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Abstract: The world is becoming more and more a global marketplace and the global environment is forcing companies to take almost everything into consideration at the same time. Increase flexibility is needed to remain competitive and respond to rapidly changing markets. In this context, supplier selection represents one of the most important function to be performed by the purchasing department. 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. This report deals with the 'supplier selection problem', where a state of the art is presented. We summarize the different selection criteria, the various problems of suppliers selection and the existing methods to solve the problem. A numerical example is presented to 1- illustrate the different selection criteria and methods and 2- to compare the advantages and the disadvantage of the selection methods.

Key-words: Supplier selection, strategic supplier, optimisation method, multi-criterion, AHP approach.

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Problème de sélection des fournisseurs: critères et méthodes de sélection

Résumé : Actuellement, de plus en plus, le monde industriel a tendance à évoluer vers un marché global dans un environnement forçant les compagnies à prendre en compte presque tout en même temps. L'augmentation de la flexibilité des compagnies est devenue une nécessité pour demeurer concurrentiel et répondre aux changements rapidement des marchés. Dans ce contexte, la sélection des fournisseurs représente une des fonctions importantes à la charge du service des achats au sein des compagnies. Cette sélection, multicritères, inclue à la fois des critères qualitatifs et quantitatifs. Dans la plupart des cas, afin de sélectionner les meilleurs fournisseurs, il est nécessaire de faire un compromis entre ces critères réels et sensibles dont certains peuvent être en conflit. Ce travail de recherche est dédié à l'étude du problème de sélection des fournisseurs. Principalement, un état de l'art est présenté dans le but d'identifier les divers problèmes de sélection rencontrés, les différents critères de sélection utilisés et les différentes méthodes existantes pour résoudre le problème. Un exemple numérique est proposé dans le but : 1) d'illustrer les différents critères et méthodes de sélection utilisés et 2) d'identifier et comparer les avantages et les inconvénients des différentes méthodes de sélection rencontrées.

Mots-clés : Sélection de fournisseurs, fournisseur stratégique, méthode d'optimisation, multicritères, approche AHP.

1 Introduction

Supply Chain Management (SCM) and strategic sourcing have been one of the fastest growing area of management, particularly over the last ten years. Under the expanded heading of logistics these are now an integral part of company activity covering areas such as purchasing management, transportation management, warehouse management, inventory management, ... As technological complexity has increased, logistics and supply chains have become more complex and dynamic. Increase flexibility is needed to remain competitive and respond to rapidly changing markets.

Nowadays, costs of purchasing of raw materials and components parts from external vendors (suppliers) are very important. As an example, in automotive industry, costs of components and parts purchased from external sources may total more than 50costs for high-technology firms (Weber et al., 1993). It shows the importance of decisions of the purchasing activity. Indeed, they determine the most important part of the final cost of the product. Among the decisions related to this activity, supplier selection is the most capital decision (Nydick and Hill, 1992) and (Mobolurin, 1995). Without any doubt, this selection is one of the decisions which determine the long-term viability of the company (Thompson, 1990).

The search for new suppliers is a continuous priority for companies in order to upgrade the variety and typology of there products range. This is essentially due to two main reasons. At first, more generally product life cycle is very short (3 to 4 years) and new models must often be developed by using completely renewed material or with new technologies. Second, more industries are, historically, a labour intensive sectors. These aspects are expressed through a complex pattern of demand for material and labour.

Two different aspects characterize the supplier selection problem:

The first aspect is the determination of the number of the suppliers and the mode of relations with them. Considering the characteristics of the company, product and market, its strategic plan can encourage a large number of suppliers or not. 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. Indeed, a strong co-operation with high number of suppliers is very difficult to manage. Ansari and Modarress (Ansari and Modarress 1986) show that in JIT (Just-In-Time) environment, the majority of the companies prefer to follow a strategy of a single supplier or at least with few suppliers. Quarly (Quarly, 1998) 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 relation with the suppliers 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 co-operation. 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 thus to reduce the costs of purchasing. Several authors like Kamath and Likert (Kamath and Likert, 1994), Bensaou (Bensaou, 1999) and D'Amours et *al.* (D' Amours et *al*, 2001) are interested in the problems of suppliers classification.

The second aspect is the selection of the best suppliers among the existing alternatives. In this work, we consider this aspect of the problem and thus we assume that the number of the suppliers to be selected is already given.

The present report is organized as follows. In Section 2, we summarize the most important criteria used in the literature of supplier selection problem. Section 3 is dedicated to the classification of the existing methods for the supplier selection study. These methods can be divided into three categories, and a method can of course be the combination of elementary methods. In Section 4, the various characteristics of the supplier selection problem are presented. A global solution must be able to consider these characteristics. Section 5 deals with the concept of "strategic supplier". In Section 6, we summarize advantages and disadvantages of the current selection methods. To illustrate the different approaches used to solve the supplier selection problem, a numerical example is presented in Section 7. We conclude the report by Section 8.

2 Decision 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 selection and measuring the performance of suppliers has been the focus of many scientists and purchasing practitioners since the 1960's.

An interesting work, which is a reference for the majority of papers dealing with supplier or vendor selection problem, was presented by Dickson (Dickson, 1966). Dickson's study was based on a questionnaire sent to 273 purchasing agents and managers selected from the membership list of the National Association of Purchasing Managers. The list included purchasing agents and mangers from the United States and Canada. A total of 170 (62.3of Dickson's study regarding the importance of 23 criteria for supplier (vendor) selection. Indeed, the 23 criteria are ranked with respect to their importance observed in the beginning of the sixties. At that time (1966), the most significant criteria were the "quality" of the product, the "on-time delivery", the "performance history" of the supplier and the warranty policy used by the supplier.

Criteria used in Dickson's study

(1) The *net price* (including discounts and freight charges) offered by each supplier.

(2) The ability of each supplier to meet *quality* specifications consistently.

Table 1: Dickson's supplier or vendor selection criteria

Rank	Criteria	Main rating	Evaluation
1	Quality	3.508	Extreme importance
2	Delivery	3.147	
3	Performance history	2.998	
4	Warranties and claim policies	2.849	
5	Production facilities and capacity	2.775	Considerable importance
6	Price	2.758	
7	Technical capability	2.545	
8	Financial position	2.514	
9	Procedural compliance	2.488	
10	Communication system	2.426	
11	Reputation and position in industry	2.412	
12	Desire of business	2.256	
13	Management and organization	2.216	
14	Operating controls	2.211	
15	Repair service	2.187	Average importance
16	Attitude	2.120	
17	Impression	2.054	
18	Packaging ability	2.009	
19	Labor relations record	2.003	
20	Geographical location	1.872	
21	Amount of past business	1.597	
22	Training aids	1.537	
23	Reciprocal arrangements	0.610	Slight importance

(3) The *repair service* likely to be given by each supplier.

(4) The ability of each supplier to meet specified *delivery schedules*.

(5) The *geographical location*.

(6) The *financial position* and credit rating of each supplier.

(7) The *production facilities and capacity* of each supplier.

(8) The *amount of past business* that has been done with each supplier.

(9) The *technical capability* (including research and development facilities) of each supplier.

(10) The *management and organization* of each supplier.

(11) The *future purchases* each supplier will make from your company.

(12) The *communication system* (with information on progress data of orders) of each supplier.

(13) The *operational controls* (including reporting quality control, and inventory control systems) of each supplier.

(14) The *position in the industry* (including production leadership and reputation) of each supplier.

(15) The *labour relations record* of each supplier.

(16) The *attitude* of each supplier toward your organization.

(17) The *desire for your business* shown by each supplier.

(18) The *warranties and claims policies* of each supplier.

(19) The ability of each supplier to meet your *packaging* requirements for his product.

(20) The *impression* made by each supplier in personal contacts with you.

(21) The availability for training *aids* and educational courses in the use of the product of each supplier.

(22) Cmpliance or likelihood of *compliance with your procedures* (both bidding and operating) by each supplier.

(23) The *performance history* of each supplier.

In (Weber et al., 1991), the authors present a classification of all the articles published since 1966 according to the treated criteria. Based on 74 papers, they observe that "Price", "Delivery", "Quality" and "Production capacity and location" are the criteria most often treated in the literature.

Overall, the 23 criteria presented by Dickson still cover the majority of the criteria presented in the literature until today. On the other hand the evolution of the industrial environment modified the degrees of the relative importance of these criteria. For example, Weber (Weber et al., 1991) insists on the high importance of the geographical position of the supplier in Just-In-Time environment, whereas this criterion appeared in the 20th position in 1966. Also, the criterions in the 10th, 12th and 13th positions (communication system, desire of business, management and organization), of Dickson's study, are very important for the actual industrial environment. Indeed, the actual situation requires a perfect coordination and a durable co-operation between various actors of the supply chain.

More and more companies establish close connections with their suppliers. This leads to the concepts of partnership, privileged suppliers, long-term agreement, etc. (Dyer et Forman, 1992). The traditional management of customer-supplier (or customer-vendor) relationships, which encouraged competition between suppliers (or vendors), made place with new fashions of arrangement based on the co-operation between supplier and company starting from the design of the product. This mode of relation privileges selection criteria which are, more particularly, the capacity of co-operation, communication system, and control and coordination of flows rather than the traditional criterions which are cost, quality, etc. (Halley, 2000).

Related to supplier or vendor selection problem, the literature is very rich. We refer to the following works as an example to show the criteria treated in the literature of the nineties. Ellram (Ellram, 1990) proposes three principal criteria which are: 1) the financial statement of the supplier, 2) organisational culture and strategy of the supplier, and 3) the technological state of the supplier. For each one of these three criteria, the author presents several sub-criteria. Barbarosoglu and Yazgac (Barbarosoglu and Yazgac, 1997) distinguish three principal criteria: 1) the performance of the supplier, 2) technical capability and financial of the supplier, and 3) the quality system of the supplier. Like Ellram (Ellram, 1990), they propose some sub-criteria for each principal one.

As an example related to a practical study, we summarize, in this section, the most important criteria presented in Barbarosoglu and Yazgac (Barbarosoglu and Yazgac, 1997) paper. The purpose of the study is to design an AHP (Analytic Hierarchy Process) (which will be presented in the next section) model to solve the supplier selection problem in the Turkish industry. The general-purpose model was applied to the leading electro motor manufacture of Turkey.

The hierarchy developed in (Barbarosoglu and Yazgac, 1997) is a five-level, incomplete hierarchy in which the top level represents the main mission of the supplier selection and the last level consists of the alternative suppliers. The primary objectives affecting the supplier selection are grouped under three main categories: performance assessment, business structure/ manufacturing capability assessment, and quality system assessment. The evaluation criteria that influence each of the primary objectives are included at the second level. The sub-criteria which are related to the second level criteria are given in the third and fourth levels.

In this report we will summarize the different criteria presented by Barbarosoglu and Yazgac which are basically related to a practical case study.

1. **First level: Performance assessment**
   - (a) **Second level: Shipment quality**
     - i. Rejection in incoming quality control: the percentage of defective incoming material detected by the incoming quality control;
     - ii. Rejection in the production line: the percentage of defective incoming material not detected by the incoming quality control, but noticed during production;

iii. Rejection from final customer: the percentage of incoming material accepted by the incoming control and production line, but returned from the customer;
iv. Lot certification: the practice of using a reliable lot certification in all procurement transactions;
v. Sorting effort: the man-hours spent for sorting the defective material shipped to the company;
vi. Defective acceptance: the percentage of defective material which can be tolerated in the final product;

(b) **Second level: Delivery**

i. Compliance with quantity: the supplier's compliance with the predetermined order quantity within the tolerance limits;
ii. Compliance with due date: the supplier's compliance with the predetermined order due date within the tolerance limits;
iii. Compliance with packaging standards: the supplier's compliance with the packaging standards (dimension, labelling, etc.);

(c) **Second level: Cost analysis**

i. Compliance with cost analysis system: the consistency of the price increase request made by the supplier with the costing system agreed upon between the supplier and the company;
ii. Compliance with sartorial price behaviour: the consistency of the price increase request made by the supplier with the sectoral average;
iii. Cost reduction activities: the actual cost reduction achieved by the supplier as a result of corrective actions and technological investments and reflected upon its pricing policy;

2. **First level: Business structure/ manufacturing capability assessment**

(a) **Second level: Technical cooperation**

i. Response to quality problems: the supplier's ability to solve the quality problems detected by the company during audit, incoming quality control, production or new product development;
ii. Design capability: the supplier's capability to develop a new design;
iii. Level of cooperation and information exchange: the supplier's cooperation and information exchange with the company about technical processes like design, prototype building, die alterations and other phases from design to production;

(b) **Second level: Employee profile**

i. Organizational structure: the organizational structure of the supplier and the clarity of employee job definitions within this structure;
ii. Number of employees: the total number of employees;

   iii. Number of technical staff: the number of employees in technical departments (ie., purchasing, quality, production, laboratory);
   iv. Education: the availability of professional educational activities and scheduled yearly training program; the accurateness of personnel educational database, and the percentage of staff attending the training programs in the supplier manufactory;

   (c) **Second level: Financial status**
   i. Total revenue: the total revenue of the previous year;
   ii. Profitability: the total profit of the previous year;
   iii. Company share within the work volume: the share of the company within the total work volume of the supplier;

   (d) **Second level: Equipment**
   i. Production machinery: the number, model, capacity utilisation ratio and the energy requirement of the production, repair/maintenance, laboratory and die-shop machine groups;
   ii. Technological compatibility: the technological compatibility of the service, material or part provided to the company;
   iii. Computer hardware: the capability of the computer hardware and basic software packages available in the supplier manufactory;

   (e) **Second level: Manufacturing**
   i. Production planning system: the effectiveness of the production planning functionality and communication with the shop floor;
   ii. Lead time: the time taken from receipt of an order to delivery;
   iii. Maintenance activities: the extent of preventive maintenance and the conformance between the actual and planned activities;
   iv. Plant layout and material handling: the efficiency of the plant layout from the material handling point of view;
   v. Transportation, storage and packaging: the effectiveness of the transportation, storage and packaging functions;

3. **First level: Quality system assessment**

   (a) **Second level: Management commitment**
   i. Quality assurance system documents;
   ii. Role of the quality function in the supplier manufactory;
   iii. Internal audit;
   iv. Work force participation in quality improvement;

   (b) **Second level: Product development**
   i. Assessment of design development activities;

   ii. Design functionality and reliability experiments;
   iii. Quality techniques in design;

(c) **Second level: Process improvement**
   i. Process improvement activities;
   ii. Process and machine capability indices;
   iii. Quality techniques in process improvement;

(d) **Second level: Quality planning**
   i. Compliance with company specifications;
   ii. Prototype controls;
   iii. Traceability;
   iv. Assessment of quality improvement activities;
   v. Quality costs;
   vi. Quality database;

(e) **Second level: Quality assurance in supply**
   i. Purchasing procedures and supplier evaluation;
   ii. Quality certified shipment;
   iii. Approval of changes;
   iv. Incoming quality control procedures;

(f) **Second level: Quality assurance in production**
   i. Part/ Product definition and sorting;
   ii. Rework;
   iii. Process control and interference;
   iv. Statistical applications;
   v. Application of advanced quality techniques;
   vi. Corrective action response;

(g) **Second level: Inspection and experimentation**
   i. In-Process inspection and reliability tests;
   ii. Final inspection and reliability tests;
   iii. Product audits;
   iv. Measuring and testing equipment;
   v. Calibration activities;

(h) **Second level: Quality staff**
   i. Number of quality staff;
   ii. Education of quality staff;

3 Selection methods

We can classify the majority of the existing methods, to solve the supplier selection problem, in three principal categories. A method can of course be the combination of the elementary methods presented below.

3.1 Elimination method

For this method, on each level, we eliminate, from the suppliers list, suppliers that do not satisfy the selection rule. With a "conjunctive" rule (Crow et al, 1980), we eliminate the suppliers whose mark, with respect to a criterion, is lower than the minimal mark. Thus, we choose one of the suppliers satisfying the minimum level of all the criteria. In a "lexicographic" rule (Wright, 1975), on the first level, we select the most significant criterion and then we compare the suppliers with respect to this criterion. If a supplier satisfies this criterion much better than the other suppliers then it is chosen, if not we compare the suppliers with respect to the second criterion, and soon.

3.2 Optimisation methods

For the optimisation method, we optimise an objective function, which can consist of a single criterion or a set of criteria subject or not to a set of constraints. Below, we present the two situations. Indeed, we consider first the situation without constraints, after that we focus on the situation where we optimise subject to a set of constraints which must be respected.

3.2.1 Without constraints

In the situation with a single criterion, generally one retains the cost like the most important criterion. We compute all the direct costs, like the purchase price, the transport cost, etc., associated to each supplier and we choose the least expensive one (Timmerman, 1986). A considerable number of companies choose practically their suppliers starting from this method. The companies which choose a strategy of "domination by the costs" are susceptible to use this method. Moreover, Verma and Pullman (Verma and Pullman, 1998) show that, although the managers declare quality as the most significant criterion, in practice rather they often decide (which supplier to take) starting from the direct cost and quality of delivery given by each supplier.

In a multi-criteria situation, we appreciate each criterion by a weight. This weight shows the relative importance of the criterion. Then we choose the supplier who has the best mark compared to the whole of the weighted criteria.

With "identical weights" (situation where all the weights are identical), we associate good (+), neutral (0) or unsatisfactory (-) to each supplier with respect to each criterion. From this comparison a total mark is calculated for each supplier (to illustrate this method see

Section 7).

With different weights, the AHP (Analytical Hierarchic Process) approach can be used. With this approach (Saaty, 1980), we determine the weight of each criterion by a binary comparison method. The mark of each supplier is calculated by comparing the suppliers with respect to each criterion. For example, in (Hoshyar and Lyth, 1992) the authors distinguish three types of criteria: critical criteria (they are essential for a supplier selection), objective criteria (monetary) and subjective criteria (qualitative). For the subjective criteria, they propose the AHP approach. Linked to the importance of this method, we propose, in details, its description.

AHP approach

The AHP (Analytical Hierarchic Process) is a decision-making method for prioritising alternatives when multiples criteria and sub-criteria must be used. 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. Generally, the hierarchy has at least three levels: the goal, the criteria, and the alternatives. For the supplier selection problem, the goal is to select the best overall supplier. Examples of criterion that might be used are quality, price, service and delivery. The alternatives are the different proposals supplied by the suppliers.

The AHP offers a methodology to rank 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 raison, AHP is ideally suited for the supplier selection problem.

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. Indeed, in most of the cases, the criteria are basically divided into sub-criteria as showing in the example of this subsection.

Managerial judgments are used to drive the AHP approach. These judgements 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.

There are many scales that could be used for quantifying managerial judgments, the scale given in table 2 is the standard usage of AHP analysis. 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).

Table 2: Measurement scales

Verbal judgment or preference	Numerical rating
Extremely preferred	9
Very strongly preferred	7
Strongly preferred	5
Moderately preferred	3
Equally preferred	1
Intermediate values between two adjacent judgments (when compromise is needed)	2, 4, 6, and 8

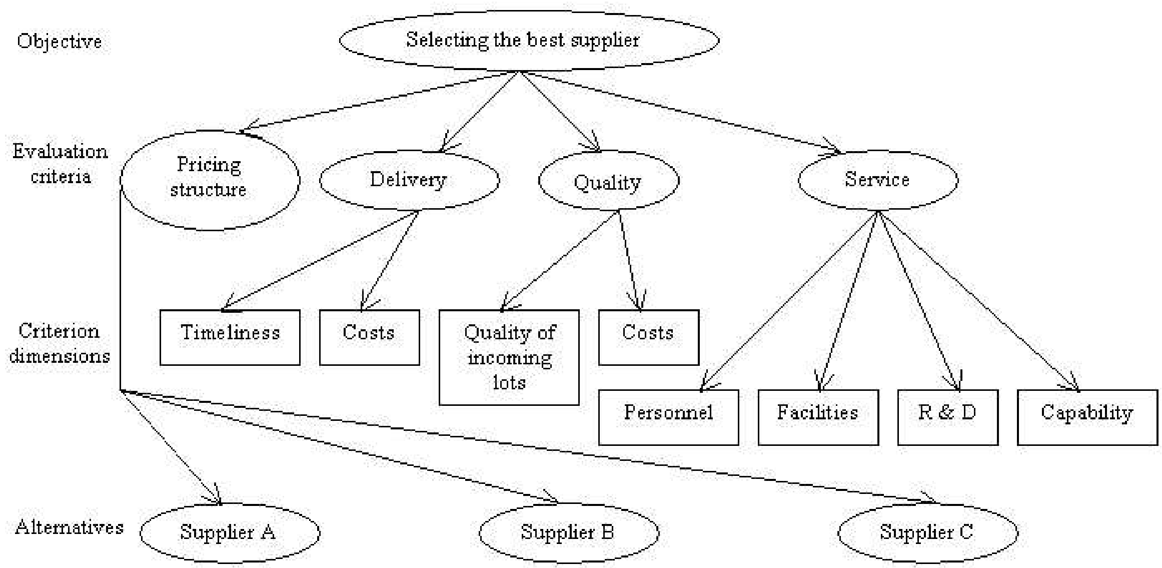
Remark 1 *Reciprocal, if activity (item) i has a specific numerical rating with respect to activity j, then J has the reciprocal value when compared to I.*

The pairwise comparison information for each component of the problem is represented by a pairwise 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. There are two reasons for this apparent savings in the required number of judgements. First, sine any alternative is equally preferred to itself, 1's are placed along the diagonal for the matrix. Second, the corresponding positions below the diagonals are the reciprocals of the judgements already entered. For example, assuming that the pairwise comparison of quality to delivery is 3, or equivalently a 3 to 1 ratio, it follows that the pairwise comparison of delivery to quality is a 1 to 3 ratio, or 1/3.

Important: One important advantage of using AHP is that it can measure the degree to which manager's judgements are consistent. In the real world, some *inconsistency* is acceptable, and even natural. For example, in a sporting contest, if team A usually beats team B, and if team B usually beats team C, this does *not imply* that team A usually beats team C. This slight inconsistency may result because of the way the teams match up overall. The point is to make sure that inconsistency remains within some reasonable limits. If it exceeds a specific limit, some revision of judgments may be required. AHP provides a method to compute the consistency of the pairwise comparisons (Nydick and Hill 1992).

Figure 1 shows an illustrative 3-level hierarchy for the supplier selection problem. In this figure, pricing structure, delivery, quality, and service make up the elements in the first level of the hierarchy. The second level represents these primary elements in terms of their dimensions. For example, the delivery criterion is dependent upon the dimensions of timeliness and delivery costs. Similarly, quality is linked to costs and quality of incoming lots, and service is linked to its dimensions, personnel, facilities, research and development, and service capability. The last level of the hierarchy represents the alternatives: suppliers A, B, C and D. Construction of the hierarchy is the first step in the problem solving process of the AHP method.

Figure 1: An illustrative decision hierarchy for supplier selection



Each one of the sub-criterion, Timeliness, Costs, Quality Incoming Lots, Costs, Personnel, Facilities, R-D and Capability, is related to Supplier A, Supplier B and Supplier C.

Remark 2 *The geometric mean of n numbers, say,* X_1, X_2, ..., X_n *is given by :*

$$\sqrt[n]{X_1 \times X_2 \times \ldots \times X_n}$$

The pairwise comparisons for the above supplier selection problem are shown below :

Figure 2: Pairwise comparisons of evaluation criteria (Highest level elements in the hierarchy)

Selecting the best supplier

	Pricing structure	Delivery	Quality	Service	Weights
Pricing structure	1	3	1	3	0.40
Delivery	1/3	1	1/3	1	0.13
Quality	1	3	1	1/2	0.26
Service	1/3	1	2	1	0.21

Figure 3: Computation of normalized weights

	Geometric mean		Weights
Pricing structure	$(1 \times 3 \times 1 \times 3)^{1/4}$	$= 1.73205$	0.40
Delivery	$(1/3 \times 1 \times 1/3 \times 1)^{1/4}$	$= 0.57735$	0.13
Quality	$(1 \times 3 \times 1 \times 1/2)^{1/4}$	$= 1.10668$	0.26
Service	$(1/3 \times 1 \times 2 \times 1)^{1/4}$	$= 0.90360$	0.21
		4.31968	

Once the normalized are computed (see figure 3) for all levels of the hierarchy, they are combined by moving through the hierarchy, starting at le lowest level. The figure below (figure 6) illustrates this procedure. For example, after one level of composition the average ratings of suppliers A, B, and C with respect to delivery are :

$$\begin{pmatrix} 0.586 \\ 0.240 \\ 0.174 \end{pmatrix} = \begin{pmatrix} 0.659 \\ 0.156 \\ 0.185 \end{pmatrix} \times 0.83 + \begin{pmatrix} 0.230 \\ 0.650 \\ 0.120 \end{pmatrix} \times 0.17$$

Figure 4: Pairwise comparisons of criterion dimensions (Second level elements in the hierarchy)

Delivery

	Timeliness	Cost	Weights
Timeliness	1	5	0.83
Cost	1/5	1	0.17

Quality

	Quality level	Cost	Weights
Quality level	1	1/5	0.17
Cost	5	1	0.83

Service

	Personnel	Facilities	R & D	Capability	Weights
Personnel	1	1	1	3	0.321
Facilities	1	1	2	1/2	0.244
R & D	1	1/2	1	1/2	0.173
Capability	1/3	2	2	1	0.262

Following this procedure, the overall weights for suppliers A, B, and C are calculated to be 0.26, 0.25, and 0.49 respectively. This indicates that suppliers A and B are about the same and that supplier C is the overwhelming choice. For more details (see Narasimhan 1983).

$$\begin{pmatrix} 0.260 \\ 0.250 \\ 0.490 \end{pmatrix} = \begin{pmatrix} 0.157 \\ 0.185 \\ 0.685 \end{pmatrix} \times 0.40 + \begin{pmatrix} 0.586 \\ 0.240 \\ 0.174 \end{pmatrix} \times 0.13 + \begin{pmatrix} 0.230 \\ 0.259 \\ 0.507 \end{pmatrix} \times 0.26 + \begin{pmatrix} 0.280 \\ 0.400 \\ 0.320 \end{pmatrix} \times 0.21$$

Figure 5: Pairwise comparisons of suppliers A, B, and C (Elements of the lowest level in the hierarchy with respect to criterion dimensions)

Price structure

Supplier	A	B	C	Weights
A	1	1	1/5	0.157
B	1	1	1/3	0.185
C	5	3	1	0.658

Timeliness

Supplier	A	B	C	Weights
A	1	5	3	0.658
B	1/5	1	1	0.156
C	1/3	1	1	0.185

Delivery cost

Supplier	A	B	C	Weights
A	1	1/3	2	0.23
B	3	1	5	0.65
C	1/2	1/5	1	0.12

Quality level

Supplier	A	B	C	Weights
A	1	1/2	1/3	0.16
B	2	1	1/2	0.30
C	3	2	1	0.54

Quality cost

Supplier	A	B	C	Weights
A	1	1	1/2	0.25
B	1	1	1/2	0.25
C	2	2	1	0.50

Personnel

Supplier	A	B	C	Weights
A	1	1/5	2	0.20
B	5	1	3	0.65
C	1/2	1/3	1	0.15

Facilities

Supplier	A	B	C	Weights
A	1	1	1	0.333
B	1	1	1	0.333
C	1	1	1	0.333

R & D

Supplier	A	B	C	Weights
A	1	1/3	1/3	0.14
B	3	1	1	0.43
C	3	1	1	0.43

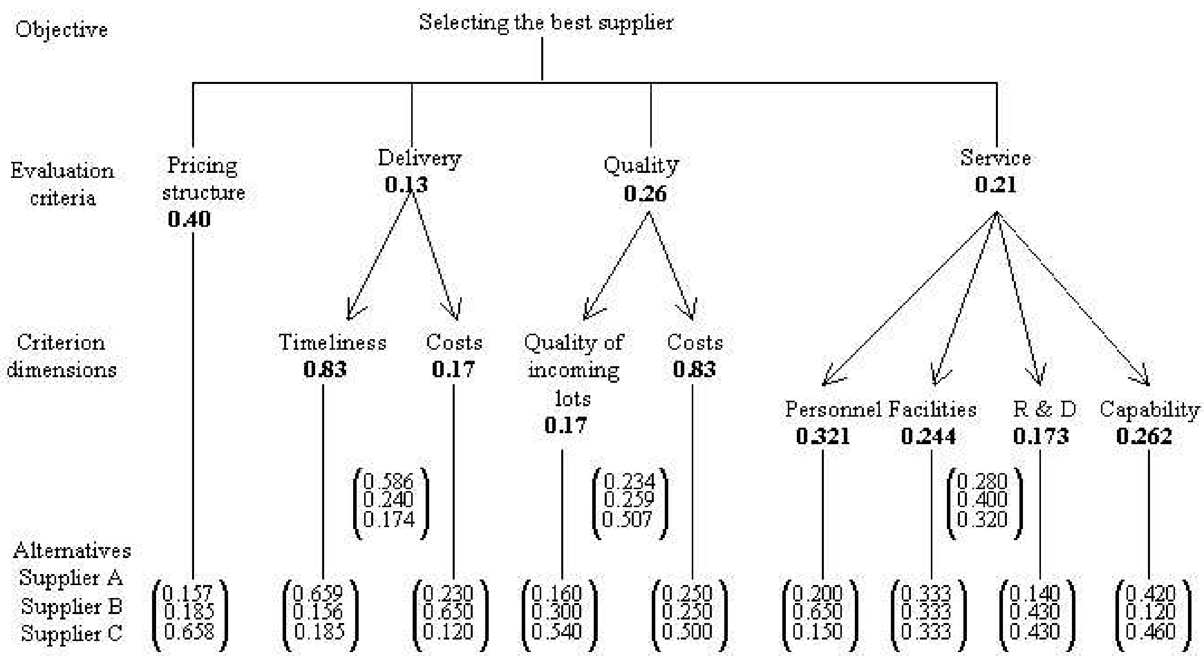
Capability

Supplier	A	B	C	Weights
A	1	3	1	0.42
B	1/3	1	1/4	0.12
C	1	4	1	0.46

3.2.2 Subject to a set of constraints

The purpose of these methods are to select one or more suppliers who maximize an objective function (decision criteria) subject to a set of constraints related basically to the suppliers

Figure 6: Hierarchy composition of weights for the supplier selection decision



and/or the customers (companies). The objective function can be with a single criterion (Moore, 1973) (often met in mathematical optimisation models) or multi-criteria ("Goal Programming" or "Multi Objective Programming"). Weber (Weber, 1991) in its state of the art, counts ten articles which used mathematical optimisation with constraints for supplier selection problem. Ghodsypour and O'Brien (Ghodsypour and O'Brien, 1998) present seven other articles published during the period between 1991-1998. The methods used are: "linear programming", "mixed integer programming", "multi-objective programming", "no-linear programming".

The objectives presented in these models are: the minimization of the total cost, the minimization of the number of components which not respect the customer conformity (quality), the minimization of the number components delivered to late or delivered in advance, the minimization of the distance (or time) between the supplier and the customer (Weber et al., 1993), etc.

The constraints of these methods are: production capacity of the supplier, the satisfaction of the request or the demand, the minimum order quantity, the total budget of purchasing, the minimum or maximum number of suppliers, the geographical preference (Weber et al, 1993) etc. For example, Ghodsypour and O'Brien (Ghodsypour and O'Brien 1998) use "the linear programming" to determine the optimal order quantity of each supplier. The constraints of the mathematical model are: the supplier capacity, the demand which must be satisfied and the tolerated number of components which does not respect the conformity (quality). The objective of the model is to maximize the total utility of the selected suppliers, where the utility (of each supplier) is the final mark of the supplier calculated by the AHP method.

3.3 Probabilistic method

The supplier selection decision can often be handled in a relatively routine fashion, either because there is little probability of the customer's making an error, or because an error would not seriously impact the performance. Under certain conditions, however, there is a relatively high probability that an inappropriate supplier will be selected and that such an error will adversely affect the customer.

When the assumptions on which purchase order requirements are based prove faulty, it may be necessary to change quantities, delivery rates, design specifications, or other important terms of the contract. Even though the selected supplier was best able to meet the terms of the original purchase order, it may not be the best choice for the modified contract.

According to the method called "Payoff Matrix" (Soukup, 1987), we define several scenarios of the future behaviour of the suppliers. For each scenario, we associate a mark to the suppliers with respect to the criteria. Then we compute the total mark of each supplier and we choose for example the supplier who has a stable mark according to various scenarios.

Soukup (Soukup, 1987) suggests, three categories of supplier selection decisions:

1. The suppliers under considerations are similar under all foreseeable circumstances: only minor differences in performance can be expected. This decision should be handled routinely.
2. The potential suppliers differ significantly: one supplier is superior under all foreseeable conditions. This decision should be handled routinely.
3. The candidate suppliers differ significantly under at least some future conditions that may be expected: the best supplier under some circumstances will not be the best under other circumstances. This decision category presents the customer with a moderate to high probability of making an error in the selection of a supplier, coupled with the possibility of serious consequences of such an error. This supplier selection situation warrants considerable effort and care.

In table 3, we summarize the conditions under which suppliers must be selected.

Table 3: Classification of supplier selection decisions (Soukup, 1987)

Condition Condition	Probability of error	Consequences of error	Decision mode
Suppliers are similar under all conditions	High	Very small	Routine
Suppliers differ significantly One supplier superior under all conditions	Low	High	Routine
Suppliers differ significantly Best supplier depends on future conditions	High	Unknown : may be very high	Complex : requires thorough analysis

4 Characteristics of the supplier selection problem

In the this section, we summarize the various characteristics of the supplier selection problem. A global solution must be able to consider these characteristics. Let us note that the majority of these characteristics are of a comparable nature that the characteristics of the problem "make or ask to make" the component or the part, in particular the strategic and the multi-criteria aspects of this problem.

4.1 Strategic decision

Selecting the most appropriate suppliers has long been regarded as one of the purchasing department's most important functions. In one of the very early purchasing texts, Howard (Howard, 1943) stated, "It is probable that of all the responsibilities which may properly be said to belong to the purchasing officers, there is none more important than the selection of suppliers. Indeed, it is in some respects the most important single factor in purchasing". Later, England and Leenders (England and Leenders, 1975), said that "supplier selection is purchasing most important responsibility". Much more recently, Doble, Lee and Burt (Doble et al. 1984) make the same point with these words: "Selecting capable suppliers is one of a purchasing manager's most important responsibilities".

Both the difficulty and the importance of supplier selection are being exacerbated by recent business trends. These developments include the increase in value of purchased components as a percentage of the total revenue for manufacturing firms, an expansion of foreign sourcing (suppliers), and the increased rate of technological change, accompanied by shorted product life cycles. Hence, without any doubt, the decisions related to the supplier selection problem determine the long-term viability of the firm or the company (Thompson, 1990).

These decisions influence the coordination of various services of the company first, and its competitive position in the market second. Consequently, this decision (supplier selection) must be in conformity with the strategy that the company decided to achieve its goals. Section 5 deals about the different methods to take into account in order to have a coherence between the strategy goals and the suppliers selection function of the company.

4.2 Multi-actors

The supplier selection decision requires the intervention of the various services of the company (Dyer and Forman 1992) and (Mobolurin, 1995). Indeed, this (these) decision (s) will be reflected on several services of the company, like production, transport, storage, purchase, etc. Moreover, the majority of the decision criteria are subjective, this is why it must be decided under the consensus of a group of decision makers with various points of view. 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 for the other services of the company. A discussion enables them to better know the interests of the various services of the company.

4.3 Multi-criteria

Normally, the decision on the suppliers selection requires to consider several criteria. These criteria are often contradictory (for example the quality of the component or (product) and the cost of the component). Consequently, we decide to select the supplier who establishes a better compromise between the criteria.

4.4 Subjective criteria

In practice, a significant number of decision criteria is subjective. The subjective criteria are criteria which we cannot represent in a quantitative way. For example, the decision "Desire of business", expressed by a supplier, is a subjective criterion.

In addition to the subjective criteria, the objective criteria are to be considered. An objective criterion is a criterion which we can measure by a concrete quantitative dimension (like cost). We give attention here to the question (How to find a quantitative dimension?). Indeed, it is not always easy to get it directly. For example the criterion "price of the product", is "easy" to measure, it can be obtained directly. The quality of products and services are "difficult" criterion, because we cannot measure them directly. We should take into account the cost of rejection of the product, the cost of the services after sale, etc.

4.5 Other characteristics

Other characteristics must be taken into account by the decision makers in order to reach an efficient suppliers selection which guaranty the long-term viability of the company.

Most of the time, the supplier selection problem deals with more than one supplier, called multi-supplier choice or situation. Indeed when, for example, the best supplier cannot satisfy all the customer demand or order (capacity limitation constraint), the customer must satisfy its demand with several suppliers. In a multi-supplier case, we are interesting 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 needs more flexibility from the company, it is very interesting when one of the suppliers, for any reason, can not satisfy the assigned demand (strike, weather conditions, war, ...).

Moreover, comparing to the criteria, the parameters of the problem or the behaviours of the suppliers can be stochastic or determinists. Also, in this problem we can have various constraints concerning the customers or the suppliers, or both, such as: limited capacity of the supplier, minimum and maximum order quantity, quality, delivery time, etc.

5 Concept of "Strategic supplier"

Before the presentation of the concept of "strategic supplier", we briefly recall the concept of the strategy of the company.

The strategy of the company chooses the spheres of activities in which she intends to be present and allocates the necessary resources, in order to guaranty its long-term viability and development (Strategor, 1993). This definition identifies two levels of strategy: 1) strategy of group called cooperate strategy, which determine the spheres of activities of the company, 2) business strategy which must be put into each one of these spheres. The business strategy defines the operations that the company must achieve in order to favorably get a good position compared to its competitors in a given sector (Strategor, 1993). Michael Porter (Porter 1980) identified three basic business strategies of each company 1) domination by the costs, 2) differentiation, 3) concentration.

The fact that the business strategy of the company is the manner by which she plans to carry on its competitors, the selected suppliers must be perfectly able to satisfy this strategy from the concept of "strategic supplier". Normally the company must select its suppliers among the strategic suppliers. For example a company having a *strategy of differentiation by the "delivery time"* and which is in a market with a personalized and not very foreseeable demand must choose obviously a supplier who can deliver the components (products) within a minimum time. For this reason, the supplier must have, for example, an electronic data interchange (EDI) system adapted to the company system. Consequently, they can exchange information and orders as quickly as possible with "reactive" productions systems (both supplier and company productions systems). On the other hand if the *strategy of the company is the domination by the cost* it must seek its strategic suppliers in another category of suppliers who offer less expensive products and not inevitably with an excellent quality or a short delivery time.

To resume, the fact of choosing a supplier who offers various advantages but which cannot reinforce the strategy of the company is not advised.

6 To a global approach

In table 4, we summarize the different advantages and disadvantages of the current selection methods. Where table 5 describes the applicability of each existing method with respect to the various situations of the problem. A synthesis of the literature shows us the following points:

The strategic nature of the supplier selection decision determines the long-term viability of the company. However the majority of the existing models are based on functional criteria like quality, price, delivery time, etc.., and does not take into account the repercussions of the company strategy on this decision.

The multi-criteria aspect of the supplier selection problem is an essential aspect when we deal with a global approach. The majority of the existing models can treat this significant aspect of the problem.

The supplier selection problem is a decision or a set of decisions which requires the intervention of different services (departments) of the company (Dyer and Forman 1992). That privileges methods which cover the multi-decision-maker aspect. The AHP (Version "Group decision making") method can take into account this aspect of the problem. Indeed, Saaty (Saaty 1982, 1989) has described group decision making with AHP, including suggestions for assembling the group, running the decision-making session, trying to get the group to agree, inequalities of power, concealed or distorted preferences, and implementing the results. Although the preferred size and composition of the group is very much context dependent. Mitchell and Wasil (Mitchell and Wasil 1989) observed that in applications, smaller decision groups were more efficient but that larger groups are often required for effective decision making so that stakeholders are represented and the final decision accepted, and implementation is facilitated.

In practice, if a supplier can not satisfy a minimal threshold compared to certain criterion, it cannot be selected in spite of its possible effectiveness with respect to other criteria. The elimination method is the only method in the literature which takes into account this aspect of the problem. But this method does not plan to choose the most powerful among qualified suppliers (Mobolurin, 1995 and Thompson, 1990). Indeed, with this method we are not interested by the total performance of the suppliers with respect to all the criteria. A method which can take into account the conjunctive rules (minimal threshold) and choose the most powerful suppliers (by considering all the criteria) is a lack in the literature.

We have *various constraints* to take into account, in order to solve the supplier selection problem. These constraints are of different nature. It can be the constraints evoked by the suppliers (for example: minimal order quantity or maximum production capacity, ...) or the constraints of the customer (budget devoted to the purchasing activity, maximum rate of not qualified products, etc). In addition, if the company would wish several suppliers, it must choose at the same time which suppliers and which quantity to be ordered from each one. Consequently, a mathematical optimisation method is the only method which can take these aspects of the problem. Unfortunately, this method cannot consider the *subjective criteria*.

In reality, the future behaviours of the suppliers and the environment are uncertain. Consequently, it is difficult to assign a fixed mark to the suppliers with respect to a criterion. However, it is more practical to affect a fork of mark or a random variable which describes the probabilistic behaviour of the supplier. The scenario method treats this type of problems. On the other hand, this method does not have the advantages of the mathematical optimisation methods, which are essential for an "optimal" selection.

The previous synthesis shows us that the current methods cannot cover the various aspects of the supplier selection problem. Our objective is to build a method which can take into account all the characteristics of the problem: the strategy of the company, the multi-actors aspect, the subjective and objective criteria, the constraints of both suppliers and customer (company), the multi-suppliers aspect, the probabilistic aspect (supplier behaviours and the economic environment,...). We will see later (section 7) how a mathematical approach can cover these various aspects of the problem.

Remark 3 *The suggested mathematical approach is not an "automatic" approach and it will be necessary of course to consider the conditions and the specific context of the company when a decision-making process is applied.*

With this approach the decisions are made in two stages. In the first stage we select the strategic suppliers, and this starting from the global strategy of the company. Other parameters, to be considered in this first level, are the minimum thresholds of the criteria. These are the minimum thresholds that the suppliers must be able to respect. If these thresholds are not respected, it can cause intolerable consequences on: the quality of service or other constraints or objectives of the company. The selected suppliers, in this first stage, can reinforce the strategy of the company on one hand and on the other hand, they can respect the minimum thresholds of various selection criteria fixed by the company.

Table 4: Advantages and disadvantages of the different selection methods

Methods			**Advantages**	**Disadvantages**
Elimination			1- Fast 2- Simple to use 3- Take into account the subjective criteria	1- The final choice is not made starting from the total performance on all the criteria 2- No possibility to introduce constraints in the model
Optimisation	Without Constraints	Multi Criteria	1- Simple to use 2- Take into account all the types of criteria (subjective and objective)	1- Depends on the human judgement 2- No possibility to introduce constraints in the model
		Oriented cost	Objective method	Does not take into account the subjective criteria
	Subject to Constraints	Mono objective	1- Proposes an optimal solution 2- Possibility to introduce several types of constraints	1- Does not take into account the subjective criteria 2- Not clear for the manager
		Multi objective	1- More than one optimal solution 2- Possibility to introduce several types of constraints	1- With difficulty take into account the subjective criteria 2- Not clear for the manager
Probabilistic			Analyse the uncertain behaviour of suppliers	1- No optimal solution 2- Not easy to analyse 3- No possibility to introduce constraints in the model

Table 5: Schema of relations between problems and methods in supplier selection problem

Problems	Methods					
			Optimisation			
	Elim	AHP	Oriented cost	Mono objective	Multi objective	Prob
Single criterion				X		
Multi-criteria	X	X	X		X	X
Single-actor	X	X	X	X	X	X
Multi-actors		X				
Selection of suppliers	X			X	X	
Suppliers ordering		X	X			
Without constraints	X	X	X			X
Subject to constraints				X	X	
Objective criteria	X	X	X	X	X	X
Subjective criteria	X	X				X
Certain	X	X	X	X	X	
Uncertain						X

A sensitivity analysis of these minimum thresholds can help the decision group to choose a suitable threshold for each criterion. In this case, the thresholds are to be considered in the second stage of this approach. From the mathematical model developed in the second stage we can do this kind of analysis.

In the second stage of this approach, the objective is to select the best supplier and the quantity required from each one, denoted by q_j, taking into account both the suppliers and the company constraints. The purpose of this model is to maximize a function U which represents the total marks of the suppliers. For each supplier, the total mark can be given by the AHP approach for both objective and subjective criteria. Indeed, for each supplier and for each criterion, we can get the mark, and then obtain the corresponding total mark by adding all the marks (for both subjective and objective criteria) (see Table 8). As we already showed, this decision requires the intervention of various actors, thus we propose to use "grouped AHP" (Golden et al, 1989) to determine the marks of the decision criteria. The grouped AHP is a method based on the traditional AHP but which allows the intervention of various decision makers.

In reality, basically related to the market, the behaviour of a supplier with respect to the decision criteria is probabilistic (Soukup, 1987). Thus, it is difficult to assign a fixed mark to the suppliers with respect to the criteria. To treat that, one approach is to estimate the behaviour of the suppliers with three scenarios: "optimistic", "pessimistic" and "most probable". We will present in the section 8 a numerical example to illustrate this approach.

We present a simple mathematical formulation related to the supplier selection problem. The model is multi-period mixed integer programming, where the period t can be a month, or less or more than one month and T the total horizon length. We assume that we have a potential set of candidates suppliers, for only one type of product. More general and complete model can be obtained.

The mathematical formulation approach

1. **Parameters**
   - n: number of suppliers to select (we should select exactly n suppliers over a set of suppliers);
   - d_t: the demand of period t;
   - D: the total demand ($\sum_t d_t$);
   - u_{jc}: mark of supplier j associated to the criterion c;
   - u_j: the total mark of supplier j, given by: $u_j = \sum_c$ *(weight of criterion c)*$\times u_{jc}$;
   - $C_{jmin}(t)$: the minimum order quantity of period t for the supplier j;
   - $C_{jmax}(t)$: the maximum order quantity of period t for the supplier j;
   - $\alpha_j(\%)$: the average percentage of products (components) delivered to late by supplier j (starting from the last performance of the supplier);
   - $\beta_j(\%)$: the average percentage of products (components) delivered by supplier j which not respect the customer conformity (starting from the last performance of the supplier);
   - $\gamma_j(t)$: unit purchasing cost from supplier j in period t (this cost includes: price, transportation, assurances,...);
   - S_c: the minimum threshold associated to the criterion c (for each selected supplier j and each criterion c, its associate mark u_{jc} must be $\geq Sc$);
   - L: the maximum tolerated rate (%) of products delivered to late from the total demand;
   - Q: the maximum tolerated rate (%) of products delivered without respecting conformity from the total demand;
   - C: the total tolerated cost in order to satisfy the total demand;
2. **Decision variables**
   - $q_j(t)$: order quantity of period t assigned to supplier j;
   - x_j: binary variable, with 1 indicates that supplier j is selected, and 0 otherwise;

$$max(U) = \sum_t \sum_j u_j \times q_j(t)$$

$$\begin{array}{lll}
\sum_j q_j(t) = d_t & \forall t & (1) \\
x_j C_{jmin}(t) \leq q_j(t) \leq x_j C_{jmax}(t) & \forall t, \forall j & (2) \\
\sum_t \sum_j \alpha_j q_j(t) \leq L \times D & & (3) \\
\sum_t \sum_j \beta_j q_j(t) \leq Q \times D & & (4) \\
\sum_t \sum_j \gamma_j q_j(t) \leq C & & (5) \\
\sum_j x_j = n & & (6) \\
S_c x_j \leq u_{jc} & \forall j, \forall c & (7) \\
q_j(t) \geq 0 \text{ and } x_j \in \{0, 1\} & \forall j, \forall t & (8)
\end{array}$$

For this linear integer programming model, the objective is to privilege the suppliers having the best marks. The mark u_j of each supplier can be made up starting from objective and subjective criteria. Hence, this significant aspect was taken into account. Constraint 1 ensures that, for each period t, the request d_t is satisfied. Constraint 2 makes it possible to satisfy, for each period t and each supplier j, the maximum capacity $C_{jmax}(t)$ and the minimum order quantity $C_{jmin}(t)$. Constraint 3 shows that the totality of the late parts of the suppliers should not exceed a maximum threshold. Constraints 4 and 5 represent respectively the maximum thresholds for the parts not respecting conformity limitation (ie. number of parts lost from the total demand) and the maximum total cost (price + transport + assurances,...) that the company can tolerate to pay its parts. Constraint 6 indicates the predetermined number of the suppliers. Constraint 7 introduces the conjunctive rules into the model. These rules are used in conjunctive elimination methods. They represent the minimal thresholds that the selected suppliers must be able to respect, for each criterion. It is very important to point out that in a global approach, we should consider these thresholds at the first stage. Nevertheless by putting these optional constraints in the model, the decision makers can measure the influence of the minimal thresholds on the objective function. This sensitivity analysis enables them to choose logical minimal thresholds for the model. Constraint 8 represents the nature of the decision variables.

7 Numerical example

To illustrate the different approaches used to solve the supplier selection problem, we present, in this section, a numerical example.

To simplify the analysis, we focus on the case where only one observation period is taken (ex. one year) and the selection is over a set of potential suppliers (suppliers which respect the minimum threshold of each criterion).

The one period mathematical model

$$max(U) = \sum_j u_j \times q_j$$

$$\begin{array}{lrr}
\sum_j q_j = D & & (1) \\
x_j C_{jmin} \leq q_j \leq x_j C_{jmax} & \forall j & (2) \\
\sum_j \alpha_j q_j \leq L \times D & & (3) \\
\sum_j \beta_j q_j \leq Q \times D & & (4) \\
\sum_j \gamma_j q_j \leq C & & (5) \\
\sum_j x_j = n & & (6) \\
q_j \geq 0 \text{ (integer) and } x_j \in \{0, 1\} & \forall j & (7)
\end{array}$$

A company needs to select, over a set of potential suppliers, a fixed number of them in order to satisfy its demand (the demand is only for one period and one product type). At the first step, the company finds 10 strategic suppliers These 10 suppliers respect the minimum thresholds fixed for each decision criterion (S_c). The company wishes to choose 4 suppliers (n= 4) among the 10 suppliers. The most significant criteria of the company for this selection are: 1) Delivery (delivery in time), 2) Quality, 3) Price, and 4) Service after sale. The demand request of the company is 10000 units. The minimum and maximum capacities (units/period) of these suppliers are given in table 6.

Table 6: Suppliers minimum and maximum capacities

Supplier	Minimum capacity (unit/period)	Maximum capacity (unit/period)
Supplier 1	180	5000
Supplier 2	150	8000
Supplier 3	200	7000
Supplier 4	220	6000
Supplier 5	140	6000
Supplier 6	160	7000
Supplier 7	190	5000
Supplier 8	210	8000
Supplier 9	170	6500
Supplier 10	200	7500

The parameters α_j (%) (the average percentage of products delivered to late by supplier j (starting from the last performance of the supplier)), β_j (%) (the average percentage of products delivered by supplier j which does not respect the customer conformity (starting from the last performance of the supplier)) and γ_j (unit purchasing cost from supplier j (this cost includes: price, transportation, assurances,...)) are given in table 7 below.

Table 7: The associated α_j, β_j and γ_j

Supplier	α_j(%)	β_j(%)	γ_j(euros)
Supplier 1	1	2.6	1
Supplier 2	2	2.1	1.1
Supplier 3	1.5	2.2	1.2
Supplier 4	1	3	0.9
Supplier 5	2.5	1.9	1.4
Supplier 6	1.3	1.5	1.3
Supplier 7	1.9	2.3	0.8
Supplier 8	1.6	2.1	1.5
Supplier 9	1.4	3.3	0.8
Supplier 10	2.1	2.8	1.1

The values of L (the maximum tolerated rate (%) of products delivered (by the suppliers) to late from the total demand), Q (the maximum tolerated rate (%) of products delivered without respecting conformity from the total demand) and C (the total tolerated cost in order to satisfy the total demand) are respectively 1.2%, 3% and 10000 euros.

The costs of a delayed unit and a unit which does not respect the company conformity are respectively 0.35 euro and 0.2 euro (these two information are used later for a comparison).

The behaviours of the suppliers are probabilistic and the company don't have more information to describe these behaviours. However it has information on the three situations : Optimist (O), Pessimist (P) and More Probably (MP) of each supplier for each criterion. Indeed, the company knows the probability of each situation (ex: 16.66% (1/6) for Optimist, 16.66% (1/6) for Pessimist and 66.68% (2/3) for More Probably). In absence of other information, the company decides to use a vote (decision makers group have to give a mark for each criterion, for each supplier in each one of the three situations). Hence, we will be able to associate a mark to each supplier starting from the average and the variance. However in this example for reason of simplification we determine the mark of each supplier starting from the average.

To illustrate the computational method of these values, let us consider for example a group of 10 decision makers who want to determine the mark of supplier 1 with respect to the criterion "Delivery". Each decision maker have to give a vote yes (1) or no (0). He can consider or not this supplier under the corresponding situation. The votes were : for supplier 1, criterion "Delivery", the Pessimist situation 5 (1) and 5 (0), the More Probably situation 7 (1) and 3 (0) and Optimist situation 10 (1) and 0 (0). The average vote can be computed by $5 \times 0.1666 + 7 \times 0.1666 + 10 \times 0.6668 = 7.16$. Consequently, the average mark of each supplier with respect to the criteria are presented in table 8 below.

According to the direction of this company the relative importance of the four criteria "Delivery", "Quality", "Price" and "Service after sale" are respectively 40%, 30%, 20% and 10%. These values can be obtained by an AHP analysis. After that we can calculate the relative marks u of the suppliers). For example the total mark of supplier1 is of $u_1 = 7.2 \times 0.4 + 6.5 \times 0.3 + 7.2 \times 0.2 + 6.2 \times 0.1 = 6.9$.

Table 8: The relative marks of each supplier according to the four criteria

Supplier	Delivery	Quality	Price	Service after sale	Total mark
Supplier 1	7.2	6.5	7.2	6.2	6.9
Supplier 2	6.5	7.3	6.3	8.2	6.9
Supplier 3	6.3	8.2	5.5	4.8	6.6
Supplier 4	8.8	7.8	7.8	5.7	8.0
Supplier 5	6.3	6.3	5.7	4.7	6.0
Supplier 6	5.3	8.2	5.7	5.7	6.3
Supplier 7	6.5	5.5	7.8	7.3	6.6
Supplier 8	7.3	8.2	4.8	7.3	7.1
Supplier 9	9.0	7.2	7.7	4.8	7.8
Supplier 10	6.3	7.3	6.3	6.5	6.7

We will treat this example with both existing methods and mathematical formulation approach.

Optimisation without constraints - oriented cost

In this case, we compute all the costs associated to each supplier and we choose the least expensive one. We know that the costs related to one unit delivered to late (by suppliers) and one unit which not respect the conformity are respectively 1 and 0.5 euro. Using the data of table 7, we can compute the direct cost of one unit purchased from each supplier. As an example, for supplier 1, this cost is equal to : $0.01 \times 0.35 + 0.026 \times 0.20 + 1 = 1.009$ euros.

Table 9: The suppliers costs

Supplier	Unit cost (euro)
Supplier 1	1.009
Supplier 2	1.111
Supplier 3	1.210
Supplier 4	0.910
Supplier 5	1.413
Supplier 6	1.308
Supplier 7	0.811
Supplier 8	1.510
Supplier 9	0.812
Supplier 10	1.113

We can see, starting from the above table (table 9), that the costs of "Delivery to late" and "product conformity not respecting" are very weak (in this example), compared to the purchase price of product. Hence, these costs do not have a considerable effect on the total cost of the purchased product.

The four selected suppliers are respectively supplier 7, 9, 4 and 1, with respectively 5000 (its maximum capacity), 4600 (close to the maximum capacity), 220 (its minimum capacity) and 180 (its minimum capacity).

Optimisation without constraints - identical weights

In this case the weights of the criteria are identical and we associate Good (+) Neutral (0) or Unsatisfactory (-) to each supplier with respect the various criteria. From this comparison a total mark is calculated for each supplier. From table 8, we will deduce table 10 when :

A mark $\geq 7 \Rightarrow +$
A mark $\leq 5 \Rightarrow$ -
A mark between 5 and 7 ($5 << 7$) $\Rightarrow 0$
Consequently, we have the following table (see table 10).

The four selected suppliers are respectively supplier 4 with (4, + and 1, 0), supplier 8, supplier 9 (with 4, + and 1, -) and supplier 7 (for the last, we have the choice between suppliers 1, 2 and 7. We chose the supplier which guaranty the best total unit cost, which is supplier 7 with 0.811 euro. The assigned quantities are respectively 6000 units (maximum capacity) from supplier 4, 3000 units (average capacity) from supplier 8, 810 units (close to the minimum capacity) from supplier 9 and 190 units (minimum capacity) from supplier 7.

Table 10: The supplier marks according to each criterion, Good (+), Neutral (0) and Unsatisfactory (-)

Supplier	Delivery	Quality	Price	Service after sale	Total mark
Supplier 1	+	0	+	0	0
Supplier 2	0	+	0	+	0
Supplier 3	0	+	0	-	0
Supplier 4	+	+	+	0	+
Supplier 5	0	0	0	-	0
Supplier 6	0	+	0	0	0
Supplier 7	0	0	+	+	0
Supplier 8	+	+	-	+	+
Supplier 9	+	+	+	-	+
Supplier 10	0	+	0	0	0

Optimisation without constraints - AHP approach

Let's suppose that we have to applied an AHP analysis and where marks are given in table 8. In this case the four selected suppliers are respectively supplier 4, supplier 9, supplier 8 and supplier 1 (at the end, we have the choice to take supplier 1 or supplier 2. We choose the supplier which guaranty the best total unit cost, which is supplier 1 with 1 euro).

Now the problem is to assign to each selected supplier its corresponding quantity. In this case, because the marks of suppliers 4, 9, 8 and 1 are very close (8, 7.8, 7.1 and 6.9), we decide, as an alternative, to compute the quantities as following :

Quantity of supplier 1 = $\frac{6.9}{8+7.8+7.1+6.9} \times$ total demand (10000) = 2300 units.
Quantity of supplier 8 = $\frac{7.1}{8+7.8+7.1+6.9} \times$ total demand (10000) = 2400 units.
Quantity of supplier 9 = $\frac{7.8}{8+7.8+7.1+6.9} \times$ total demand (10000) = 2600 units.
Quantity of supplier 4 = $\frac{8}{8+7.8+7.1+6.9} \times$ total demand (10000) = 2700 units.

Conjunctive elimination method

In this approach, we eliminate the suppliers whose mark, with respect to a criterion, is lower than the minimum mark (given by the company). Thus we choose one of the suppliers satisfying the minimum level of all the criteria. Since these 10 suppliers respect the minimum thresholds of the decision criteria, according to this method there is no difference between these suppliers. A choice like 5000 units from supplier 1, 4000 units from supplier 2, 500 units from supplier 3 and 500 units from supplier 4, is acceptable.

Lexicographic elimination method

In a **Lexicographic** rule, on the first level we select the most significant criterion and then we compare the suppliers with according to this criterion. If a supplier satisfies this criterion much better than the other suppliers then we choose it, if not we compare the suppliers with respect to a second criterion. In this example the most significant criterion is the "Delivery" with a weight of 40% (of importance) with respect to the other criteria. Supplier 9 respects this criterion much better than the other suppliers. Thus 6500 units of supplier 9 are taken (its maximum capacity). Supplier 4 is in the second position, thus we can take the remainder of the demand (3500 units) from him. But let us recall that we must choose four suppliers. Thus we take the two following suppliers who have the best notes with respect to the "Delivery" criterion, which are supplier 8 and supplier 1. The final result will be: supplier 9: 6500 units (its maximum capacity), supplier 4: 3110 units (its average capacity), supplier 8: 210 units (its minimum capacity) and supplier 1: 180 units (its minimum capacity).

The above mentioned methods have two major disadvantages. Initially, they cannot take into account all the constraints of the company and the suppliers. In this small example we could consider the constraints of the suppliers (maximum capacity). To consider the other constraints (constraints related to the parameters L, Q and C), even in this small example, is not easy. Not to consider the total performance of a supplier is the second disadvantage of these methods (except AHP approach). For example the method "oriented cost" considers only the criterion of "cost" or the "lexicographic elimination method" considers only the criterion "delivery". In the method of identical weights, all the criteria have the same importance. Thus, it cannot choose the suppliers according to their real performances. The major difference between the solutions, suggested by these various methods, shows the absolute legitimacy of the "total performance" to select the best suppliers.

The above linear integer programming model makes it possible to support these two major disadvantages of the existing methods. It considers the total performance of the suppliers (values u_j of table 8) and chooses the best supplier(s). The proposed solution takes into account both the suppliers and the company constraints. The optimal solution is : supplier 2: 150 units, supplier 4: 6000 units (its maximum capacity), supplier 8: 850 units and supplier 9: 3000 units (its average capacity). The objective function value is 78470.

The relative distance (%) is equal to : $(\sum_j (u_j \times q_j)$ (*given by the corresponding method*) - 78470)/78470.

For example, using the AHP approach, the corresponding total mark is = 74790 and the relative distance = (74790-78470)/78470 = -5%. Which indicate that the relative distance between the optimisation method and the AHP approach is equal to -5%.

As we can see (table 11), the optimisation method (OPT) presents the optimal solution because it respects all the constraints of the company and the suppliers while maximizing

Table 11: The solutions and the performances of the different selection methods

	Oriented cost	Identical weights	AHP approach	Conjuctive rule	Lexi elim	OPT
Supplier 1	**190**	0	**2300**	**5000**	**180**	0
Supplier 2	0	0	0	**4000**	0	**150**
Supplier 3	0	0	0	**500**	0	0
Supplier 4	**210**	**6000**	**2700**	**500**	**3110**	**6000**
Supplier 5	0	0	0	0	0	0
Supplier 6	0	0	0	0	0	0
Supplier 7	**5000**	**190**	0	0	0	0
Supplier 8	0	**3000**	**2400**	0	**210**	**850**
Supplier 9	**4600**	**810**	**2600**	0	**6000**	**3000**
Supplier 10	0	0	0	0	0	0
Total marks U	71465	76872	74790	69400	74413	78470
Relative distance (%)	-9%	-2%	-5%	-12%	-5%	0%
Constraint 3	$163 \geq 120$ -	$123 \geq 120$ -	$125 \geq 120$ -	$143 \geq 120$ -	$120 \geq 120$ +	$118 \leq 120$ +
Constraint 4	$278 \leq 300$ +	$274 \leq 300$ +	$277 \leq 300$ +	$240 \leq 300$ +	$300 \geq 300$ +	$300 \geq 300$ +
Constraint 5	$8059 \leq 10000$ +	$10700 \geq 10000$ -	$10410 \geq 10000$ -	$10450 \geq 10000$ -	$8094 \leq 10000$ +	$9240 \leq 10000$ +

the total mark at the same time. In this example, the selection method OPT gives the best value of the total mark. The three methods: conjunctive rule, identical weights and AHP propose solutions which exceed the total tolerated cost (given by the company as a constraint). Except the optimisation method, only the oriented cost method and the Lexicographic elimination method propose two solution which respect the total permitted cost. The solutions given by the four methods : oriented cost, identical weights, conjunctive rule and AHP don't respect the delivery constraint (3). Contrary to constraint (3), all the methods respect the quality constraint. Consequently, the mathematical optimisation method respects the best selection method.

8 Conclusion

In this report, a state of the art related to the supplier selection problem was presented. We summarized the different selection criteria, the various problems of suppliers selection and the existing methods to solve the problem. An analysis enabled us to find some lacks in the literature. Indeed, the principal lack of the literature was the absence of a total approach which can treat various characteristics of the problem. To contribute to solve this lack, we showed the essential points which can help to define a suitable approach to solve efficiently the suppliers selection problem, like: conjunctive rules, multi-actors (decision makers) aspect, subjective and objective criteria, constraints of both the suppliers and the company, the multi-supplier aspect (best suppliers and required quantities) and the probabilistic aspect. Particularly, a concept of "strategic supplier" was suggested, in order to select the suppliers which guaranty the long-term viability of the company.

The approach suggested in this report requires that the decision be made into two stages. In the first stage, we select the strategic suppliers and this starting from the strategy of the company it self. Another parameter to be considered in this stage is the minimum threshold of each criterion. In the second stage of this approach, we proposed a linear integer model to select the best suppliers and the required quantities by considering the constraints of both the suppliers and the company. The purpose of this model is to maximize the function U which represent the total marks given by the decision group. We proposed a way in order to take into account the probabilistic behaviours of the candidates suppliers.

To illustrate the different approaches used in the literature to solve the supplier selection problem, a numerical example was presented. This example showed us that the mathematical approach was the best selection method which takes into account all the constraints.

Furthermore, it is necessary to make a vaster study in order to develop a selection method which can consider the probabilistic behaviours of the candidates suppliers.

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