [14]
7. Folan and Browne. [15]
8. Shin-Chan. [16]
9. Weele. [2]
10. Leenders and Fearon. [17]
11. Ramanathan. [18]

12. Bayazit. [19]
13. Bragia and Petroni. [20]
14. Forker and Mendez. [21]
15. Gencer and Gürpinar. [1]
16. Sarkis and Tarulli. [22]
17. Choy and Lee. [23]
18. Choy, Fan and Lo. [24]
19. Chan [25]

The nineteen studied sources come up with thirteen different criteria. The criteria definitions are described below.

- **Quality.** Product quality. (See Section 3.1)
- **Performance Delivery.** The certainty of the right product delivered at the right time in the right quantity. (See Section 3.2)
- **Service.** Follow instructions handling complaints, ease of doing business and quick response. (See Section 3.3)
- **Price/Cost.** Competitive pricing and total cost including price. (See Section 3.4)
- **Lead-time.** The elapsed time from order being placed to delivery.
- **Financial strength.** Cash flow and stability.
- **Flexibility.** Ability to adjust volumes and delivery times.
- **Technical ability.** Modern equipment, ability to follow the development.
- **Development**. Innovation, improvement in order to improve products and reduce costs.
- **Fill rate**. Fraction of orders that are completely filled within the stated lead-time.
- **Production Capacity**. Capacity to increase and decrease volumes.
- **Management approach**. Good relationship and commitment.
- **Geographic location**. Place where the supplier is located.

Quality was considered in 100% of the authors in the supplier selection process, more than 50% of the authors also point out that cost (89% of authors), performance delivery (79% of authors) and service (58% of authors) are important criteria as well. (See Figure 2)

The sources which include cost as part of the criteria include selling price, which means that when evaluating the cost, the price is evaluated as well, so these criteria can both go under cost. In addition, if the supplier reduces their costs, and maintain the same margin, they can decrease their price, which is the cost seen by the customer so these two criteria are very tightly connected.

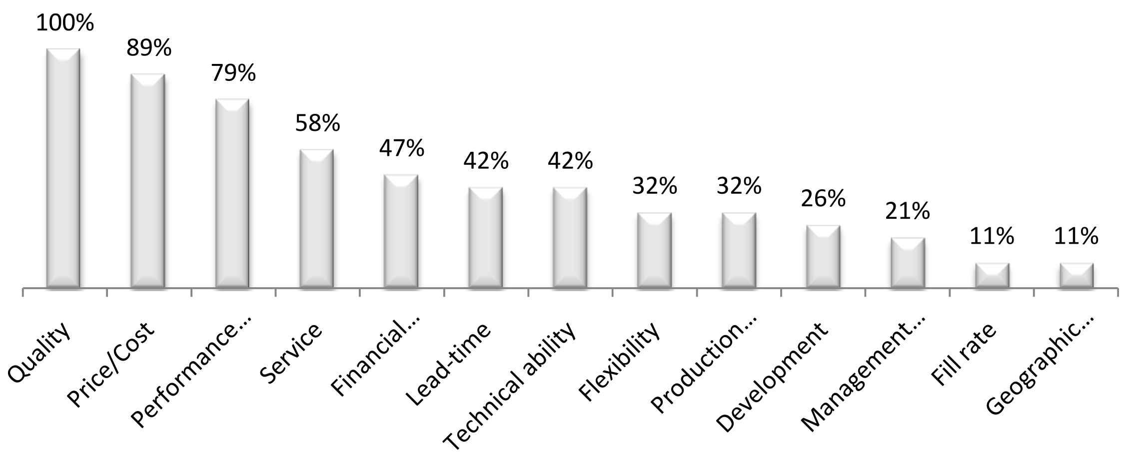

Figure 2. Criteria importance according the authors who are studied.
Source: Author's own.

Comparing Dickson's study and the list developed above quality and delivery are still the most important criteria, but some criteria have been ranked differently, like price or service, some criteria are new like lead-time, and others do not appear in the actual list, like impression.
In conclusion, there are four main criteria: quality, performance delivery, service and price, which are explained further in the Sections, *4.1 Quality* to *4.4 Cost*, since they seem most important.

3.1. *QUALITY*

The concept of Quality is not easy to define. It has been found almost as many definitions as authors who have written about it. Bellow it is compiled some of the most representative definitions.

Leenders and Fearon [17] say that "Quality is a competitive tool that can give high contribution to the organisation." Dober and Burt [26] define it like "one of the purchasing supplier performance management major responsibilities. Product quality failures lead directly to costly difficulties that reduce productivity, profit and often market share." Weele [2] prefers to define it with the IBM's definition, "Quality is the degree in which customer requirements are met. We speak of a quality product or quality service when both supplier and customer agree on requirements and these requirements are met."

The success of the buying organisation is highly dependent on how well the suppliers perform. It is also important that the supplier and the buyer have the same idea of what satisfactory quality is. [17] They need to agree on: the basic requirements of the transaction, the way in which the requirements are to be realized, how to check that the requirements are fulfilled and the measures to be taken when the expectations are not met. These steps form the four basic elements of the Plan-Do-Check-Act cycle (See Figure 3) [2].

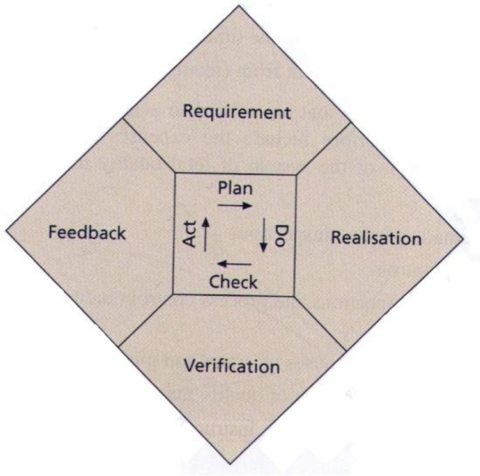

Figure 3. The Plan-Do-Check-Act cycle
Source [2]

There are at least eight dimensions of quality [17]:

- Performance: The primary function of the product or service.
- Features: Extra functions and innovations of the product.
- Reliability: The probability of failure within a specified time period.
- Durability: The life expectancy.
- Conformance: Meeting the specifications.
- Serviceability: The operability and maintainability.
- Aesthetics: The look, smell, feel and sound.
- Perceived quality: The image in the eyes of the customer.

In the traditional approach, the quality-cost curve is U shaped because this allowed a number of defects, since it is considered that it would be very costly to keep a quality level of none of very few defects (See Figure 4). [17]

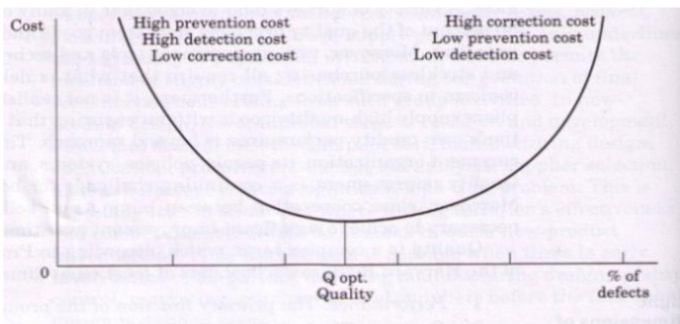

Figure 4. Traditional View of the Quality Cost Trade off.
Source: [17]

The new way of looking at quality is that every defect are expensive and that prevention of defects decreases cost, as shown in Figure 5. [17]

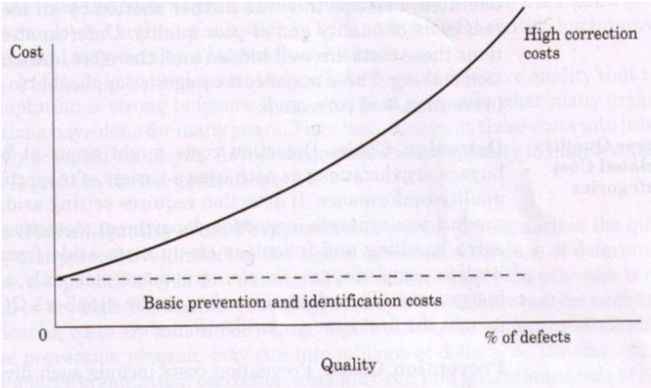

Figure 5. The Current View of the Quality –Cost Trade-off
Source: [17]

However, if higher quality is achieved by extensive inspection, this activity will cause cost to increase. It is reasonable for a purchaser and a seller to work together on achieving both improved quality and lower costs. [17] There is an optimal trade-off between the cost of poor quality and the investment required in the process to improve the quality, as represented in Figure 6. [27]

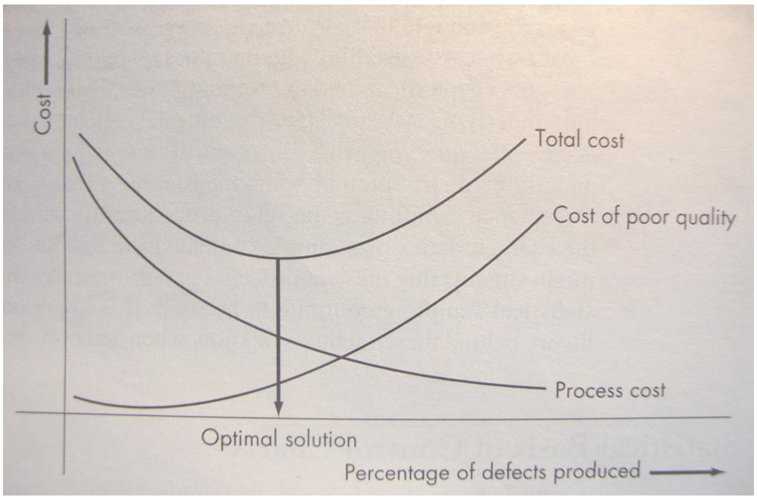

Figure 6. The trade-off between quality and cost.
Source: [27]

Otherwise, the lack of quality involves an important cost which often seems invisible for many companies. There are three types of quality costs that are explained below. [2] and [17]

- Prevention costs: the costs of preventing errors. They include pre-certifying and qualifying suppliers; employee training and awareness programs; machine, tool, material, and labour check-outs; preventive maintenance; and single sourcing with quality suppliers, as well as the associated personnel, travel, equipment and space costs.

- Assessment costs: the costs related to the timely recognition of errors. If detection requires setting apart lots, or sending product to a separate inspection department, detection costs should include extra handling and inventory tie-up costs aside from the assessment costs itself in terms of space, people, equipment, materials, and associated reporting systems.
- Correction costs: the costs that result from mistakes. This kind of cost has a wide diversity and may include some costs substantially greater than prevention or assessment costs. The simplest correction costs are those associated with rework, replacement or disposal of products or services found unacceptable. Typical minimum costs for a purchaser include transportation back to the supplier, extra handling, rescheduling, extra inspection and extra paperwork costs. But, defective products cause other important consequences like the loss of customers, the inability to secure new customers or the penalties paid to keep existing customers.

For many years the emphasis has shifted from correction to prevention. As result, to reduce the total quality costs, the preventive quality management has been enhanced.

In summary, quality management relates to all activities and decisions aimed at taking the organization's products and services to the desired quality level and to maintain that level. Therefore it requires intensive consultation between the various departments in the organization and with outside suppliers and customers. After the desired quality level has been established, the complete production process must be organized in such a way that this level of quality is reached and maintained in a controllable manner. To accomplish this, quality management has at its disposal four interrelated functions: setting standards, assessment, control and assurance. An external assessment establishes the degree to which the methods and procedures used satisfy the conditions that have been recorded in national and international standards. The best known are the ISO-9000 standards. [2]

3.2. *PERFORMANCE DELIVERY*

Performance Delivery describes the efficiency rate of business operations when preparing and delivering an order to a customer. [28]

The work starts with the evaluation of the processes and procedures used to receive orders from clients, schedule the production of the goods or services necessary to fulfil those orders and finally, the time necessary to deliver the goods or services to meet client expectations. The goal is to manage and pay attention on every task across the whole process chain to deliver goods and services as efficient as possible. [28]

There are seven key elements in performance delivery [29]:

- Order lead-time: The elapsed time from order being placed to delivery.
- Delivery reliability: The reliability of the delivery time.
- Delivery certainty: The right product with the right quality delivered in the right quantity.

- Information: Information exchange between buyer and seller.
- Customer adaptation: The adaptability to the customers' demands.
- Flexibility: The adaptability to condition changes.
- Service level: The probability of demanded product being on the shelves.

The most important benefit of a good delivery performance is the customer satisfaction. [28] There are different levels of satisfaction (See Table 4).

Top rating:	a. Meets delivery dates without expediting. b. Requested delivery dates are usually accepted.
Good:	c. Usually meets shipping dates without substantial follow-up. d. Often is able to accept requested delivery dates.
Fair:	e. Shipments sometimes late, substantial amount of follow-up required.
Unsatisfactory:	f. Shipments usually late, delivery promises seldom met, constant expediting required.

Table 4. Delivery Performance Satisfaction.
Source: [17]

In the other hand, sometimes there are delivery problems like suppliers deliver too late, deliveries are not complete, products are damaged or do not meet quality requirement, packaging is unsound or information labels cannot be read by bar code systems. The reason for these problems usually can be traced back to unclear specifications or a careless supplier selection. To prevent these problems, companies need clear rules and guidelines with regard to procurement governance. [16]

3.3. *SERVICE*

The purpose of service is to satisfy the customers' needs, it means that service includes issues such as delivery reliability and short order lead-times. This means that service is an extensive issue which is hard to define exactly. But, most of the sources that mentioned service as a criterion to measure argue that service is about giving quick response to all inquires and requests, handle complaints efficiently, making the business easy and, of course, follow the customers' instructions (regarding invoicing, packaging and shipping note...). [14]

Evaluating supplier's service performance is usually done by subjective judgements. Opinions need to be collected on the quality of assistance, supplier attitude and response time to requests for assistance, support staff qualifications and so on. Therefore most companies that evaluate the suppliers' service performances have a relatively simple rating scale for service, such as outstanding, acceptable and poor, along with explanations regarding specific incidents to explain these rating. [17]

A study of customer service practices suggests that customer service could be examined under three headings: pre-transactions elements, transaction and post-transaction elements. The pre-transaction elements of customer service relate to corporate policies or programmes, for example written statements of service policy, adequacy of organizational structure and system flexibility. The transaction elements are those customer service variables directly involved in performing the physical distribution function, for instance, product and delivery reliability. The post-transaction elements of customer service are generally supportive of the product while in use, for instance, product warranty, parts and repair service, procedures for customer complaints and product replacement. [14]

Table 5 indicates some of the many elements of customer service under these tree headings.

Pre-transaction elements	Transaction elements	Post-transaction elements
• Written customer service policy. • Accessibility. • Organization structure. • System flexibility.	• Order cycle time. • Inventory availability. • Order fill rate. • Order status information.	• Availability of spares. • Call-out time. • Product warranty. • Customer complaints, claims...

Table 5. The components of customer service.
Source [14]

In any particular market situation, some of these elements are more important than others. Each market that the company services attach different importance to different service elements, for this reason a universally appropriate list of elements does not exist. [14]

3.4. *COST*

Purchasing cost is related to the total acquisition costs, including the price as is explained above. [16]

In the situation with a single criterion, generally it considers the cost like the most important criterion. It computes all the direct cost, like the purchase price, the transport cost and so on, associated to each supplier and it chooses the lowest cost bidding. [3] Although, it is studied in Section 2.1 that the traditional single criterion approach based on lowest cost bidding is no longer supportive and robust enough in contemporary supply management; actually a considerable number of companies choose their suppliers starting from this method and then they use other method to select the best supplier (See Section 4).

4. SUPPLIER EVALUATION METHODS.

This section explains different supplier evaluation methods and reviews the literature. The goal of the methods explained below is to evaluate suppliers to select one of them; it explains the main idea of each method and it develops alternatives for each method that were proposed by different authors. This paper doesn't study methods to evaluate suppliers that are working in the company to know if they are doing well or not their job.

It is necessary to use methods to select supplier since there are some criteria that are necessary to take into account to make this decision, like it is explained in Section 3.

4.1. ANALYTICAL HIERARCHIC PROCESS (AHP).

4.1.1. Definition

The Analytical Hierarchic Process (AHP) is a decision-making method for prioritizing alternatives when multiples criteria and sub-criteria must be used. It is developed by Saaty in 1980 [30]. It has been applied to a wide variety of decisions areas, including research and development project selection, evaluating alternative product formulations, and selecting a microcomputer. This method allows the decision maker to structure complex problems in the form of a hierarchy or a set of integrated levels. [3]

Generally, the hierarchy has at least three levels: the goal, the criteria and the alternatives, as it is represented in Figure 7. For the supplier selection problem, the goal is to select the best overall supplier. It considers multiple criteria, quantitative as well as qualitative, and allows them to integrate into a single overall score. The alternatives are the different proposals supplied by the suppliers. [3]

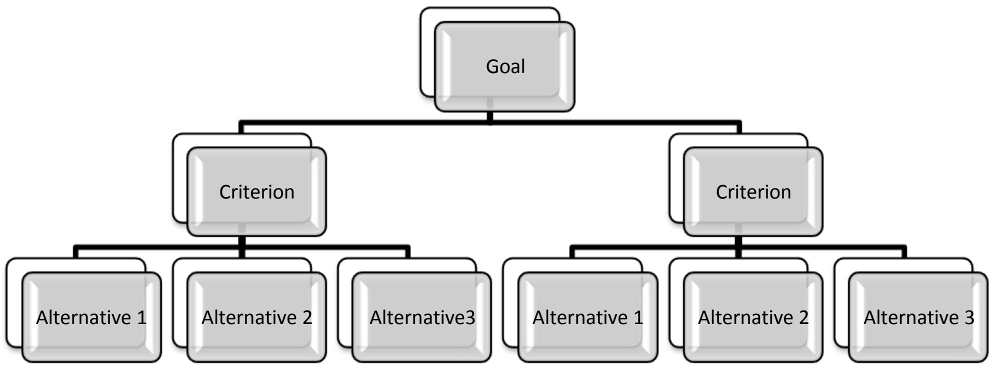

Figure 7. A simple AHP hierarchy.
Source: Author's own.

4.1.2. *Methodology*

The AHP offers a methodology to order alternative courses of action based on the decision's judgments concerning the importance of the criteria and the extent to which they are met by each alternative. For this reason, AHP is ideally suited for the supplier selection problem. [3]

The problem hierarchy lends itself to an analysis based on the impact of a given level on the next higher level. The process begins by determining the relative importance of the criteria in meeting the goals. Next the focus shifts to measuring the extent to which the alternatives achieve each of the criteria. Finally, the results of the two analyses are synthesized to compute the relative importance of the alternatives in meeting. This is done when we have only three levels, otherwise we do it level by level. The criteria for the performance evaluation should be mutually independent. [3]

Managerial judgments are used to drive the AHP approach. These judgments are expressed in terms of pair-wise comparisons of items on a given level of the hierarchy with respect to their impact on the next higher level. Pair-wise comparisons express the relative importance of one item versus another in meeting a goal or a criterion. [3]

There are many scales that could be used for quantifying managerial judgment; the scale given in Table 6 is the standard usage of AHP analysis. The decision maker can express his preference between each pair of elements verbally as equally important, weak important than other, strongly more important, very strongly more important and absolute more important. These descriptive preferences would be translated into numerical values 1, 3, 5, 7, 9, respectively, with 2, 4, 6, and 8 as intermediate values for comparisons between two successive judgments. Reciprocals of these values are used for the corresponding transposed judgments. For example, if a customer believes that quality is moderately more important than delivery, then this judgment is represented by a 3. Judgments are required for all the criterion and sub-criteria comparisons and for all the alternative comparisons for each criterion. This information is usually provided by the customer (buyer). [30]

Intensity of importance	Definition	Explanation
9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation.
7	Very strong importance	An activity is favored very strongly over another.
5	Strong importance	Experience and judgment strongly favor one activity over another.
3	Weak importance of one over another	Experience and judgment slightly favorer one activity over another.
1	Equal importance	Two activities contribute equally to the objective.
2,4,6 and 8	Intermediate values between adjacent scale values.	When compromise is needed.

Table 6. Measurement scales.
Source: [30]

The pair-wise comparison information for each component of the problem is represented by a pair-wise comparison matrix. If there are n items that need to be compared for a given matrix, then a total of n(n-1)/2 judgments are needed. This is because since any alternative is equally preferred to itself 1's are placed along the diagonal for the matrix and the corresponding positions below the diagonals are the reciprocals of the judgments already entered. For example, assuming that the pair-wise comparison of quality to delivery is 3, it follows that the pair-wise comparison of delivery to quality is 1/3. [3]

Every pair-wise comparison matrixes should pass the consistent test. To measure the degree of consistency, Saaty suggested the consistency index, which is represented by equation (1). [16]

$$\mathrm{CI} = \frac{(\lambda_{\max} - \mathrm{n})}{(\mathrm{n} - 1)} \qquad (1)$$

For each nxn pair-wise comparison matrix A, it can calculate the eigenvalue λmax and the eigenvector w $(w_1, w_2, \ldots, w_n)$, by using the theory of eigenvector that is shown in Equation (2) [16].

$$(\mathrm{A} - \lambda_{\max} \cdot \mathrm{I}) \cdot \mathrm{w} = 0. \qquad (2)$$

To employ this index, it can compare with a random index (RI) (See Table 7) by using the consistency ratio (CR) that is represented by Equation (3). [16]

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \qquad (3)$$

A value of CR of less than or equal to 0.1 is considered as sufficiently consistent. [16]

Order	1	2	3	4	5	6	7	8	9	10
R.I.	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

Table 7. Average random index (RI) values for common matrix sizes.
Source: [30]

The basic procedure to carry out the AHP consists of the following steps [31] :

1- To structure a decision problem, like Figure 7, and selection of criteria.

2- Priority setting of the criteria by pair-wise comparison (weighing).

Using the scale in Table 6, it values the relative priority of the criteria. To know the average weight of each criterion, the weighing are normalized and averaged.

3- Pair-wise comparison of alternatives on each criterion (scoring).

Using again the scale in Table 6, each score records how well alternative "x" meet criterion "y". Afterwards, the ratings are normalized and averaged.

4- To obtain an overall relative score for each alternative.

In a final step the option scores are combined with the criterion weights to produce an overall score for each alternative. The overall score is calculated multiplying the weight for each criterion by the weight of each alternative relative with this criterion and adding the weights of all criteria.

The decision maker selects the decision alternative with the highest overall priority.

4.1.3. *Advantages and limitations of AHP*

The main advantage of AHP is its ability to handle complex problems such as supplier rating, which cannot be usually handled by rigorous mathematical models. In addition to simplicity, ease of use, flexibility and intuitive appeal, it has the ability to mix qualitative and quantitative criteria in the same decision framework.[9] Moreover, it provides a mechanism for checking the consistency of the evaluation measures and alternatives. [31]

Furthermore, there are a variety of extensions to the AHP approach, which can increase its usefulness for managerial decision making (See Section 4.1.4). [32]

In the other hand, this method has some disadvantages. AHP method decomposes the problems into a various subsystems and need to do the pair-wise comparisons, so sometimes it is a lengthy task. [31] In addition, when a new criterion is added, the whole process has to be repeated. [32]

Another important limitation is the scale that uses to evaluate criteria and alternatives (See Table 6). Sometimes, the decision maker might find difficult to distinguish among them and tell for example whether one alternative is 4 or 5 times more important than other. [31]

Additionally, 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. This problem can be solved with Analytic Network Process that is studied in Section 4.2.

4.1.4. *Individual approach.*

There are some journal articles proposing AHP to deal with the supplier selection problem. Authors like Akarte et al.[33], Muralidharan et al. [9], Chan [25], Chan and Chan [34], Liu and Hai) [35], Chan et al. [36], Hou and Su [37] or Shin-Chan Ting [16] wrote about this topic and developed extensions of AHP approach to improve the model. In this section, it develops some of them.

Akarte et al.[33] develop a web-based AHP system to evaluate the casting suppliers with respect to 18 main criteria, but the program developed in this study allows introduction of new ones. In the system, suppliers have to register, and then input their casting specifications. To evaluate the suppliers, buyers had to determine the relative importance weightings for the criteria based on the casting specifications, and then assigned the performance rating for each criterion using a pair-wise comparison. The overall approach to casting supplier evaluation using the multi-criteria decision marking AHP methodology is shown in Figure 8.

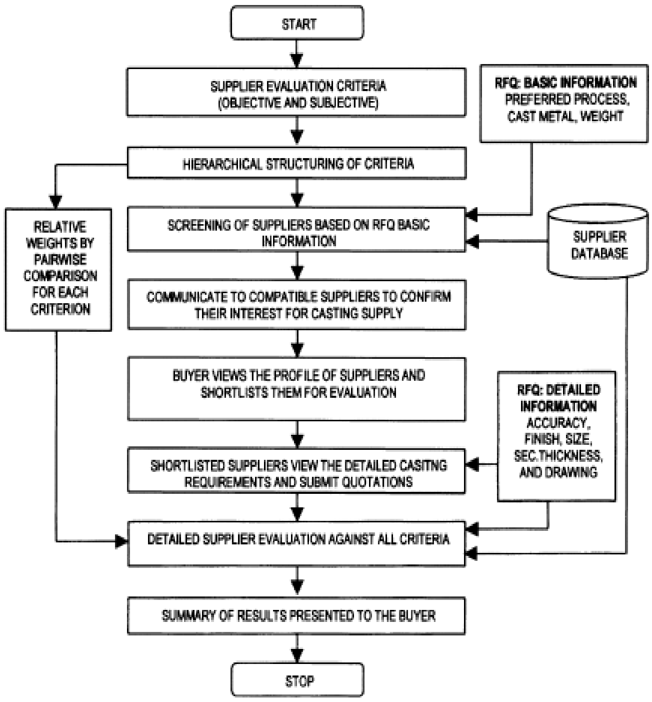

Figure 8. Flow chart for web-based supplier evaluation.
Source [33]

Muralidharan et al. [9] propose a five-step AHP-based model to aid decision makers in rating and selecting suppliers with respect to nine evaluating criteria (see Section 4). People from different functions of the company, such as purchasing, stores, and quality control, are involved in the selection process. The five steps proposed in this model are:

1- Identify the active participants to be involved in decision making. It calculates the weights.
2- Identify the significant factors involved in decision making.
3- Identify the alternatives to be rated.
4- Rank the alternatives.
5- Obtain the consensus ranking.

Chan [25] develops an interactive selection model with AHP to facilitate decision makers in selecting suppliers. The model was so-called because it incorporated a method called chain of interaction, which was deployed to determine the relative importance of evaluating criteria without subjective human judgment. AHP was only applied to generate the overall score for alternative suppliers based on the relative importance ratings.

Shin-Chan Ting [16] proposes an approach, which integrates the two important types of purchasing decisions in the multi-sourcing supplier selection problem, can be used to determine the number (and identity) of the candidate suppliers, as well as to allocate the optimal order quantity among the selected suppliers. By changing the weights of the defined objectives, the proposed models enable the management to reflect corporate strategies in the purchasing activities and to analyze trade-offs among multiple objectives such as cost, quality, and delivery reliability, simultaneously and interactively. The models have been applied to the supplier selection problem at a high technology company in Taiwan, which mainly manufactures motherboards for desktop PCs and notebook computers. The results show that the models are effective and applicable, and provide the decision makers with a better understanding of their purchasing decisions. In order to select candidate suppliers and find the optimal allocations of order quantities to the select supplier, in this approach uses AHP and Multi-Objective Linear Programming.

4.2. *ANALYTIC NETWORK PROCESS (ANP)*

4.2.1. *Definition*

The Analytic Network Process (ANP) is a generalization of the Analytic Hierarchy Process (AHP) studied in Section 4.1 and can be used to treat more sophisticated decision problem than the AHP. [19] It was developed by Saaty in his book "The Analytic Network Process" in 1996. [1]

Many decision problems cannot be built hierarchically because they involve the interaction and dependence of higher-level elements in a hierarchy on lower level elements. [19] ANP provides a general framework to deal with decisions without making assumptions about the independence of higher-level elements from lower level elements and about the independence of the elements within a level. [1] Therefore, ANP is represented by a network without the need to specify levels as in a hierarchy.[38]

The structural difference between hierarchy and network is shown in Figure 9. A hierarchy is constituted of a goal, levels of criteria and connection between criteria and alternatives. These connections are oriented only to elements in lower levels. [38] A network is structured of clusters, elements and links. A cluster is a compilation of relevant elements within a network or sub-network. The clusters of the system with their elements are determined for each control criterion.[19] The elements of one cluster are connected to elements in another group (outer dependence) or in the same group (inner dependence).[38] An internal interdependency (a curved arrow) means that factors within this cluster will influence each other and the impact of these factors among themselves need to be considered in the evaluation process. For example, cost may be influenced by other criteria like quality and time. [22]

A hierarchy is a special case of a network with connections only in one direction. [38] Inner and outer dependencies are the best way which decision-makers can represent the concepts of influencing or being influenced, between clusters and between elements with respect to a specific element. [19]

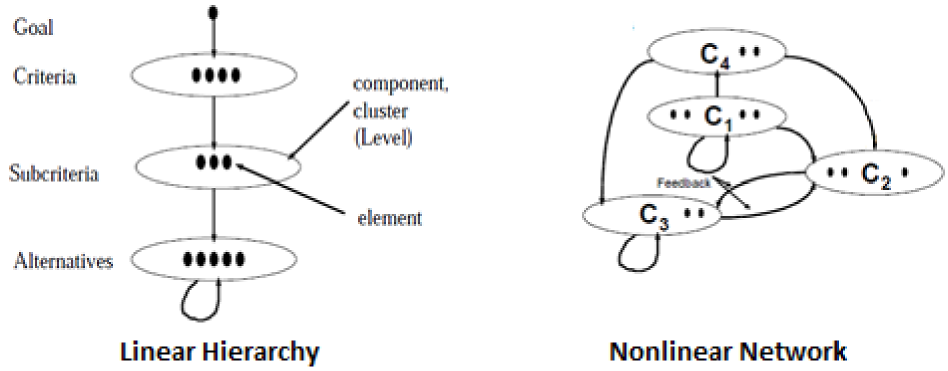

Figure 9. Structural Difference between a linear and nonlinear network. Source: [39]

4.2.2. *Methodology*

The ANP starts with the decision about the criteria and sub-criteria that control the interactions in the system studied and how they influence among the elements and clusters. For each control criterion, it constructs a cluster versus a cluster matrix with one or zero as an entry depending on whether a cluster on the left side, influences or does not influence a cluster represented at the top of this matrix. It repeats the similar process for criteria versus criteria matrix. Again with one or zero as an entry depending on whether a criterion on the left side influences or does not influence a criterion represented at the top of this matrix. [38]

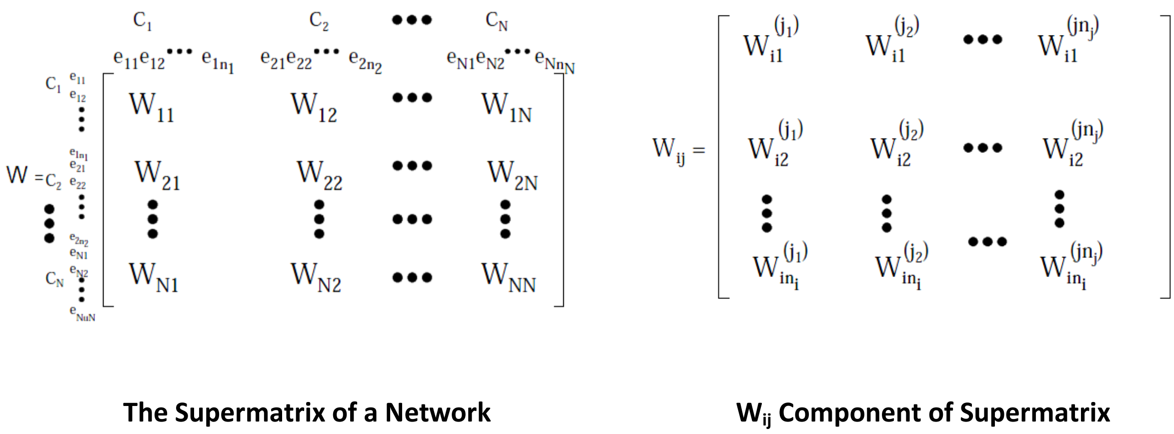

Figure 10. The Supermatrix of a Network and Detail of a Component in it. Source: [38]

The priorities derived from pair-wise comparison matrices are entered as parts of the columns of a supermatrix. The supermatrix represents the influence priority of an element on the left of the matrix on an element at the top of the matrix with respect to a particular control criterion. Figure 10 shown the Suprematrix of a Network and detail of a component in it. [19] It performs the following paired comparisons to derive eigenvectors and to form a supermatrix.

- Cluster comparisons: Perform paired comparisons on the clusters that influence a given cluster with respect to control criterion. Weights derived from this process will be used to weight the elements in the corresponding column blocks of the supermatrix corresponding to the control criterion.
- Comparisons of elements. Perform paired comparisons on the elements within the clusters. Compare the elements in a cluster according to their influence on an element in another cluster to which they are connected (or on elements in their own cluster).
- Comparisons for alternatives. Compare also the alternatives with respect to all the elements.

In supplier selection, the goal of this model is to select the best supplier. For example, we have three suppliers and we choose the decision attributes to evaluate the alternatives. The relevant factors can be gathered in supplier's performance and supplier's capability clusters. Then three suppliers are clustered into the alternatives cluster. Therefore, three clusters in the model are supplier's performance, supplier's capability and alternatives. This is a simple network model and it is shown in Figure 11. [19]

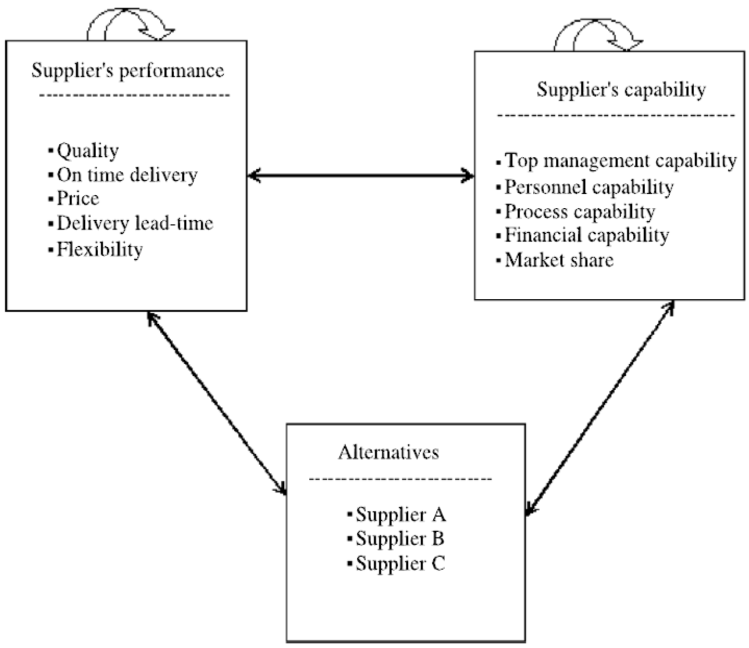

Figure 11. Example of overall ANP model.
Source: [19]

Pair-wise comparisons are made with the same comparison scale as the AHP (See Table 6) to indicate how an element dominates another with respect to the criterion. [19] Furthermore, every pair-wise comparison matrixes have to pass the consistent test, as it is explained in Section 4.1.2.

The outcome of the process above is an unweighted supermatrix. It shows the pair-wise comparisons of the criteria. In the unweighted supermatrix, the columns may not be column stochastic. Multiply the blocks of the unweighted supermatrix by the priority of corresponding influencing cluster and obtain stochastic matrix, which consists of columns all added up to one. Raise the supermatrix to large power to capture first, second, third degree influences. Take the powers of supermatrix until the differences between consecutive matrix elements less than very small number. To obtain the final priorities of all the elements in the limit matrix, normalize each block. Finally select the highest priority alternative. [19]

In the application of ANP, software like, Ecnet, Super Decision or mathematical programs like Excel, Maple, Mathematics can be used. [1]

4.2.3. *Advantages and limitations of ANP*

The ANP has additional insights not possible with AHP or with other traditional methods and deals with uncertainty and complexity. It incorporates feedback and interdependent relationships among decision attributes and alternatives. This model can be used by organizations for a supplier selection process that involves various criteria and contains interactions. It is capable of handling both quantitative and qualitative criteria and capturing more realistic results and dealing with all kinds of feedback and dependence in a decision system. It provides a more precise approach when modelling a complex decision environment. [19]

This model has some limitations. One of them is that it requires more comparisons than the AHP and it increases the effort. However, complex decisions may require complex methodology. Another limitation is that it would be quite demanding in terms of making a number of pair-wise comparisons if there are several alternatives in the decision model. [19]

4.2.4. *Individual approach*

Three papers proposed ANP to solve the supplier selection problem: Sarkis and Talluri [22], Bayazit [19] and Gencer and Gürpinar [1].

Sarkis and Talluri [22] believed that supplier evaluating factors would influence each other, and the internal interdependency needed to be considered in the evaluation process. The authors applied ANP to evaluate and select the best supplier with respect to organizational factors and strategic performance metrics. The impact of these factors among themselves was considered.

Bayazit [19] proposed an ANP model to tackle the supplier selection problem. The evaluating criteria in the model were classified into supplier's performance and capability clusters. To formulate interrelationships among all criteria, each of them was considered as a controlling factor for a pair-wise comparison matrix.

Gencer and Gürpinar [1] developed an ANP model to evaluate and select the best suppliers with respect to various supplier evaluating criteria in a feedback systematic, which were classified into three clusters. The proposed model is implemented in an electronic company.

4.3. Techniques for Order Preference by Similarity to an Ideal Solution (TOPSIS)

4.3.1. Definition

The TOPSIS method is a multiple criteria method proposed by Hwang and Yoon to identify the similarity of the ideal solution from finite set of points. The basic principle is that the chosen points should have the "shortest" distance from the positive ideal and the "farthest" distance from the negative ideal solution. [41] It introduces the criteria space in which every alternative A_i is represented by a point in the n-dimensional criteria space. Then, it determines of ideal and anti-ideal points and it finds the alternative with the closest Euclidean distance from the ideal point, but at the same time, the farthest Euclidean distance from the anti-ideal point. [42].

The best solution can be represented like:

$$A^{*}= (X^{*}_{1}, \dots , X^{*}_{j}, \dots ,X^{*}_{n})$$

X^{*}_{j} is the best value of each attribute j among all alternatives.

The worst solution can be represented like:

$$A^{-}= (X^{-}_{1}, \dots , X^{-}_{j}, \dots ,X^{-}_{n})$$

It is not necessary that the solution the nearest the best solution is the same that the solution farthest the worst solution. [4]

It is assumed that criteria have been determined and the relative criteria weights (w_j) have been defined. [42]

4.3.2. Methodology

The main steps of this method are as following [42]:

To calculate the normalized matrix using the normalization vector. The matrix elements for the max type criteria are calculated by equation (4) and the min type criteria are calculated by equation (5).

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \qquad \text{i=1 … m; j=1… n} \qquad (4)$$

$$r_{ij} = 1 - \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \qquad \text{i=1 … m; j=1… n} \qquad (5)$$

Figure 12 shows the normalized decision-making matrix.

	f_1	f_2	$\cdots$	f_j	$\cdots$	f_n
a_1	r_{11}	r_{12}	$\cdots$	r_{1j}	$\cdots$	r_{1n}
a_2	r_{21}	r_{22}	$\cdots$	r_{2j}	$\cdots$	r_{2n}
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
a_i	r_{i1}	r_{i2}	$\cdots$	r_{ij}	$\cdots$	r_{in}
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
a_m	r_{m1}	r_{m2}	$\cdots$	r_{mj}	$\cdots$	r_{mn}
	$\binom{\max}{\min}$	$\binom{\max}{\min}$		$\binom{\max}{\min}$		$\binom{\max}{\min}$

Figure 12. Normalized decision-making matrix.
Source:[42]

1. To multiply the normalized matrix elements by the normalized weight coefficients and it obtains the normalized valued weighted $V_{ij.}$ that is represented by equation (6).

$$V_{ij} = W_{ij} \cdot r_{ij} \qquad i=1 \ldots m; \; j=1\ldots n \tag{6}$$

2. To identify the ideal and the anti-ideal solution among the normalized values weighted.

$A^{*}= (V^{*}_{1}, \ldots , V^{*}_{j}, \ldots ,V^{*}_{n})=$ (min. V_{ij} $j\epsilon J_1$, max. V_{ij} $j \epsilon J_2$); i=(1 … m)

$A^{-}= (V^{-}_{1}, \ldots , V^{-}_{j}, \ldots ,V^{-}_{n})=$ (min. V_{ij} $j\epsilon J_1$, max. V_{ij} $j \epsilon J_2$); i=(1 … m)

Whereas $J_1 \subset$ {1,2,..., n) j −max} applies for the max type criteria,
while $J_2 \subset$ {1,2,..., n) j −min} applies for the min type criteria.

3. To calculate of Euclidean distance S_i^* of each alternative a_i from the ideal point (See equation (7)) and S_i^- of each alternative ai from the anti-ideal point. (See equation (8)).

$$S_i^* = \sqrt{\sum_{j=1}^{n}(V_{ij} - V_{ij}^*)^2} \qquad i=1 \ldots m \tag{7}$$

$$S_i^- = \sqrt{\sum_{j=1}^{n}(V_{ij} - V_{ij}^-)^2} \qquad i=1 \ldots m \tag{8}$$

4. To calculate the similarities from the ideal solution and anti-ideal points with the equation (9).

$$C_i^* = \frac{S_i^-}{S_i^- + S_i^*} \ ; \text{i= 1 … m} \qquad (9)$$

$$0 < C_i^* < 1$$

If C_i is closer to value one, it means that ai is closer to the ideal solution A*.

5. To set up the rank according to C_i. The biggest C_i is the best alternative.

4.3.3. *Advantages and limitations of TOPSIS*

The main TOPSIS' advantage is that the best and worst alternatives are considered simultaneously with a scalar value which is calculated with a simple procedure easily programmed. In addition, it is capable of representing the search of the best performance of a company's service operation for each evaluation criterion in a simple mathematical form. Moreover, TOPSIS allows objective weights to be incorporated into the comparison process. [40]

However, TOPSIS considers a solution with the shortest distance to the positive ideal solution and the greatest distance to the negative ideal solution, the relative importance of these distances is not considered. [40]

4.3.4. *Individual approach*

In the literature, there are some papers that proposed TOPSIS to solve the supplier selection process.

Hosseinzadeh et al. [41] develop a extension of the TOPSIS method for decision making problems with Fuzzy data. In the paper, it determines an algorithm to decide the most preferable choice among all possible choices in the case of fuzzy presented.

Markovic [42] describes the possible modifications in TOPSIS to add more advantages in the real business problems. This modifications reflects in how to determinate the criteria and in the standardization of quantification.

Chen, C.T. [43] extended TOPSIS to fuzzy environment. The rating of each alternative and the weights of each criterion are described by linguistic terms which can be expressed in triangular fuzzy numbers. This method proposed to calculate the distance between two triangular fuzzy numbers.

Wang et al. [44] modified Chen's theory [3] proposing hierarchical TOPSIS that provides more objective and precise criterion weights than Chen's theory and avoiding the problems of that method.

4.4. Data Envelopment Analysis

4.4.1. Definition

Data envelopment analysis (DEA) is a mathematical programming method to provide a relative efficiency evaluation for a group of decision making units (DMU) with multiple numbers of inputs and outputs. [45]. It is proposed by Charnes, Cooper and Rhoders in 1978 [46]. To allow for applications to a wide variety of activities, it uses the term DMU to refer to any entity that it to be evaluated in terms of its abilities to covert inputs into outputs. It assumes that there are n DMUs to be evaluated. [47]

It is also recognized as a non-parametric method that allows efficiency to be measured without having to specify either the form of the production function or the weights for the different inputs and outputs chosen. As a reference for efficiency measures, it defines a non-parametric best practice frontier. [20] Consequently, a DMU is efficient from the observed data if the DMU is on the "frontier" of the production possibility set. [45]

DEA, apart from supplier evaluation, has been applied to such assorted activities as airline operations, banking, the defence industrial base, education, electricity generation, health care, manufacturing, non-profit organizations, pay equity in professional baseball, retail organization, transportation and logistics; and vehicle maintenance. [21]

4.4.2. Methodology

The objective function in DEA model is considered to reach the best set of weights for the single ratio of the weighted outputs to the weighted inputs for a particular DMU denoted by DMUo. In this model, along with evaluations the efficiency, all the DMUs are projected to the efficient frontier separately [48].

The efficiency score in the presence of multiple input and output factors is defined as a weighted sum of its *m* outputs divided by a weighted sum of its *n* inputs [20]. (10)

$$Efficiecy = \frac{weighted\ sum\ of\ outputs}{weighted\ sum\ of\ inputs} \tag{10}$$

Each DMU chooses weights which maximize its own efficiency, fulfilling the following rules:

- Efficiency is less than or equal to one.
- Every weight is greater than zero.

Each DMU consumes varying amounts of *m* different inputs to produce *s* different outputs. The model proposed by Charnes et al. obtains the relative efficiency score of a test DMUp solving the following equations (11) [47]:

$$\max \frac{\sum_{k=1}^{s} v_k \cdot y_{kp}}{\sum_{j=1}^{m} u_j \cdot x_{jp}}$$

$$\text{s.t } \frac{\sum_{k=1}^{s} v_k \cdot y_i}{\sum_{j=1}^{m} u_j \cdot x_{ji}} \leq 1 \quad \forall\, i \tag{11}$$

$$v_k, u_j \geq 0 \qquad \forall\, k, j$$

Where,

$$k = 1 \; to \; s,$$

$$j = 1 \; to \; m,$$

$$i = 1 \; to \; n,$$

$$s = number \; of \; outputs$$

$$m = number \; of \; inputs$$

$$n = number \; of \; DMUs$$

$$y_{ki} = amount \; of \; output \; k \; produced \; by \; DMU \; i,$$

$$x_{ji} = amount \; of \; input \; j \; utilized \; by \; DMU \; i,$$

$$v_k = weight \; given \; to \; output \; k,$$

$$u_j = weight \; given \; to \; input \; j.$$

The rational program shown as in equation (11) can be converted to a linear program as shown in equation (12).

$$\max \sum_{k=1}^{s} v_k \cdot y_{kp} \tag{12}$$

$$\text{s.t } \sum_{j=1}^{m} u_j \cdot x_{jp} = 1$$

$$\sum_{k=1}^{s} v_k \cdot y_{ki} - \sum_{k=1}^{s} u_j \cdot x_{ji} \leq 0 \quad \forall\, i$$

$$v_k, u_j \geq 0 \quad \forall k, j.$$

For more details on model development see [46].

Equation (12) is run n times in identifying the relative efficiency scores of all the DMUs. Each DMU selects input and output weights that maximize its efficiency score. If it obtains a score of one, the DMU is considered to be efficient and if the score is less than one is inefficient. [47]

For every inefficient DMU , DEA identifies a set of corresponding efficient units that can be utilized as benchmarks for improvement. The benchmarks can be obtained from the dual problem shown as Equations (13) [47]:

$$\begin{aligned} & \min \theta \\ \text{s.t.} \quad & \sum_{i=1}^{n} \lambda_i x_{ji} - \theta x_{jp} \leq 0 \qquad \forall\, j \\ & \sum_{i=1}^{n} \lambda_i y_{ki} - y_{kp} \geq 0 \\ & \lambda_i \geq 0 \quad \forall i \end{aligned} \qquad (13)$$

Where,

$$\theta = \text{efficiency score}$$

$$\lambda_i = dual\ variables$$

A test DMU is inefficient if a composite DMU can be identified which utilizes less input than the test DMU while maintain at least the same output levels. [47]

When it uses DEA to supplier selection, the term DMU refers to the suppliers that can be selected. Like in every application of DEA model, it requires a specification of inputs and outputs; this means that is necessary to decide the criteria that will be used to make a decision. Cost usually has the characteristic of inputs since it will be better if it is lower. [18]

4.4.3. *Advantages and limitations of DEA*

DEA provides a set of potential role models that an organisation can look to improve its operations. This makes DEA a useful tool for benchmarking and change management implementation programmes. [49]

DEA has some disadvantages. Firstly, DEA model shows very poor discriminatory power. Secondly, the basic DEA model makes complete weight flexibility possible and thus may result in identifying a DMU with an unrealistic weighting proposal as being efficient. These DMUs are 'false positive' candidates, which achieve a relative efficiency score of 1 by weighing heavily on a few favourable inputs and outputs and completely ignoring the others. This type of DMU performs well with respect to a few input/output measures, but is not a good overall performer. Therefore, a simple efficiency measure alone is not sufficient for the analysis. [49]

4.4.4. *Individual approach*

DEA has been suggested in the literature for some authors. Some of them are the following: Wu et al [49], Saen [50], Seydel [51], Liu et al. [52], Forker and Mendez [21], Talluri and Baker [53], Talluri and Sarkis [54], Talluri and Narasimhan [55], Tarulli [47], Garfamy [56], Ross et al. [57], Braglia and Petroni [20], Charnes and Copes [46] and Malekmohammadi et al. [48].

Wu et al. [49] proposed a modified DEA method for supplier selection which can operate under conditions of imprecise information. In addition, it includes the elimination of the poor discriminatory power and inability of traditional DEA to rank the efficient suppliers. Furthermore, it develops a web-based system to allow potential buyers for supplier evaluation and selection.

Saen [50] developed a DEA method to evaluate the performance of suppliers in the presence of both quantitative and qualitative data. The model allowed the decision makers to provide a complete rank ordering of the supplier on supplier reputation.

Seydel [51] used DEA to solve the supplier selection problem, but there was no input considered in the model. To assign ratings to the qualitative criteria the author utilized a seven-point scale.

Liu et al. [52] developed a simplified DEA model to evaluate the overall performances of suppliers. The model aims at selecting a supplier having higher supply variety.

Forker and Mendez [21] applied DEA to identify the most efficient suppliers and those suppliers who are not on the efficient frontier but who could move toward it by emulating the practices of their “best peer” supplier. These “best peer” suppliers can be imitated by firms with similar organizational structures with the least amount of effort. For each supplier, it calculates the maximum ratio of a single input to multiple outputs. Those outputs are based on the critical factors of quality management proposed by other authors.

Talluri and Baker [53] evaluated suppliers, manufactures and distributors using DEA for the logistics distribution network design. It obtained the optimal number of stakeholders and the optimal routing of material from select suppliers to manufactures to warehouses were identified.

Talluri and Sarkis [54] applied DEA to measure the performance of supplier.

Talluri and Narasimham [55] used DEA for effective supplier sourcing. To divide the supply base into various clusters utilized cross-efficiencies and statistical methods.

Tarulli et al. [47] presented a DEA approach to evaluate the performance of suppliers in the presence of stochastic performance measures. The model was compared with the deterministic DEA to highlight its usefulness.

Garfamy [56] applied DEA to measure the overall performances of suppliers based on total cost of ownership concept. A supplier providing a single unit of output charging the least amount of costs was regarded as the most efficient.

Ross et al. [57] used DEA to evaluate the supplier performance with respect to both buyer and supplier performance attributes. Three sensitivity analyses were carried out. The first analysis was to compute the supplier efficiency scores without considering the evaluation team's weights and bounds. The second analysis considered the evaluation team's preferences on the supplier performance attributes, whereas the third analysis considered the buyer's preferences on the supplier performance attributes.

Braglia and Petroni [20] described a multiple attribute theory based on the use of DEA and aimed at helping purchasing managers to formulate viable sourcing strategies in the changing market place.

Malekmohammadi et al. [48] solved a problem in which the centralized decision maker encounters limited or constant resources for total inputs or total outputs. It considered the decrease of total input consumption and the increase of total output production. Considering the importance of imprecise data in organizations, it defined a model to deal with interval and ordinal data.

4.5. *CASE-BASED REASONING (CBR)*

4.5.1. *Definition*

Case-Based Reasoning (CBR) is a recent problem solving technique that is attracting increasing attention. The origins of CBR start in 1977 when Schank and Abelson developed a model of dynamic memory that are the basis for the earliest CBR system. [58]

CBR combines a cognitive model describing how people use and reason from past experience with a technology for finding and presenting such experience. It solves new problems utilizing specific knowledge of past experience and basic competence is encoded within a corpus of previous problems solving episodes called case-base. CBR is also an incremental learning approach since new experience is retained each time a problem has been solved. CBR provides a conceptual framework in which to store operator experience and to later provide that experience to other operators to facilitate the situation assessment and solution formulation processes. This is accomplished by providing a context in which the human operator can view the current state and recent activities of the system and gain easy access to previous experience. [23]

4.5.2. *Methodology*

CBR process is represented in Figure 13 by a schematic cycle with four steps [23]:

1- **Retrieve** the most similar situation from a set of cases, according to investigation or request.

2- **Reuse** the cases to solve the problem in order to construct the solution for the new problem. This solution becomes the output of a proposed solution.
3- **Revise** the suggested solution if there is a difference between the new problem and the retrieved case. This solution is verified and exported as a solution.
4- **Retain** the new solution as knowledge in a case database for future usage.

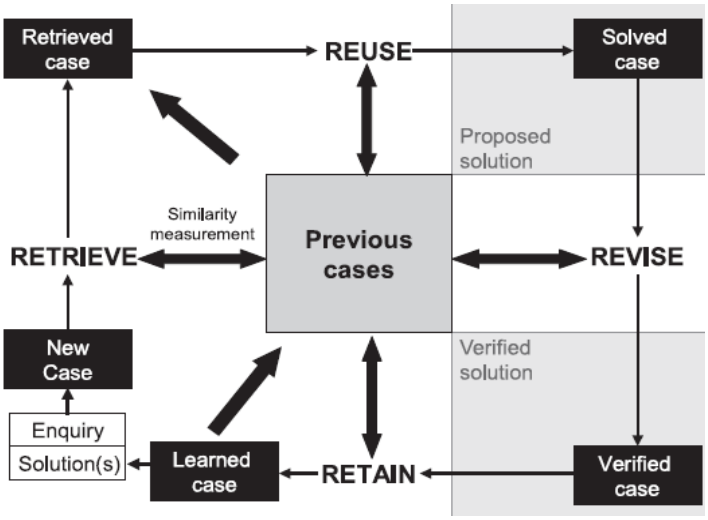

Figure 13. CBR Cycle.
Source: [23]

It is illustrated that a new problem is matched against historical cases in the case base using heuristically cased indexed retrieval methods with one or more similar cases being retrieved. A solution suggested by the matching cases is reused and tested for success. At this stage, if the best-retrieved case is a perfect match, then the system has achieved its goal. However, it is more usual that the retrieved case matches the problem case only to a certain degree. In this situation, the closest case may provide a sub-optimal solution or the closest retrieved case may be revised using some pre-defined adaptation rules. Adaptation CBR systems means that systems have a rudimentary learning capability which can improve or become more discriminatory as the number of case increases. Nevertheless, while adaptation is useful in many situations, it is by no means essential as in the case of supplier selection. Many of the most successful commercial CBR systems do not perform adaptations at all. They either simply reuse the solution suggested by the best matching case or they leave adaptation to people. [59]

In the step of case retrieval, the groundwork for representing knowledge from previous cases called similarity measurement has several related algorithms for efficient similarity-based retrieval of experience such as statistical weighting and a fuzzy mathematical method. [60] The nearest neighbour technique is a weighted average similarity measurement and perhaps the most widely used technology in CBR. The similarity of the problem with previous cases is determined. This measure may be multiplied by a weighting factor. Then the sum of the similarity of all attributes is calculated to provide a measure of the similarity of that case. This can be represented by equation (14). [23]

$$\frac{\sum_{i=1}^{n} w_i \times sim(f_i^I, f_i^R)}{\sum_{i=1}^{n} w_i} \quad (14)$$

Where,

$w_i = weight\ of\ feature\ I;$

$sim = similitary\ function;$

$f_i^I, f_i^R = the\ values\ for\ feature\ i\ in\ the\ input\ and\ retrieved\ cases\ respectively;$

Algorithms similar to this are used by most CBR tools to perform nearest neighbour retrieval. Similarities usually fall within a range of zero to one, where zero is totally dissimilar and one is an exact match, or as a percentage similarity where 100 per cent is an exact match. CBR techniques such as the induction technique are commonly used since many of the more powerful commercially available CBR tools provide this facility. For instance, KATE from AcknoFoft, ReCall from Isof, CBR-Works from TecInnoand ReMind from Cognitive System. [23]

CBR also incorporates learning as part of its architectural design and can scale up to take advantage of large databases of cases. [60]

CBR techniques are widely used in various industries nowadays, as they are useful in searching the knowledge, helping users in comparing various tasks and items, automatically notifying users with relevant new knowledge update, and so on. [60]

Based on these steps, the CBR method is suitable for use in the development of a supplier selection tool, which can act as a significant contribution in the management of such selection. [60].

The supplier selection process with CBR is described by the follow steps: [60]

1- Define the objective(s) and rule(s) of retrieval in order to set single or multiple goal(s) for supplier case retrieval.
2- Define weightings for criteria as a pre-set step. The priority of criteria is defined by the previous user input values or the default weightings from the above survey results. The preference of all attributes in different levels of supplier selection hierarchy is then defined.
3- Generate match method for case retrieval.
4- Retrieve all supplier cases in the case-base and then extract these stored cases. Profiles of technical capability, quality systems and organization profile of each supplier case are then loaded as part of a relation under the case-base of the authorized supplier list.

5- Compare the retrieved cases and shortlist possible supplier cases by the weighted average similarity measurement method. The degree of similarity in this measurement is expressed by a real number between 0 and 1, where 0 means “completely not” similar and 1 means “very similar”. Each weighted attribute in each profile form the supplier case is computed with the corresponding input values, as the goal of case retrieval.
6- Analyze the supplier attributes. This stage consists of two main tasks. The first one is to test the solution of the current supplier case against the validity of the real-world data. The second task is to rank the similar short-list supplier cases in an ascending order. The most similar supplier cases will be ranked at the top of the list.
7- List out the most similar supplier as a solution in this process.
8- Supplier adoption. In this step, the solution would be adopted according to the supplier adoption rules and then updated to a supplier case-base. Finally, all capable suppliers are identified. The output supplier case and its attributes can be exported to other application in an authorized database format.

The step 1 and step 2 can be defined again by the user. The processes from step 3 to step 8 can be operated by any commercial case-based reasoned for the customized supplier selection process.

4.5.3. *Advantages and limitations of CBR*

To use CBR method has some advantages. Firstly, it is easy to capture knowledge. The structure of cases is much less constrained that rules are. There is no need for discovering complex interrelations between cases or the relationship between the cases attributes and the solution is not understood well enough to represent it in rules. [61]

There are also disadvantages of using CBR. If the knowledge repository does not have a sufficiently similar case, the retrieved cases may be inappropriate for the new problem. The case-based system may exhibit the bias associated with the availability heuristic, just as an inexperience decision maker may do. When the case base lacks of sufficiently relevant case, CBR may not be able to recognize a new problem type when a new case is distinguished form prior cases by a feature. [61]

4.5.4. *Individual approach*

In the literature, there are some authors who wrote about CBR method and its applications in supplier selection. There are other papers about CBR method but with different applications.

Choy and Lee [23] presented an intelligent generic supplier management tool using the CBR technique. The model was implemented in a consumer products manufacturing company, which had stored the performance of past suppliers and their criteria in a database system. The proposed model would select a supplier who met the specification predefined by the company.

After that document, Choy with different authors ([59], [60], [62], [24], [63], [64], [65], [66]) wrote more papers about the application of CBR model to aid decision makers in the supplier selection problem. The approach was very similar to the first one and the model was applied in the same company.

Zhao et al. [67] analyzed CBR system of supplier selection based on data mining. It studies a case in a Chinese oil company to know the advantages, practicability and validity of the project.

4.6. DECISION-MATRIX METHOD

4.6.1. *Definition*

Decision-Matrix Method, also Pugh Concept Selection, is a quantitative technique which was proposed by Pugh in 1990. It consists of establishing a set of criteria upon which the potential options can be decomposed, scored and summed to gain a total score which can then be ranked. The criteria are not weighted to allow a quick selection process. [68]

It is frequently used in engineering for making decision but can also be used to rank investments options, vendor options, product options or any other set of multidimensional entities. [68]

4.6.2. *Methodology*

The method is a qualitative evaluation in which design concepts are compared to a reference design concept. The reference concept may be a standard design, a design that is considered just acceptable or one of the proposed concepts that appears to be the favourite on first check. [68]

An evaluation matrix is constructed as shown in Figure 14, comprising the concepts 1 to *m* which are arranged against the assessment criteria 1 to n.

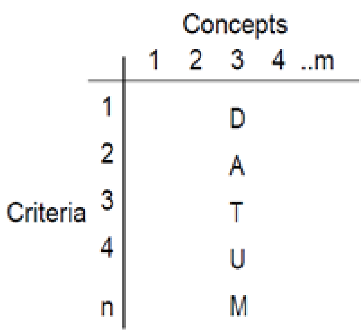

Figure 14. Concept evaluation matrix.
Source: [68]

The reference concept is chosen as the datum. Each concept is then compared with the datum with respect to each assessment criterion independently: [68]

- If a concept is better than the datum with respect to a certain criterion then a “+” is inserted into the matrix for that concept against that criterion.
- If the concept is worse than the datum then a “-“ is inserted into the matrix.
- If it is the same as the datum or if no judgment can be made then an “S” is inserted into the matrix.

Thus the matrix is completed with “+”, “-“ and “S” points and the points are totaled for each concept. Figure 15 shows the appearance of a completed matrix.

		Concepts 1	2	3	4	..m
Criteria	1	-	+	D	+	S
	2	+	+	A	-	-
	3	+	S	T	-	S
	4	S	-	U	-	+
	n	-	S	M	S	S
Total	+	2	2		1	1
Total	S	1	2		1	3
Total	-	2	1		3	1

Figure 15. Completed concept evaluation matrix.
Source: [68]

The matrix highlights the strengths and weaknesses of concepts. The objective of the evaluation process is to eliminate weak concepts and to identify those strong concepts that are suitable for further design work. The “-“ and “S” points of the concepts are reviewed to see if significant improvements can be made. In Figure 15 concepts 1 and 2 appear strong and concept 4 is weak. Concepts 1 and 2 would be reviewed with respect to criteria 1, 3 and 4 to see if their rating could be improved to “+” before the final choice between these two concepts is made. In this way concepts can be systematically reviewed to make them robust and suitable for further design work. [68]

4.6.3. *Advantages and limitations of Decision Matrix-Method*

The advantage of this approach to decision making is that subjective opinions about one alternative versus another can be made more objective. Furthermore sensitivity studies can be performed. An example of this might be to see how much your opinion would have to change in order for a lower ranked alternative to out rank a competing alternative. [69]

One disadvantage of the rating structure for this method is that it is less descriptive that other methods like AHP scale (See Table 6). Moreover, it uses an arbitrary rating structure. [69]

4.7. OTHER METHODS

This paper studies only some of the methods to evaluate supplier but there are more methods used in supplier selection. This section mentions other methods with some of the authors who wrote about it.

Chen [70], Sarkar and Mohapatra [71] or Florez-Lopez [72] wrote about Fuzzy Set Theory in the supplier selection process. Barla [73] or Huang and Kiska [74] used SMART (Simple multi-attribute rating technique) to solve the supplier selection problem. Ding et al. [75] presented a Genetic Algorithm based optimization methodology for supplier selection.

Furthermore, there are various papers that formulated the supplier selection problem as types of mathematical programming models. Ng [76] and Talluri and Narasimham [77]developed a linear programming model to evaluate and select potential suppliers. Tarulli [78] and Hong et al. [79] presented an integer linear programming. Ghodsypour and O'Brien [80] formulated a mixed integer non-linear programming model to solve the multi-criteria sourcing problem. Karpak et al. [81] constructed a goal programming (GP) model to evaluate and select the suppliers. Narasimham et al. [82] and Wadhwa and Ravindran [83] constructed a multi-objective program to select the optimal suppliers.

In addiction it is possible to integrate different methods. Thereby, Ramanathan [18], Saen [84] and Sevkli et al. [85] proposed an integrated AHP-DEA approach; Perçin [86], Kull and Tarulli [87] and Mendoza et al. [88] presented an integrated AHP-GP approach; Mendoza and Ventura [89] proposed an integrated AHP and mixed integer non-linear programming approach; Weber et al. [90] and Talluri et al. [91] utilized an integrated DEA and multi-objective programming to develop a new method; Seydel [92] applied a integrated DEA and SMART; Liao and Rittscher [93] formulated an integrated GA and multi-objective programming model.

5. AN ENERGY SECTOR COMPANY SUPPLIER EVALUATION

This section describes the supplier evaluation in an energy sector company. As a successful company, it is an extraordinary example about how to select the best supplier keeping competitive prices but at the same time quality and satisfaction with its clients.

To know more about the company and about the supplier selection some interviews with a company's Engineering Manager are carried out. To complete the information, some of the tools that are used in the company are sent to me by e-mail.

5.1. SUPPLIER SELECTION PROCESS

The company procurement policy's states the activities that are necessary to carry out for each procurement activity.

Firstly, the purchase's necessity is determinate and the criteria which are taken into account to decide the supplier are specified. (To know more about the company's criteria see Section 5.2). Then, it carries out a scouting or market survey in order to identify the companies that may suit better to their requirements. These companies receive a cover letter about the energy sector company, the services that are sought and how it acts in the request for quotation process (RFQ).

Companies which are interested in this process have to fill out some annexes which are included in the cover letter. The process is as follows:

1. First, they have to send the "Confirmation of Interest" (See Annex A), to confirm that they want to participate in the RFQ process.

2. To receive the complete information needed for responding the RFQ process, the bidders have to sign a "Confidentiality agreement" (See Annex B).

3. They have to fill out the "Acknowledge of receipt" (See Annex C) to assure that all of them received all documentation.

4. There is one week to submit all questions in a written way to the appointed Point of Contact. Responses to questions, which are clarifications of a general nature, are sent to all bidders by e-mail so all of them have the same information. If there are questions subsequent to this date, they have to be solved at the eventual clarification meeting.

5. With all of this information, bidders are ready to present their tenders which should be their best offer in a complete and transparent way because they are only allowed to present one offer during RFQ procces. Once the tenders are received, there are

some meetings with the bidders which it is necessary at least two people from the company, in this way there are not possibilities of fraud in the process.

Moreover, there is a website which publishes every tender with all the information necessary and the supplier uploads its tender. The main advantages are:

- Every company have the same information.
- There is not manipulation between the information from the supplier and from the company. Consequently it is difficult the corruption in the process.

Bidder's information is gathered and analyzed. Since, all companies have sent the information in the annexes that they received; it is easy to compare the different offers.

Next step it is to examine characteristics like price, global risk or cost optimization. If the basic requirements are not satisfied, the company is ruled out. The rest of the companies are examined in detail for each criterion and they are marked like it is agreed in the beginning of the evaluation process. The global mark of each supplier is calculated multiplying the weight for each criterion by the weight of each supplier relative with this criterion and adding the result for each supplier.

Finally, it studies the result comparing supplier proposals and it decides which is the best supplier for this process. A full purchase agreement is signed.

In the company, there are some managers who can commit, procure and sign off contracts. It is always necessary two people, but there are some rules about who can sign each kind of contract.

Table 8 indicates a summary about how it should to apply the policy of purchasing and when it is the moment to do it.

Typical yearly Committed Value (Euro)	Qualified Suppliers & Products	Specification & Acceptance Criteria	Tender Bidders	Pre acceptance Payments	Full Purchase Agreement	Involve Contract manager
<5k	Exempt, but HSE always	Exempt	Exempt	Exempt	offer+acceptance, payment preferrably AMEX	no
< 10k Services < 25k Goods	Exempt, but HSE always	Exempt	Exempt	Only if essential, up to 10k	PO*, T &C with HSE and COC reference	no, except below comment
< 50k	Contractor accreditation for Installation, After sales, engineering / Supplier evaluation for goods and non core services	Required: to be defined based on scope	at least 3			
< 200k				Must be secured (bank warrantee)	PO*, T & C, Contract recommended, HSE + COC always	**copy, except below comment**
>200k					PO, T & C, Contract, HSE, COC	**yes**
When?	Before RFQ	RFQ		understand before award	send with RFQ, close at award	acc to policy

Table 8. Procurement
Source: Company

Note:
AMEX. American Express, T&C (Terms and Conditions), HSE (Health, Safety and Environment), COC (Code of Conduct).

During tender process and prior to commitment, all communication with the market is through a single individual to ensure consistency of approach and adherence to the procurement policy.

Purchase orders are saved in the Oracle system (a database system management) and a paper copy including eventual scope and signatures both from company side as the supplier side are kept by the person opening the purchasing order, during at least 5 years.

Procurement strategy is to have long term agreements based on mutual trust with a limited number of preferred suppliers, selected after request for quotation process (RFQ). Supplier opportunities coming up after RFQ process are not considered, unless a clear business need or regional requirement exists to deviate from the procurement strategy.

RFQ procces is carried out in approximately one month.

5.2. SUPPLIER EVALUATION CRITERIA.

Business requirements can be organised into five major groups representing the critical elements of the voice of the Stakeholder (Figure 16):

- **Assurance of Supply and Ethical Right to Use:** it guarantees availability of regulatory compliant goods and services when needed. It includes: available capacity, ability to ramp up and ramp down capacity, quantities required (when and where), legal and regulatory compliance, environmental and similar ethical needs, safety and health, safety, security and environment (HSSE).
- **Quality.** Parameters include are quality in design of goods or processes, quality in meeting specifications and reliability.
- **Service** deliverables include: lead-times and order flexibility horizon, Electronic Data Interchange, vendor scheduling, inventory holding and staging, co-location of production, response times, dedicated account manager and continuous improvement.
- **Cost** expectations include: current and future cost requirements, cost reduction, continuous improvement and total cost (including any acquisition, inventory, or disposal costs).
- **Innovation** needs include: preferred access for competitive advantage, new product plans, use of leading-edge technology, market-driven innovation and supplier supported innovation.

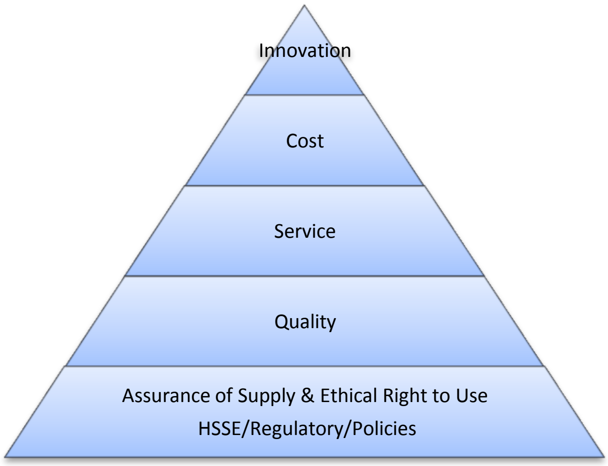

Figure 16. Pyramid of Value Model
Source: Adapted from Company

Once the purchase's necessity is determinate (what it is required, by whom, when…), the information is gathered and company managements must to decide the criteria and their importance for this process, using the Pyramid of Value framework (Figure 16). Since not all criteria have the same importance, it is necessary to give a weight to each criterion. To get an objective process if different people evaluate the bidders, it is important to explain very well how to evaluate each criterion and how to get each mark.

These activities are done before to receive the tender from the companies. Consequently the process is really clear and no company have more advantages than other to get the tender.

5.3. *TECHNICAL EVALUATION OF STRUCTURES.*

This section includes an example of the technical evaluation of structures in order to understand better the supplier selection of this company.

The aim of the RFQ is to look for a supplier who designs mounting structure for Photovoltaic solar panels.

This company had a previous contract with Company B, but it wants to decide if it continues with this supplier or if there is another which it can get better conditions.

There are two different kind of structures depending on the corrosion protection:

- Hot dipped galvanized steel.
- Hot rolled galvanized sendzimir.

The main different between both are: Sendzimir is not valid for 100% of zones and hot dipped galvanized steel is valid for 100% of zones but is a little bit more expensive, althought it does not represent a very high extra cost (See Figure 17).

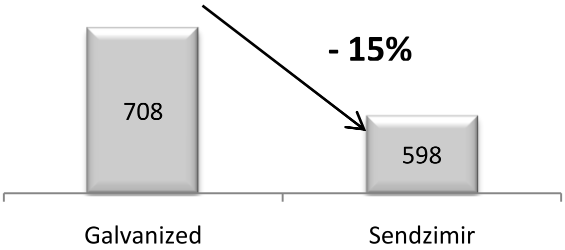

Figure 17. Comparison between Galvanized steel and Sendzimir.
Source: Company

RFQ process include three rounds. First, it invites some suppliers to quote structures and it analyzes the cost of each company. It rules out the companies which do not comply with the mounting structure specifications, or if their cost is too high. In the second round, it analyzes the criteria of each bidder and it marks each one. In the final round, it carries out the last negociations and comparison to decide the supplier and to sign the contract.

After inviting many supplier to quote structures, some of the companies did not answer or the answer is not complete, so finally there were ten companies in the selection process.

The cost of these ten companies are represented in Figure 18. It compares the costs including profiles manufacturing, galvanization, plates, screws, transport and other extra costs. The cut-off price is 1250 Euro/34 module structure so C and D Companies are excluded from analysis because the offer is expensive.

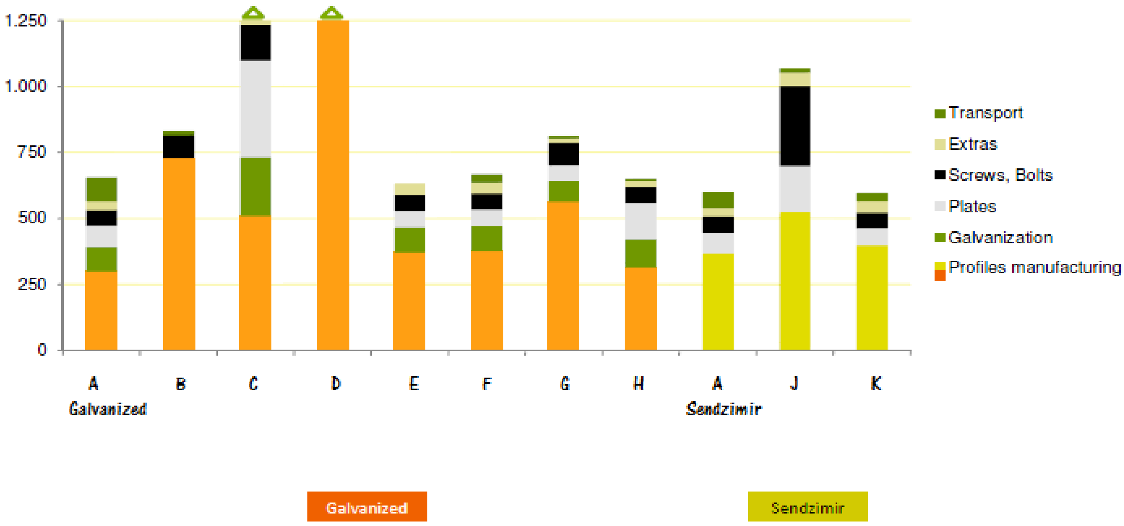

Figure 18. Cost structure.
Source: Company

Not all companies offer the same product, the Company B and G offer the complete product that it is necessary, with the Company A (galvanized) and H it is necessary to contract screws supplier; and with the Company A (sendzimir), E and K, it is necessary to contract galvanizing, plates and screws suppliers. It can see in Figure 19 that the solution 1 and 2 are more efficient regarding operation complexity.

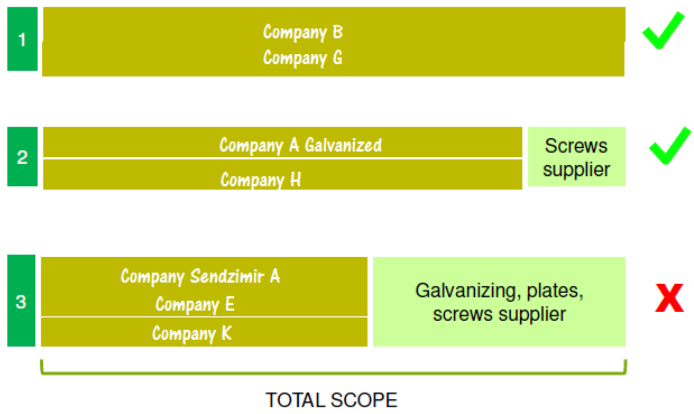

Figure 19. Solution 1 and 2 are more efficient regarding operational complexity.
Source: Company

In order to compare offers, cost optimization and risk level are plotted in Figure 20.

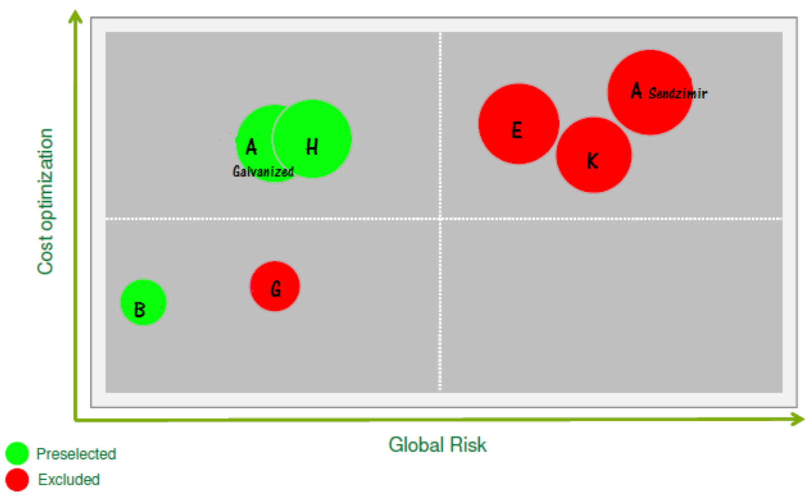

Figure 20. Cost Optimization and Global Risk
Source: Company

Note:
Cost optimization: how the company has been able to offer a very cost competitive structure.
Global risk: risk of not been compliant with the contract signed. Especially on delivery time, Quality and Safety.

In this case, Company G is Company B's supplier and do not represent enough cost optimization to be selected against Company B, so it is excluded. Company E, K and A (Sendzimir) are excluded too because the global risk is very high.

In the first round three suppliers are preselected: Companies A, B and H; then it studies the cost per complete structure for 1 MW project.

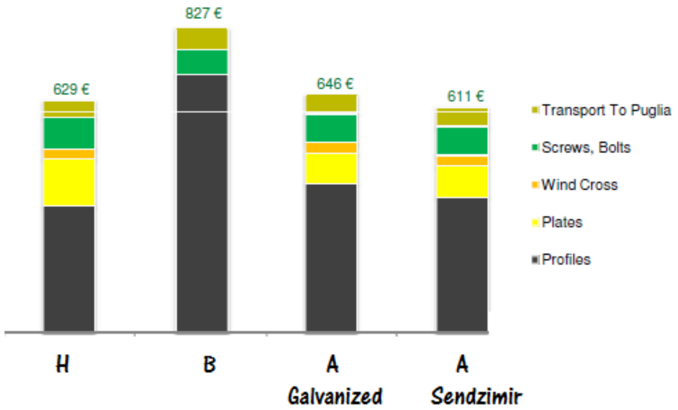

Figure 21. Cost per complete structure for 1 MW project
Source: Company

In the second round, it updates the offers and it analyzes each supplier with the criteria which are agreed in the beginning of the process. Each criterion has a weight that depends of its importance for this process (Figure 22). The criteria are divided in six groups: general assessment, quality, service, cost optimization and health, safety, security and environment (HSSE).

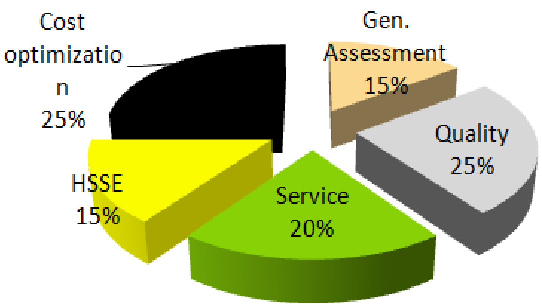

Figure 22. Importance of each criteria.
Source: Company

- General assessment: it evaluates financial risk, turnover (% based on 40 MW), suitability of solution to supply all European projects, simplicity operations, flexibility on forecast changes, development department for future new designs and cost reduction and experience with the Company (Table A 1). The weight of this criterion is 15%.

- Quality: it analyzes technical risk material, technical risk design, documentation and design capability, traceability, requirements comply and manufacturing quality (Table A 2). The weight of this criterion is 25%.
- Service: Analyzes local contact, design, documentation and IP, profiles or steelwork, plates, screws and anchors volts, mounting or installation, foundation or civil works and volume capacity (Table A 3). The weight of this criterion is 20%.
- HSSE: it analyzes the evaluation supplier questionnaire and meetings and comments (Table A 4). The weight of this criterion is 15%.
- Cost optimization: it analyzes the cost, the price validity and steel indexation transparent (Table A 5). The weight of this criterion is 25%.

To get the final mark of this criterion, it is necessary to evaluate each sub-criteria. In Annex D is developed how to get points according to each criteria.

Once it analyzes the supplier's criteria, it has the final mark of each one. The final mark is calculated like it is explained in Section 5.1.

Company H has the highest mark and Company B has the lowest. (Figure 23 and Figure 24).

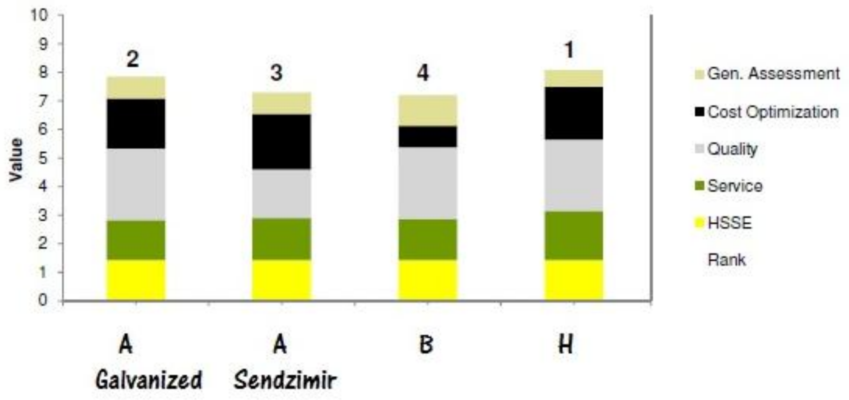

Figure 23. Global proposals evaluation.
Source: Company

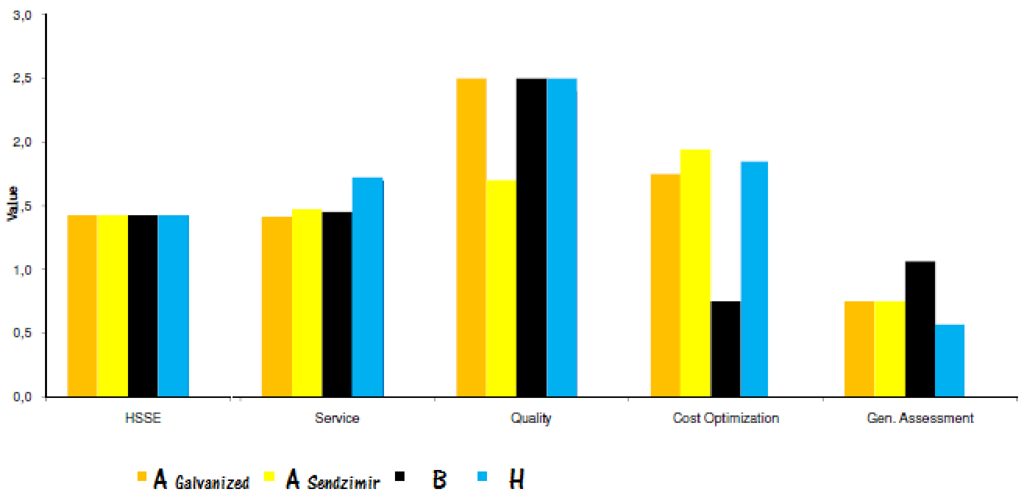

Figure 24. Global proposal evaluation.
Source: Company

The main advantages and disadvantages are analyzed against the criteria in the each company and they are represented in Table 9.

	Advantages	Disadvantages
Contract Prolongation with Company B	• Risk = 0 • Successful Experience with the company. • Able to propose competitive alternative. • Able to design all type of structure. • Main contractor.	• Not most competitive offer in term of cost.
Company A	• Very competitive offer • European supplier	• No 100% scope (screws) • Local contact
Company H	• Most competitive offer including alternative. • High volume capacity. • Local contact.	• Low Company volumes vs global company sales.

Table 9. Advantages and Disadvantages of each company.
Source: Author's own.

Finally, the conclusion was to sign a new contract with Company H and also to extend the contract with Company B. Although Company B is not the most competitive offer in term of cost, the successful experience with this company and the rest of advantages make its offer the second best solution to supply structures.

6. ANALYSIS

The presented case is a good example of supplier evaluation process and to demonstrate its importance in a company. The main steps defined in this dissertation were considered for the company studied. The company spends time and resources in this process, from the start, defining the purchasing necessity until the end when it decides who will be the new supplier. Consequently, it appreciates the importance that this process has for the company, since it needs at least one month to make this decision.

It is important to see how the company tries to do a clear process avoiding corruption in the supplier selection process. Thus, more than one manager has to participate in every decision and the objectives and criteria are decided before to select the companies who can participate in the selection process.

This company gathers criteria in six main groups and represents their importance in a pyramid of value model. But it does not mean that it always uses these criteria with that priority. This is corroborated in the example of the technical evaluation of metallic structures where, for instance, the most important criteria are cost optimization and quality while in the pyramid appear in fifth and third position respectively or HSSE is in the last priority position instead of the first position like in the pyramid model (it appears inside of the group Assurance of Supply and Ethical Right to Use).

To evaluate criteria objectively, the company develops a detailed list with all criteria and how it can get each mark. Since it is difficult to evaluate some criteria, it divides these criteria in some sub-criteria to help with the evaluation. But although it tries to carry out an objective process independent of the person who evaluates it, sometimes it is not easy, for example to distinguish in quality between very well, well, satisfying... Instead, there are other criteria really clear with the mark, like general assessment.

One solution to obtain an objective selection process is to specify more the different between very well, well, satisfy and sufficient and can be easier difference each mark. Another solution is that only one person does the evaluation process for all bidders, so all of them are evaluated in the same way or that to know more than one approach of that or that two people can do it and then compare if both results are the same or why there are differences between them. But, the last solution maybe it is not useful since it is more expensive for the company if it is necessary to do it twice in each evaluation process.

Comparing the criteria that are used for this company with the list developed in this project and with Dickson's list, it appreciates that all of them coincide that quality, service, delivery and cost are the four most important criteria, although not in the same position. The main difference occurs with the most important criterion in the company: Assurance of Supply and Ethical Right to Use which does not appear in the criteria explained in the theory and for the company is one of the most important criteria.

Other good point of this company to compare the different bids is that every bidder has to fill out the same documents with the same format, so there is the same information of all companies and like it is the same format it is easy to compare it. Furthermore, it creates tables in Excel with all of that information and graphics that facilitating its evaluation.

Finally, the method used for the company to make this decision is not the same that any methods which are explained in Section 4, but it is similar to AHP approach. It tries to avoid the main disadvantages that AHP has, thus it does not use the standard scale and it adapts it for each criterion (sometimes, it is not necessary to mark among 1 to 9, with 4 points are enough to evaluate it). Furthermore, it tries to difference well although in my opinion not always it achieves it satisfactorily. In addition, to simplify the process and reduce the number of bidders, it stars with the cut-off price and then it continues the process using the rest of the criteria so it avoid to evaluate companies which have price uncompetitive.

7. CONCLUSION

The main objectives of this thesis, explained in the introduction were accomplished successfully.

Firstly, a literature review was carried out in order grasp depth knowledge of the topic and its importance. There is a long list of literature that studies this topic that emphasizes the importance of the suppler selection process. Furthermore, the practical example in the company gives us a practical approach and shows how important it is for them this process.

It has been observed how the criteria has been modified from using the price as most important criteria in the traditional approach, to nowadays where quality can be considered the most important criteria followed by cost, performance delivery and service. Although it does not mean that always these criteria are considered in supplier selection, in the study developed in this master thesis, it was appreciated that each author had his own approach and opinion about which criteria and its priority can be used, but they coincide in these four criteria as the most important.

Thus, it can say that it is complex to create an exclusive list, but it is possible to have a list and in each situation modify it paying attention of the criteria that are more important in this moment. Consequently, the traditional single criterion approach based on lowest cost is not supportive and robust enough. Although, it can use this criterion to start the selection process and to reduce the list of bidders, like the company does in its process.

Additionally, there are different methods to evaluate the suppliers. It depends on the complexity of the problem or the time that it has to solve it, it can choose one different or a combination between them. All of them have its advantages or limitations, so it is not possible to find the perfect one, but for this reason authors try to combine them to develop an improved one.

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ANNEX A. Confirmation of interest.

Please mark ONE of the squares below:

☐ I have received all the documentation regarding the RFQ XXX and hereby confirm my interest in participating in the process by submitting an offer. I am fully aware of the terms of the RFQ and will submit an legally binding offer that might be considered as the basis for a contract. I am interested in offering:

- ∇ The complete scope

A partial scope, including

- ∇ Part 0: General requirementes
- ∇ Part I: Preparation of the land and fencing
- ∇ Part II: Medium-voltage line and transformer stations
- ∇ Part III: Support structures
- ∇ Part IV: Inverters (supplied by [redacted] and not part of the RFQ)
- ∇ Part V: Safety and surveillance
- ∇ Part VI: PV electro-mechanical installation
- ∇ Part VII: Supervision, quality and HSE
- ∇ Part VIII: Civil works

☐ I have received all the documentation regarding the RFQ XXXXXXXXX and hereby confirm our lack of interest in the process. I am fully aware that, in signing this option, my company will be excluded from the process and that [redacted] Company can and will not be held liable for all works that might have been undergone by my company in the context of this RFQ process

By signing this document, you oblige yourself to the conditions expressed in each of the options. Please mark the option selected and return by fax as soon as possible

Completed by: **<Person>**

On behalf of: **<state vendor name>**

Date: **<state date>**

Signature:

Please send a copy of this form by fax to [redacted] or by e-mail to [redacted] before Monday May 9th 12.00 noon, CET.

ANNEX B . Confidentiality Agreement.

CONFIDENTIALITY AGREEMENT

This agreement between

[redacted] **ESPAÑA SA**
Pol. Ind. XXXXX s/n.

XXXXX Madrid

Spain

hereinafter called [redacted]

AND

COMPANY

address

address

hereinafter called Company

is entered into in good faith and in mutual confidence between the two parties.

The agreement is in relation to planned discussions between us and yourselves concerning the RFQ for SUBJECT. This agreement is expandable to other works.

In furtherance thereof, it will be necessary for us to provide you with certain information concerning the aforesaid work which is of commercial value to [redacted]. We therefore set out below the terms and conditions under which we propose that we disclose such confidential information to you.

1. In this letter, "Confidential Information" means all data, information, experience and know-how which is either directly or indirectly:

   (i) disclosed by [redacted] to you hereunder, or

   (ii) otherwise acquired by you from [redacted] pursuant to this Agreement

2. In consideration of [redacted] making available Confidential Information to you hereunder, you undertake for a period of ten (10) years from the date of receipt of the last disclosure of Confidential Information hereunder, and subject to paragraph 3 below, that you will ensure that such Confidential Information will not, without [redacted]'s prior written consent;

   (i) be disclosed to any third party, or

   (ii) be used for any purpose other than in connection with any work you carry out with or for [redacted]

3. The restrictions on use and disclosure set out in paragraph 2 above shall not apply to any information which;

   (i) at the date of its disclosure by [redacted] is public knowledge or which subsequently becomes public knowledge other than by any act or failure to act on your part,

   (ii) is already known to you (as evidenced by your written records) at the date of countersignature of this letter and was not acquired directly or indirectly from [redacted]

   (iii) is at any time after the date of countersignature of this letter acquired by you from any third party who did not acquire such information directly or indirectly from [redacted], to the extent only that you may lawfully use or, as the case may be, disclose such information.

4. For the purposes of paragraph 3 above, information shall not be deemed to be public knowledge or known to you on the ground only that;

   (i) the general principle is public knowledge or known to you if the particular practice is not itself public knowledge or so known, or

   (ii) it constitutes a combination, conclusion or finding (not itself public knowledge or known to you) of or drawn from information which is public knowledge or known to you.

5. You further undertake

   (i) to limit access to Confidential Information to those of your employees who reasonably require the same,

   (ii) to inform each employee to whom Confidential Information is disclosed of the restrictions as to disclosure of Confidential Information contained herein and ensure that each such employee shall observe such restrictions.

6. Property in all documents and/or other physical records or reproductions containing Confidential Information shall remain with [redacted] and shall be returned to [redacted] upon demand except insofar as the same shall have been submitted and lodged with governmental authorities required by law to hold the same.

7. Nothing in this Agreement shall be construed as conferring upon you any licence or rights in respect of such Confidential Information nor shall this Agreement be construed as an offer or agreement to do so.

8. The construction, validity and performance of this Agreement shall be governed by and construed in accordance with the laws of Spain and shall be subject to the exclusive jurisdiction of the Spanish Courts. Unless otherwise agreed by the Company in writing, all communications, documents, drawings and data shall be made or drawn up in the English language.

We confirm acceptance of the above terms

	For and on behalf of [redacted] ESPAÑA SA	For and on behalf of Company
Signed:		
Name :		
Title :		
Date		

20/05/2011 Confidentiality Agreement between [redacted] España SA and Company name Page 2

ANNEX C. Acknowledge of receipt

Please mark in the following table the documents you have received concerning the RFQ XXX:

Document	Received
Cover letter	
Annex 1: Expression of interest	
Annex 2: (this document)	
Annex 3: Supplier evaluation questionnaire	
Annex 4: Frame Agreement General Terms & Conditions	
Annex 5: Annexes to the contract, including calendar for the works to be proposed by bidder	
Annex 6: Compliance Matrix (as you have confirmed interest)	
Part 0: General requirements	
Part I: Preparation of the land and fencing	
Part II: Medium-voltage line and transformer stations	
Part III: Support structures	
Part IV: Inverters (supplied by [redacted] and not part of the RFQ)	
Part V: Safety and surveillance	
Part VI: PV electro-mechanical installation	
Part VII: Supervision, quality and HSE	
Part VIII: Civil works	
Part 0: General requirements	
Annex 8: Health, Security & Environmental requirements	
Annex 9: Prices	
Annex 11: Confidentiality Agreement	
Annex 12: Expected Volumes and Movement	

Annex 5: partially to be proposed by the tenderer
Annex 7: Non compliant, development plans and Alternative proposals
Annex 10: Company profile & Positioning in terms of the evaluation criteria

These last 3 annexes are to be submitted by the tender and are not included in the package sent by [redacted]
If any of the documents hereby stated has not been delivered to you, or is in a damaged state or contains any errors, contact [redacted] at the contacts specified in the cover letter.

You are reminded [redacted] will accept no liability for any omission or error in the Documentation, which could have been reasonably identified by you.

Completed by: **<Person>**

On behalf of: **<state vendor name>**
Date: **<state date>**

Signature:

Please send a copy of this form by fax to [redacted] or by e-mail to [redacted] before Thursday July 8th 10.00 am CET.

ANNEX D. Company's criteria

100%	GENERAL ASSESSMENT	Points
37%	**Financial Risk**	
30%	**Turnover % based on 40MW (4,5MEuros)**	
	> 30	0
	25 < % < 30	8
	20 < % < 25	10
	10 < % < 20	8
	5 < % < 10	4
	1 < % < 5	2
	< 1	0
1%	**Suitability of solution (various suppliers) to supply all European projects**	
	Experience in Spain, Italy, Greece	10
	Experience in 2 of 3 countries	6
	Experience in 1 country	2
	Not evaluated	0
1%	**Simplicity Operations**	
	All process responsability	10
	2nd S. external	5
	None 2nd Source	0
	Not evaluated	0
1%	**Flexibility on forecast changes**	
	Yes	10
	Yes, but depends on volumes	8
	Yes, but not guaranted	5
	No	0
	Not evaluated	0

10%	Development department for future new designs and cost reduction	
	Yes included experience in FVenergy	10
	Yes but no experience in FVenergy	6
	Limited	2
	No	0
	Not evaluated	0
20%	**Experience with the Company**	
	Yes and good	10
	Yes but problems	2
	No	0
	Not evaluated	0

Table A 1. General assessment.
Source: Company

100%	QUALITY	Points
20%	**Technical risk material**	
	Very well	10
	Well	8
	Satisfying	6
	Sufficiently	4
	Not sufficiently	2
	Unsatisfactorily	0
	Not evaluated	0
30%	**Technical risk design**	
	Very well	10
	Well	8
	Satisfying	6
	Sufficiently	4
	Not sufficiently	2

	Unsatisfactorily	0
	Not evaluated	0
10%	**Documentation and Design capability, traceability**	
	Very well	10
	Well	8
	Satisfying	6
	Sufficiently	4
	Not sufficiently	2
	Unsatisfactorily	0
	Not evaluated	0
20%	**Requirements comply**	
	Very well	10
	Well	8
	Satisfying	6
	Sufficiently	4
	Not sufficiently	2
	Unsatisfactorily	0
	Not evaluated	0
20%	**Manufacturing Quality**	
	Very well	10
	Well	8
	Satisfying	6
	Sufficiently	4
	Not sufficiently	2
	Unsatisfactorily	0
	Not evaluated	0

Table A 2. Quality.
Source: Company

100%	SERVICE	Points
5%	**Local contact**	
	Very well	10
	Well	8
	Satisfying	6
	Sufficiently	4
	Not sufficiently	2
	Unsatisfactorily	0
	Not evaluated	0
2%	**Design, documentaion and IP**	
	Very well	10
	Well	8
	Satisfying	6
	Sufficiently	4
	Not sufficiently	2
	Unsatisfactorily	0
	Not evaluated	0
1%	**Profiles or steelwork**	
	Very well	10
	Well	8
	Satisfying	6
	Sufficiently	4
	Not sufficiently	2
	Unsatisfactorily	0
	Not evaluated	0

1%	**Plates**	
	Very well	10
	Well	8
	Satisfying	6
	Sufficiently	4
	Not sufficiently	2
	Unsatisfactorily	0
	Not evaluated	0
1%	**Screws & anchors bolts**	
	Very well	10
	Well	8
	Satisfying	6
	Sufficiently	4
	Not sufficiently	2
	Unsatisfactorily	0
	Not evaluated	0
5%	**Mounting or installation**	
	Very well	10
	Well	8
	Satisfying	6
	Sufficiently	4
	Not sufficiently	2
	Unsatisfactorily	0
	Not evaluated	0

5%	**Foundation or civil works**	
	Very well	10
	Well	8
	Satisfying	6
	Sufficiently	4
	Not sufficiently	2
	Unsatisfactorily	0
	Not evaluated	0
5%	**Volume capacity**	
	> 10.000 tm /year	10
	< 10.000 tm /year	8
	< 5.000 tm /year	6
	< 2.500 tm /year	4
	< 1.000 tm /year	2
	< 500 tm /year	1
	< 100 tm /year	0
35%	**Delivery lead time**	
	Very well	10
	Well	8
	Satisfying	6
	Sufficiently	4
	Not sufficiently	2
	Unsatisfactorily	1
	Not evaluated	0

10%	**Mounting lead time (based on design, not on Mounting company)**	
	less than 1 week / 1MW	10
	less than 2 week / 1MW	8
	less than 3 week / 1MW	6
	less than 4 week / 1MW	4
	more than 4 week / 1MW	2
30%	**Contract acceptance**	
	Very well	10
	Well	8
	Satisfying	6
	Sufficiently	4
	Not sufficiently	2
	Unsatisfactorily	0
	Not evaluated	0

Table A 3 Service.
Source: Company.

100%	HSSE	
80%	**Evaluation Supplier Questionnaire**	
	Very well	10
	Well	8
	Satisfying	6
	Sufficiently	4
	Not sufficiently	2
	Unsatisfactorily	0
	Not evaluated	0
20%	**Meetings and comments**	
	Very well	10
	Well	8
	Satisfying	6
	Sufficiently	4
	Not sufficiently	2
	Unsatisfactorily	0
	Not evaluated	0

Table A 4. HSSE
Source: Company

100%	COST OPTIMIZATION	Points
50%	**Cost**	
25%	**Price validity**	
	End 2009	10
	Mid 2009	5
	Spot	0
25%	**Steel indexation transparent**	
	Yes and easy to check	10
	Yes but difficult to check	8
	No	6

Table A 5. Cost Optimization.
Source: Company.