THE ANALYTICAL HIERARCHY PROCESS IN THE SUPPLIER SELECTION PROBLEM

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ABSTRACT

The Supplier Selection Problem (SSP) consists of analyzing and measuring the performance of a set of suppliers in order to rank and select them for improving the competitiveness of the whole supply system. As many conflicting factors should be taken into account in the analysis, the problem can be tackled using multi-criteria models and methods. In this work a careful scrutiny of the papers appeared on international scientific journals in the recent years about SSP is provided. The survey highlights that the most used methodology is the Analytical Hierarchy Process (AHP). Thus, an overview view of the current proposals based on AHP and its variants to cope with the SSP is provided. Crucial aspects which arise when the methodology is actually applied in real cases are identified and discussed.

Keywords: Supply System, Supplier Selection, AHP.

1. Introduction

In a competitive market, consumers demand cheaper and higher quality products, on-time delivery and excellent after-sale services. Therefore, companies need to cut costs while maintaining a high level of quality and after-sale services. Various studies devoted to the analysis of customer-supplier relationships highlighted that attention should be paid on the organization and management of the entire supply chain in order to improve the quality of services and/or products provided to the final consumers. Moreover, with the trend to outsource a constantly increasing quota of the value-chain activities, purchasing decisions become crucial. Thus, a key role is played by the supplier evaluation process (Sarkara and Mohapatrab, 2006; Saen, 2007). In particular, suppliers' selection has assumed a strategic role in determining large customer firms' competitiveness. Consequently, customers devote

more and more resources both to suppliers' development programs (Lamming et al., 1996; Krause and Ellram, 1997) and to early suppliers' involvement (O'Neal, 2006). In this perspective supplier selection has received extensive attention in the literature (de Boer et al., 2001; Kamann and Bakker, 2004).

The Supplier Selection Problem (SSP) consists of analyzing and measuring the performance of a set of suppliers in order to rank and select them to improve the competitiveness of the entire supply system. Many conflicting factors should be taken into account in the analysis, both qualitative and quantitative. Several approaches and methodologies have been developed to cope with this problem. However, while the number of proposals is growing, there is little empirical evidence of the practical usefulness of such tools in the supplier selection corporate practice (de Boer and van der Wegen, 2003). Indeed, the methodologies are often tested on some numerical examples, without emphasis on the development process and on the real appreciation by the user. As the problem is intrinsically multi-objective, several papers have been focused on the definition of appropriate mathematical multi-criteria approaches to be adopted (de Boer et al., 2001). The most utilized methodology is represented by the well-known Analytical Hierarchical Process (AHP) (Saaty, 1980 and 1994) with its different variants.

The AHP is a general theory of measurement that depends on the values and judgments of individuals and groups. In particular the method is based on an evaluation model structured in a hierarchical way. Weights are assigned to each criteria or sub-criteria through pair-wise comparisons using a "semantic" scale to define their relative importance. Due to this sophisticated technique to derive weights avoiding the use of absolute numerical values in judgments, the AHP has been widely applied to solve several decision problems. Despite its diffusion, the method can be considered reliable if it is applied with awareness of its characteristics and risks of failures.

In this paper we show the results of a thorough survey of scientific papers focusing on the application of the AHP and its numerous variants for the SSP. The aim is to provide a view of the current proposals and to discuss crucial aspects which arise when the methodology is actually applied in real cases. The paper is organized as follows: in the next section the SSP is defined and illustrated. Afterwards a synthetic description of AHP and its possible variants is provided. Then the methodology of the literature survey and its results are shown, with a specific focus on the use of the AHP and its variants for SSP. Finally, a discussion on the crucial aspects related to the use of multi-criteria approaches and of AHP-based methods is developed and some conclusions are drawn.

2. The Supplier Selection Problem (SPP)

The evolution of supply relationships underlines that suppliers are required to have an adequate set of competencies to be part of a supply system capable of facing market competition (Esposito and Passaro, 2009). To this aim, customer firms have performed various actions and strategies: in particular the assessment processes has assumed a crucial importance. It represents a compulsory and critical starting point for the achievement of a collaborative customer–supplier system (de Boer et al., 2001).

The assessment process presents two different stages (de Boer et al., 2001). The first concerns the selection process (*selection problem*) of new suppliers for inclusion in a supplier list. Selecting the right supplier is a difficult task as suppliers are characterized by strengths and weaknesses which require careful evaluation. This is generally done through a ranking process (*ranking problem*) of a set of suppliers previously qualified. The second phase regards the monitoring and control of the suppliers' behaviour. In some applications some constraints about supplying capacity of each supplier can occur; in this case an *order allocation problem* can be defined. It consists of the determination of the order size to be provided by each supplier, with the objective of optimizing a given utility function.

Since 1960s, the identification of relevant attributes and criteria to be considered in the SSP has constituted an attractive research area. Traditionally, supplier evaluation was fundamentally based on financial measures; recently, more and more emphasis has been devoted to other aspects, bringing multiple criteria into the evaluation process. Dickson (1966) listed 23 criteria for suppliers' selection, based on a survey of 273 purchasing manager. The analysis showed that quality, delivery and performance history could be considered, in their respective order, the three most important criteria. Ha and Krishnan (2008) updated this set of attributes as shown in Table 1. This attribute list provides a first flavor of the complexity of the problem as many conflicting factors should be taken into account. Moreover, while some of these factors can be easily measured some others are qualitative concepts: the aggregation of these attributes in a final judgment can result in a tricky problem. For these reasons, a wide spectrum of methodologies has been developed and applied during the last years to deal with the SSP.

Table 1 – Supplier selection attributes according to Ha and Krishnan (2008) framework

After sales service	Geographical location	Product appearance
Amount of past business	Impression	Production facilities and capacity
Attitude	JIT capability	Quality
Catalog technology	Labor relations	Reciprocal arrangements
Communication system	Maintainability	Reputation and position in industry
Delivery	Management and Organization	Response to customer request
Ease-of-use	Operational controls	Technical capability
E-commerce capability	Packaging ability	Technical support
Environmetally friendly products	Performance history	Training aids
Financial position	Price	Warranties and claims

3. The Analytic Hierarchy Process

The AHP is a general measurement theory that depends on the values and judgments of individuals and groups. More precisely, judgments are brought together according to a multilevel hierarchic structure that allows deriving priorities. The major advantage of the hierarchical structure is that it allows for a detailed, structured and systematic decomposition of the overall problem into its fundamental components and interdependencies, with a large degree of flexibility. The AHP has found its widest applications in multi-criteria decision making, in planning and resource allocation and in many other fields (see for instance Byun, 2001; Ngai 2003; Sarkis and Talluri, 2004). This methodology is made up of the following steps.

- *Structuring of the problem into a hierarchy*. In general hierarchies concern the distribution of a property (the goal) among the elements being compared, to judge which one influences or is influenced more. In the SSP, the goal is the evaluation of suppliers. Thus, this phase consists of individuating the hierarchy of attributes and indexes to measure suppliers' characteristics.

- *Comparative judgment*. The aim is to measure the relative importance of the elements (attributes, indexes) to the overall goal. The question to ask when comparing two elements is "*how important is one of the two elements with respect to the goal of the problem*?". In the SSP the objective is the customer and the aim is to investigate on his perceptions; in practice the output of this phase is a priority vector associated with the set of elements.

- *Synthesis of the priorities*. The objective of this phase is to derive a total score for each alternative starting from the measured scores and the calculated priorities of each element of the hierarchy.

As the hierarchical framework does not allow dealing with problems characterized by more sophisticated and complex interactions and dependencies, an evolution of the original methodology, the so called ANP (Analytic Network Process) has been proposed (Saaty, 2001) based on the replacement of the hierarchies with networks.

The massive diffusion of these techniques has promoted the development of hybrid approaches in which one or more steps of the AHP and/or ANP are performed through other mathematical methodologies such as Fuzzy Set theory, Data Envelopment Analysis or further optimization approaches.

4. Literature survey

As mentioned before, in the last years a strong interest has occurred in the literature about the SSP. Academicians and practitioners of several countries have been involved in the development of analysis, theoretical methodologies and practical application about the problem. This interest is proven by the large number of papers which have appeared on the most significant scientific journals in the recent years. For this reason we performed a survey in order to understand the characteristics of the research demand about the problem and to individuate perspectives for further studies.

4.1 Methodology

The survey was carried out through a search of papers recently published on international scientific journals. In order to select the papers to be analyzed, we used the web-based tool Google™ Scholar that includes all the most popular academic search engines. We considered all the scientific papers, published between 2003 and 2008, provided by the advanced search finding the exact phrases "Supplier Selection", "Vendor Selection", "Supplier Evaluation", "Vendor Evaluation" in the title or among the key-words or within the abstract of the articles.

4.2 General results

In Table 2 the result of the search process in terms of number of papers published per year is shown. The considerable total number of papers (201) reveals the significant and growing attention devoted to the SSP in the last years. The papers are hosted on a total number of 68 scientific journals.

Table 2 – Historical series of papers published about the SSP

Year	2003	2004	2005	2006	2007	2008	Total
Papers	21	13	18	37	47	65	201

A first level of analysis was focused on the geographical expression of the interest on the base of the country where the institution of the first author is based (Table 3). Neglecting USA which are the major contributor with 41 papers, Taiwan (37) and Turkey (21) appear as the most productive countries, followed by further Asian nations, like China (19), India (15) and Iran (14). European scholars and institutions seem to be less involved in this field of study. These aspects may be explained by considering that a stronger attention comes from the geographical areas that have been strongly involved in innovation and transformation processes of their manufacturing systems in the last decade.

Table 3 – Papers published (2003-2008) per country

Country	USA	Taiwan	Turkey	China	India	Iran	UK	Italy	Germany	Others	Total
No. papers	41	36	21	19	15	14	8	8	6	33	201

4.3 Research fields

The selected papers are focused on various aspects of the SSP. In particular the most popular topics concern the strategic role played by the SSP to improve the performance of the entire supply chain, the definition of the more appropriate attributes and variables to be considered in the selection process, the choice of suitable methodologies to rank suppliers, the construction of practical tools to implement the decisional process. For this reason scientific journals hosting papers on this problem refer to various research fields and scientific areas. Despite the number of journals (68) publishing papers on the SSP, it is possible to individuate a subset of journals which host the most significant number of contributions. Table 4 shows the top five contributors which account for 72 papers (35.82% of the total number).

Table 4 – Top 5 contributors for publications in the period 2003-2008

Scientific journals	**Papers**
International Journal of Production Economics	21
Expert Systems with Applications	17
International Journal of Production Research	15
European Journal of Operational Research	10
Journal of Purchasing and Supply Management	9
Total Number of Papers	72
Percentage on Total Number of Papers	35,82%

The list includes journals from different areas, like Manufacturing (*International Journal of Production Economics, International Journal of Production Research*), Logistics (*Journal of Purchasing and Supply Management*), Operations Research (*European Journal of Operational Research*), Computer Science (*Expert Systems with Applications*). Papers also appear on journals about Management and Information Sciences. This highlights that the interest for the topic involves different research fields in the attempt to face the SSP from multiple points of view and with different methodologies.

4.4 Methodologies

The variety of the literature is also demonstrated by the numerous approaches proposed to analyze and solve the problem. Recently Ha and Krishnan (2008) have proposed a classification of the employed approaches in dealing with the SSP. A first level of classification regards the use of a single methodology and the combined use of more methodologies.
Within the first category, methodologies can be classified in

- mathematics;
- statistics;
- artificial intelligence;
- qualitative and descriptive models.

In the second category we can distinguish

- combination of mathematical methodologies;
- combination of mathematical approaches with artificial intelligence;
- hybrid approaches using methodologies belonging to different categories.

According to this classification, the surveyed papers have been categorized as depicted in Figure 1. The analysis of the results shows the large use of mathematical approaches: in particular 86 out of 201 papers were developed using mathematical methodologies (Optimization techniques, Multi-Criteria Decision Making methods). 22 out of these 86 papers combined two or more different mathematical approaches. The total number of papers in which mathematical methodologies are involved is 118 out of 201, accounting for the 58,7% of the total.

5. The use of AHP and its variants for the SSP

As illustrated in Figure 1, AHP-based approaches represent the most utilized methodology to tackle the SSP. In particular 51 out of 201 papers employ AHP and/or ANP in a pure way or in combination with other approaches. We analyzed these papers in order to underline the suitability of the AHP-based models to describe the problem and to indicate some further research perspectives.

5.1 General results

In Table 5 the number of papers using AHP and its variants compared to the total number of papers on the SSP is shown. The data reveal that in the last years the application of AHP and its variants is quite frequent and involves almost one third of the papers. 30 out 51 (58.82% of the total) papers turned out to be published on ISI ranked journals: calculating the average impact factor as weighted sum of journals' impact factors, assuming the number of papers published by the specific journal as weight, it results an average impact factor of 0.901. Considering the geographic origin of the papers (Table 6), AHP-based methods are mostly used in emerging economies (Turkey, Taiwan, China, India) testifying to the great interest for this technique in countries where manufacturing is still the prominent economic activity.

Table 5 – Historical series of papers using AHP and its variants about the SSP

Year	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**Total**
Papers using AHP	6	1	3	9	13	19	51
Total number	21	13	18	37	47	65	201
% of papers using AHP	28.6%	7.7%	16.7%	24.3%	27.6%	29.9%	25.4%

Table 6 – Papers published using AHP-based methods (2003-2008) per country

Country	**Turkey**	**Taiwan**	**China**	**India**	**USA**	**Others**	**Total**
No. papers	13	11	8	8	6	5	51

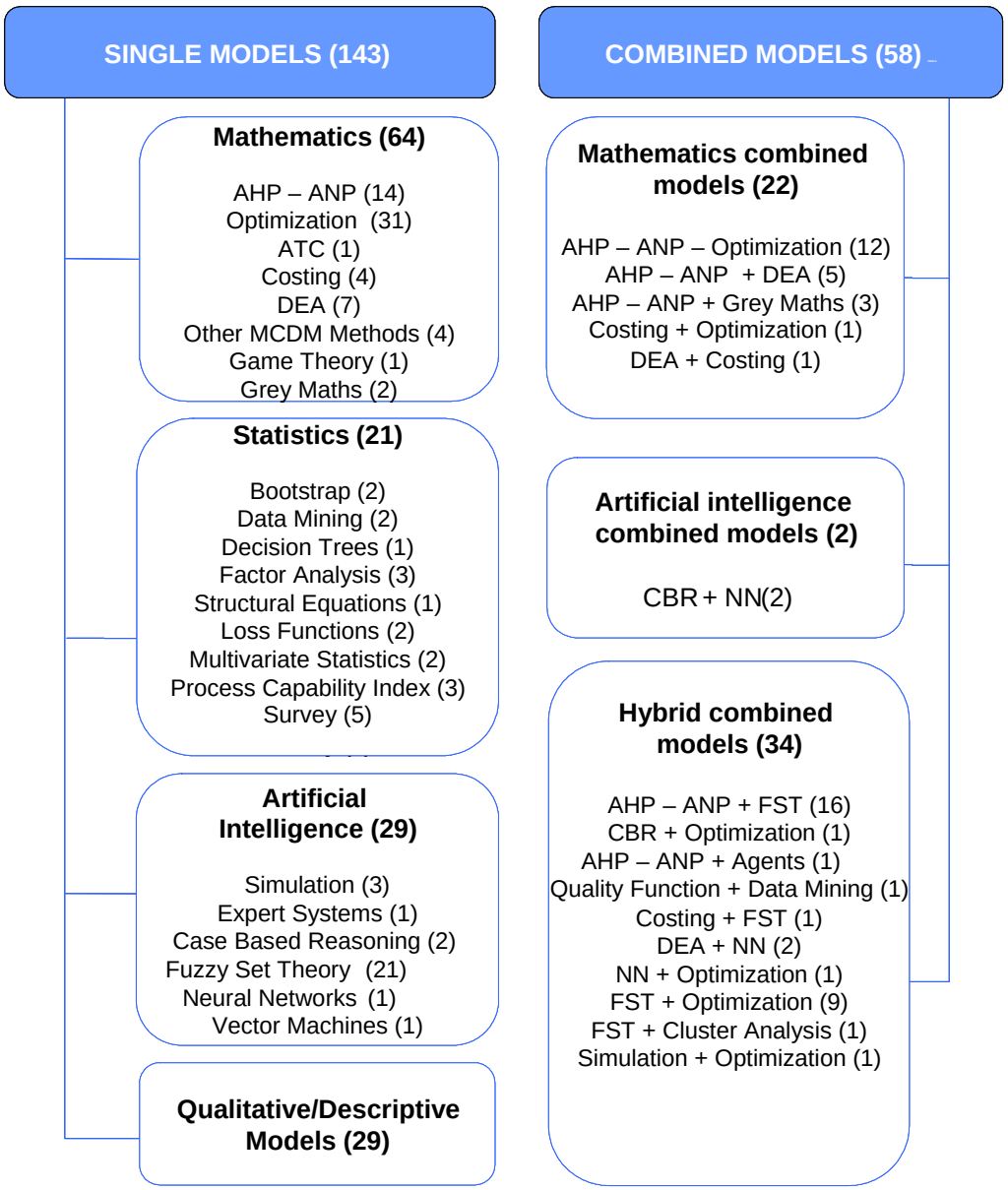
5.2 Research fields

The 51 analyzed papers have been published on journals belonging to different disciplines, coherently with the multi-disciplinary nature of the SSP already underlined in the previous section.

Table 6 – Classification of Papers about SSP using AHP by journal area (2003-2008)

Area	**Papers**	**%**
Operations Research	8	15,69%
Management	11	21,57%
Computer Science	4	7,84%
Information Sciences	6	11,76%
Manufacturing	13	25,49%
Logistics	9	17,65%
	51	100,00%

In Table 7 the journals which have hosted more than two papers about the application of AHP-based methods are indicated. The major contributor is given by *Expert Systems with Applications* (5) that published a special issue on the SSP. The top seven contributors (papers accounting for at least three papers) account for the 45% of the total number of papers.



AHP	Analytic Hierarchy Process
ANP	Analytic Network Process
ATC	Analytic Target Cascading
CBR	Case Based Reasoning
DEA	Data Envelopment Analysis
FST	Fuzzy Set Theory
MCDM	Multi-Criteria Decision Making
NN	Neural Networks

Figure 1 – Papers classification according to Ha and Krishnan (2008) framework

Table 7 – Journals which have hosted more than two papers about the application of AHP-based methods on the SSP (2003-2008)

Journal	**Published papers**
Expert Systems with Applications	5
International Journal of Production Research	4
Computers & Industrial Engineering	3
International Journal of Advanced Manufacturing Technologies	3
International Journal of Production Economics	2
Omega	3
Supply Chain Management: An International Journal	2
Industrial Management & Data Systems	2
Information Sciences	2
International Journal of Information Technology & Decision Making	2
International Journal of Services and Operations Management	2
Journal of Manufacturing Technology Management	2
Logistics Information Management	2
Total Papers	34

5.3 Objective

With reference to the objective, most of the papers (37 out of 51) are focused on the ranking problem. To this aim papers offer a wide variety of structures (hierarchic or network) characterized by different numbers and typologies of attributes. Considering the papers in which a classical hierarchical schema is adopted, the average number of criteria considered in the first level is 6.19. This testifies the suitability of AHP to model and solve complex decision making problems. Generally, in tackling the ranking problem it is assumed that all suppliers in the list satisfy buyer's requirements: in other words the suppliers are considered feasible and there is no need to previously verify constraints satisfaction conditions. The remaining papers (14 out of 51) deal with the order allocation problem. These papers face situations in which no supplier is capable in providing the buyer with required quantities, as there are some limitations on suppliers' capacity, quality and delivery. In order to demonstrate the suitability of the proposed approaches, most of the papers include the illustration of real case studies (33) rather than numerical examples (16). Two papers present questionnaires to validate the derived hierarchical schema.

5.4 Methodologies

The analyzed papers contain many variants of the original AHP. Together with works using AHP and/or ANP in the classical version, very often the method is applied in combination with other mathematical approaches. Table 8 shows the number of papers for each implemented version. Moreover, a synthetic description of the papers belonging to each version is provided.

AHP + Fuzzy Set Theory

The AHP is based on pair-wise comparisons expressed by numerical judgments based on a semantic ratio scale. In the literature there have been various proposals to try to improve this aspect through forms of "fuzzification". While general criticisms have been addressed towards the use of fuzzy numbers especially when it is applied indiscriminately as an approach to express certain and crisp judgments (Saaty and Tran, 2007), there is a growing interest in combining fuzzy set theory with AHP (Benyoucef and Canbolat, 2007; Bottani and Rizzi, 2005; Buyukozkan et al. 2008; Chan and Kumar, 2007; Chan et al., 2008; Altinoz, 2008; Kahraman et al., 2003; Kumar et al., 2008; Lee, 2008; Lee et

al., 2008; Önüt, 2008; Zaim et al. 2003; Yang et al. 2008; Sevkli, 2008; Haq and Kannan, 2006a). In most of the proposals, triangular fuzzy numbers are used as a pair-wise comparison scale for deriving the priorities of different criteria and attributes.

AHP + Optimization methods
AHP-ANP is very often used in combination with optimization methods. In particular AHP is utilized with Integer Programming (Linear, Non-Linear, Mixed) (Kokangul and Susuz, 2008; Mendoza and Ventura, 2008; Yu and Tsai, 2008; Wang et al., 2005; Wu et al., 2008a) and Multi-Objective (Linear, Non-Linear, Integer and Goal) Programming (Çebi and Bayraktar, 2003; Demirtas and Ostun, 2007 and 2008; Ozgen, 2008; Percin, 2006; Ting and Cho, 2008; Xia and Wu, 2007; Venkata Rao, 2007).
In general, the combination between AHP and optimization methods is utilized to deal with the order allocation problem. Suppliers are ranked utilizing AHP priorities; then, as no supplier is capable of providing the buyer with required quantities, the optimization model estimates how much should be purchased from each selected supplier in order to maximize a given objective function. The objective function can represent, for example, the total value of purchasing weighted on suppliers' priorities. AHP can be also used to derive the weights for a multi-criteria objective function including several performance criteria measures.

Pure AHP (ANP)
Basic versions of AHP and ANP are still widely used in the literature to deal with the SSP. All these papers, applying the methodology at its simplest level, do not take into account any kind of constraint about suppliers. Thus, these papers face the SSP from a ranking perspective, just providing a final standing of different suppliers. The adopted hierarchical schema is composed by four hierarchical levels (main goal; attributes; characteristics; alternatives). To rank the suppliers, pair-wise comparisons among suppliers themselves are utilized (Bayazit, 2006; Chan, 2003; Chan and Chan, 2004; Chin et al., 2006; Gencer and Gurpinar, 2007; Hou and Sou, 2006 and 2007; Levary, 2007 and 2008; Schoenherr et al., 2008; Wu et al. 2008b). Onesime et al. (2004) and Pi and Low (2006) derive priorities for the hierarchical schema of AHP through pair-wise comparisons among its elements, deriving supplier scores for each characteristics through the utilization of indicators based on a Quality Function approach.

AHP + Data Envelopment Analysis
Data Envelopment Analysis (DEA) is an approach for evaluating the performance of a set of entities which convert multiple inputs into multiple outputs, defining a *best practice frontier* that can be used as a reference for efficiency measures. This methodology is employed in combination with AHP in a multi-phase decision process in which both quantitative and qualitative attributes are involved. Generally, AHP is executed to appraise suppliers on their qualitative benefits, generating quantitative data from these qualitative dimensions. Secondly, DEA is used to synthesize the data to achieve a ranking of the suppliers. Examples of these applications can be found in Liu and Hai (2005), Ramanathan (2007), Saen (2007), Sevkli et al. (2007), Hasan et al. (2008).

AHP + Grey Mathematics
Grey Theory (GT) is one of the methods used to study uncertainty based on the presence of systems with partially known information (grey systems). The integration of GT and AHP is quite similar to the development of fuzzy AHP: in the composition of the pair-wise judgment matrices, inputs are considered as grey numbers. Yang and Chen (2006), Haq and Kannan (2006b and 2007) provide examples of this application.

AHP + Agent Based Simulation
Chen and Huang (2007) propose an integration of AHP and Agent-Based Modeling. Suppliers and customers are represented by agents that negotiate terms and conditions of an agreement. AHP is used to determine relative preferences and to evaluate supplier criteria during the negotiation.

Table 8 – Classification of papers using AHP (2003-2008) in Supplier Selection Problem by methodology.

Version	Published Papers
AHP + Fuzzy Set Theory	16
AHP + Optimization methods	14
Pure AHP (ANP)	14
AHP + Data Envelopment Analysis	5
AHP + Grey Mathematics	3
AHP + Agent Based Simulation	1
Total	53

6. Discussion

The literature review reveals that a large number of researches have been devoted to the development of different kind of methodologies to cope with the Supplier Selection Problem (SSP). Moreover, AHP and its derived approaches turn out to be the most popular one. As stated by Chan (2004), the suitability of AHP to the SSP can be explained by its ability to:

- handle both tangible and intangible attributes;
- structure problems through hierarchies that allows gaining insights into the decision making process;
- monitor the consistency of decision maker's judgments;
- provide a synthetic score for each supplier.

However, Chan (2004) indicates the following drawbacks in AHP use:

- Its use is not straightforward for practitioners;
- Consensus may need to be reached in aggregating individual judgments for pair-wise comparison matrices;
- The definition of the hierarchy strongly depends on the practical problem;
- The reliability of the outcome depends not only on the quality of the data, but also on knowledge and judgments of decision makers.

Indeed, the analysis highlights that the translation of theoretical models into practical applications is a complex problem. First of all, high customization of models is required in order to represent a specific organizational and technological system. For instance, considering the selection of the attributes, which represents the core of the SSP, the choice is strongly related to the specific application.

Another issue regards the distance between literature and firms' practice in terms of model building. The literature review has shown that often firms' management doesn't recognize the list of attributes proposed by Ha and Krishna (2008) as applicable in their specific context. Further definition and specification of the criteria are needed.

Moreover, in order to derive the priority schema, managers from several departments of the buyer firm have to be interviewed. Managers coming from different areas express very different judgments according to their specific strategic objective. This can affect the consistence of the aggregate pair-wise comparison matrices. For this reason, the choice of the managers to be interviewed turns out to be relevant.

Finally, since the hierarchical schema and the priority vectors are identified and evaluated on the basis of the strategic objectives of the decision maker, any change in the latter implies a revision of the

model. Hence, once the model has been built, it has to be considered only as a starting point to be continuously monitored and improved.

All these considerations highlight that a tool for SSP is generally characterized by several features. Consequently, it is possible to compare different approaches through a benchmark that considers a set of performances depending on the problem to be solved. In particular in Table 9 the comparison between AHP and qualitative models is proposed.

Table 9 - Supplier selection models performances

Performance	AHP Models	Qualitative models
Learning	High	Low
Cost Effectiveness	Low	High
Flexibility	Low	High
Involvement	High	Low
Measurability	High	Low
Motivation	High	Low
Reliability	High	Low
Timeliness	Low	High

The table underlines that AHP models are characterized by high levels of performance in terms of learning, involvement, measurability, motivation and reliability. Indeed, this approach needs an effort to formalize the model that forces the firm to understand how the supply system really works (learning process) and to define a set of relevant and measurable characteristics to assess supplier performances (measurability). This results in an improved reliability of the supplier selection system. The hierarchical structure of AHP and its way of collecting collective judgments also allows the involvement of different departments in the selection process (involvement) and pushes them towards virtuous behaviors.

By contrast, qualitative models appear to be characterized by high level of cost effectiveness, flexibility and timeliness. Indeed, since these models are built relying on experts and their qualitative judgments, they do not need high costs of development. In addition, the absence of a formalized and specific structure allows for rapid reactions to changes in the objectives or in the environment (flexibility and timeliness).

Although the number of applications for supplier selection is growing, these final aspects underline why firms are not likely to use these tools since they are often too far from the corporate world. Thus, the most of the firms approach the SSP just employing qualitative judgment from some experts, as also stated by de Boer and van der Wegen (2003).

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