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AHP-based approaches for supplier evaluation: Problems and perspectives

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ABSTRACT

Supplier evaluation has assumed a strategic role in determining competitiveness of large manufacturing companies. An increasing number of researches have been devoted to the development of different kind of methodologies to cope with this problem. Nevertheless, while the number of applications is growing, there is little empirical evidence of the practical usefulness of such tools with a dichotomy between theoretical approaches and empirical applications. Considering this evidence, the goal of this paper is to contribute to understand the above dichotomy by implementing, in a corporate environment, a model for supplier evaluation based on the Analytical Hierarchical Process (AHP), one of the most prominent methodologies used to address the problem. The analysis of the implementation process of the methodology allows the identification of strengths and weaknesses of using formalized supplier selection models to tackle the supplier evaluation problem, also highlighting potential barriers preventing firms to adopt such methods. Relevant issues arising from the application and managerial implications for both customer and suppliers are discussed.

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1. Introduction

Outsourcing has always represented a key component of firms' strategy aimed at enhancing quality and competitiveness levels. The phenomenon has remarkably grown in the last few decades. Nowadays, in manufacturing companies, the purchasing share typically ranges from 30% to 90% of the total turnover (Ronchi, 2003). As a consequence, business management literature has highlighted the crucial importance of supplier relationships within a supply network (de Boer et al., 2001, 2003; de Boer and van der Wegen, 2003; Bhutta, 2003; Kamann and Bakker, 2004). Many have observed the need to move from an *adversarial relationship* perspective to one based on cooperation and reciprocal trust (Hines, 1996; Cox and Lamming, 1997; Barrat, 2004; Soosay et al., 2008). Others have stressed that selecting the appropriate suppliers represents a critical success factor for any outsourcing decision (Dahel, 2003; Choy and Lee, 2003; Prahinski and Benton, 2004). Indeed, the supplier evaluation process allows the selection of suitable suppliers in order to develop a supply relationship system able to rapidly react to market requirements and to innovation dynamics (Reck and Long, 1988; Gules and Burgess, 1996; Van Weele, 1999; Prahinski and Benton, 2004; Sarkara and Mohapatrab, 2006; Saen, 2007; Esposito and Passaro, 2009a, 2009b).

An increasing number of researches have been devoted to the development of different kind of methodologies to cope with this problem. Nevertheless, while the number of applications is growing, there is little empirical evidence of the practical usefulness of such tools (Weber et al., 1991; de Boer and van der Wegen, 2003). Very often, the proposed models are tested on generic applications, numerical examples and computational experiments (Bhutta and Huk, 2002; Dahel, 2003; Saen, 2007; Ting and Cho, 2008; Ordoobadi, 2009), with less emphasis on the problems emerging in the practical implementation of the methodology, on its strengths and weaknesses, and on the appreciation given them by the practitioners and managers involved in decision making processes.

Considering this evidence, the goal of this paper is to contribute to understand the above dichotomy by implementing, in a corporate environment, a methodology for supplier evaluation based on the Analytical Hierarchical Process (AHP), one of the most prominent methodologies used to address the problem (Saaty, 1980, 1994). After a thorough literature review, highlighting the relevance of the problem in the literature and the main methodologies employed to cope with the problem, the analysis of the implementation process of the methodology allows the identification of strengths and weaknesses of using AHP-based models (and, generally, formalized supplier selection models), also highlighting potential barriers preventing firms to adopt such methods.

The paper is organized in 7 sections. Following this Introduction, in Section 2, an extensive analysis of published articles on the supplier selection problem during the last few decades is provided; in Section 3, a focus on AHP-based approaches for supplier selection is shown. The objectives of the research are then illustrated in Section 4, and some context information about the case study and the unit of analysis are provided in Section 5.

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Table 1
Surveys on articles about supplier selection.

Author/s	Articles	No. of Journals	Period	Articles per year	Annual articles per journal	Research area (%)
Weber et al. (1991)	74	21	1966–90	3.1	0,147	MN/OM:10.7; SCM:56.8 OR/CS: 9.5; GM: 23.0
Bhutta (2003)	154	68	1986–02	9.6	0.142	MN/OM:18.3; SCM:60.8 OR/CS: 4.2; GM:16.7
Sonmez (2006)	147	54	1985–05	9.6	0.136	MN/OM:14.5; SCM:34.2 OR/CS:25.2; GM:26.1
Bruno et al. (2009)	218	68	2003–08	36.3	0.531	MN/OM:28.9; SCM:18.4 OR/CS: 35.8; GM: 16.9

MN/OM: Manufacturing and Operation Management; SCM: Purchasing/Supply Chain. Management; OR/CS: Operational Research and Computer Science; GM: General Management.

The implementation of the AHP-based methodology is shown in Section 6, while Section 7 hosts a discussion of the lessons learned during the implementation process, after conclusions are drawn.

2. The Supplier Selection Problem: a literature review

The Supplier Selection Problem (SSP) consists of the definition of models and methods to analyze and measure the performance of a set of suppliers (vendors) in order to improve customer competitiveness. It is an intrinsically multi-attribute problem, since many qualitative and quantitative factors, very often conflicting with each other, should be taken into account (Bhutta and Huk, 2002; Bhutta, 2003; Sonmez, 2006; Ramanathan, 2007; Ordoobadi, 2009).

In order to deepen the interest in the literature on the SSP, there has been a wide review of the related articles published in recent years on the most significant scientific journals. Considering the international journals listed in the web-based tool Google Scholar (which includes all the most popular academic search engines) and searching for the words "Supplier Selection", "Vendor Selection", "Supplier Evaluation", "Vendor Evaluation" within title, key-words and abstract of the surveyed population of articles for the period 2003–2008, 68 journals have been analyzed (Bruno et al., 2009).

This analysis has been compared with three previous similar analyses. Table 1 shows a description at a glance of four surveys published since 1991 and covering the period 1966–2008. Observing data reported in the surveys, a specific initial focus on the supplier selection since 1966 clearly emerges. In the last column, articles are divided into four scientific areas: Manufacturing and Operations Management (MN/OM); Purchasing/Supply Chain Management (SCM); Operational Research and Computer Science (OR/CS); and General Management (GM). Even though we take into account that the periods analyzed in the surveys overlap each other and that the four samples are not completely homogeneous, it emerges that:

- the more balanced distribution share among the four areas could be interpreted as the result of the fact that supplier selection has no longer been under the almost exclusive domain of Purchasing/Supply Chain Management area since the expansion of the outsourcing phenomenon has determined a general interest in different research directions;
- the increasing attention in the OR/CS and MN/OM could be the consequence of the increasing search for methodological and technical viable solutions to the problem;
- an increasing interest (testified by a massive number of annual articles per journal) appears since the early 1980s due to the relevance played by the topic both in theory and practice.

Table 2
Supplier selection 2003–2008 articles of articles.

Year	2003	2004	2005	2006	2007	2008	Total
Papers	23	17	21	40	49	68	218

Table 3
Top 5 contributors for publications in the period 2003–2008.

Top 5 contributors	Articles	Area
International Journal of Production Economics	22	MN/OM
Expert Systems with Applications	19	OR/CS
International Journal of Production Research	15	MN/OM
European Journal of Operational Research	10	OR/CS
Journal of Purchasing and Supply Management	9	SCM
Total Number of Articles	75	
Percentage on Total Articles	34.40%	

In particular, data from more recent surveys reveal that the attention devoted to this topic is strikingly increasing, as depicted in Table 2. The number of articles published soared from 23 in 2003 to 68 in 2008; a total of 218 articles were published in this period.

As for journals, the top five contributors account for 75 articles, 34.40% of the total sample (Table 3).

Another perspective is offered by the analysis of the geographic origin of the articles. Considering the country where the institution of the first author is based, USA is the main contributor to the literature with 49 articles, followed by Taiwan (36), Turkey (27), China (21), India (16), and Iran (14) as shown in Table 4.

This evidence testifies that the SSP is a relevant issue involving academics and practitioners of several countries, especially those—such as the Asian ones—where manufacturing is the prominent economic activity and/or is based on the attraction of investment by large foreign companies.

In recent years there has been a great focus on the mathematical side of the SSP. 97 out of 218 articles were developed using mathematical methodologies trying to answer to the complexity of the problem, intrinsically multi-attributed. Among these, several approaches are becoming more and more popular in facing this issue; Analytical Hierarchical Process, and its network-based counterpart, Analytical Network Process (Saaty, 1980, 2001a) are among the most utilized. AHP/ANP-based approaches account for 53 articles (15 single models and 38 combined with other models) out of 218. This underlines how the combination of AHP with other methodologies is very common: the use of AHP/ANP with fuzzy set theory is widely accepted (14 articles), especially to deal with qualitative evaluation attributes. AHP/ANP is also used with optimization methods (15 articles), in many

Table 4
Articles published (2003–2008) per country (countries accounting for more than 5 articles).

Country	USA	Taiwan	China	Turkey	India	Iran	UK	Italy	Germany	Total
No. papers	49	36	27	21	16	14	8	8	6	218

Table 5
Supplier selection attributes according to Ha and Krishnan (2008)'s 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
Environmentally friendly products	Performance history	Training aids
Financial position	Price	Warranties and claims

cases to determine the importance of the several components of the multi-dimensional objective function.

As regards the different attributes used in the literature to measure supplier performance and then to aggregate them in synthetic models, the first attempt to provide a general and comprehensive framework was provided by Dickson (1966) and also adopted by Weber et al. (1991). Ha and Krishnan (2008) updated this set of attributes as shown in Table 5.

As Ha and Krishnan (2008) show, Price, Quality and Delivery are the three most used attributes; however, the list shows an extensive nature since the attributes are not always mentioned in a specific way and often no indications to the translation of these attributes in measurable characteristics are provided.

A classification of the employed approaches in dealing with the supplier selection problem has been provided by Ha and Krishnan (2008). Surveyed articles have been categorized according to this classification, as depicted in Fig. 1.

3. The Analytic Hierarchy Process in the Supplier Selection Problem

The AHP is a general theory of measurement that depends on the values and judgments of individuals and groups. More precisely, judgments are brought together according to a multi-level hierarchic structure to derive 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.

As already mentioned, AHP (and ANP) appears to be the most utilized methodology to cope with the supplier selection problem. The reason behind this evidence can be explained according to the following reasons:

- It has been widely applied in multi-attribute decision making problems, planning and resource allocation and many other fields (Byun, 2001; Ngai, 2003; Sarkis and Talluri, 2004);
- It provides a hierarchical representation of the problem that helps analytic decision making.
- AHP can handle both tangible and intangible attributes and characteristics;
- It provides mechanisms to monitor the consistency with which a decision maker makes a judgment;
- It can be used in combination with many other approaches (fuzzy set theory, optimization, etc.);

As regards the last point, the capability of AHP/ANP to be combined with other methodologies an in-depth review of the retrieved papers reveals the following:

- According to Bottani and Rizzi (2005) the adoption of the fuzzy approach in combination with AHP allows decision makers expressing ill-defined judgments such as "the relative importance of a criterion versus another is about double", or "a supplier performance versus one criterion is either in a range or almost in a range";
- AHP-ANP is also used very often in combination with optimization methods. In particular AHP is used in combination with Integer Programming (Linear, Non-Linear, Mixed) (see, for instance, Kokangul and Susuz, 2008) and Multi-Objective (Linear, Non-Linear, Integer and Goal Programming) (Çebi and Bayraktar, 2003; Demirtas and Üstün, 2007). In general, the combination between AHP and optimization methods is utilized to deal with the definition of the optimal order allocation among a set of suppliers. In practice optimization models provide estimates on how much should be purchased from each selected supplier in order to maximize a given objective function; AHP still provides a sort of priority related to each supplier;
- Hasan et al. (2008) has shown the efficacy of using Data Envelopment Analysis (DEA) in combination with the AHP. DEA is used to synthesize the data to achieve a ranking of the suppliers;
- AHP has been employed also in combination with Grey Theory (GT), which is one of the methods used to study uncertainty based on the presence of systems with partially known information (grey systems). Noorul Haq and Kannan (2007) provide examples of this application.

In general, the methodology is articulated in the following steps (Saaty, 1980, 1994).

A. *Structuring the problem into a hierarchy*. Hierarchies distribute a property (the goal) among the elements being compared (attributes and characteristics), to judge which one influences or is influenced more.
B. *Comparative judgments*. The aim is to measure the relative importance of the elements (attributes, characteristics) to the overall goal. The question to ask when comparing two elements is "how important is one of the two elements to the goal of the problem?" Pair-wise comparison matrices are associated with the set of attributes and each set of characteristics within each attribute. To compare two generic attributes and characteristics i and j, the ratio scale illustrated in Table 6 is generally used. At each hierarchical level the decision-maker establishes scores between elements by constructing a matrix of pair-wise comparison judgments regarding relative importance or preference between any two elements. The a_{ij} value of the matrix represents the relative importance of the ith elements over the jth element.
In general a reciprocity condition applies, stating $a_{ji}=(a_{ij})^{-1}$. However, AHP allows for inconsistencies in pair-wise judgments, i.e. $a_{ij} \times a_{jk}$ need not be equal to a_{ik}.

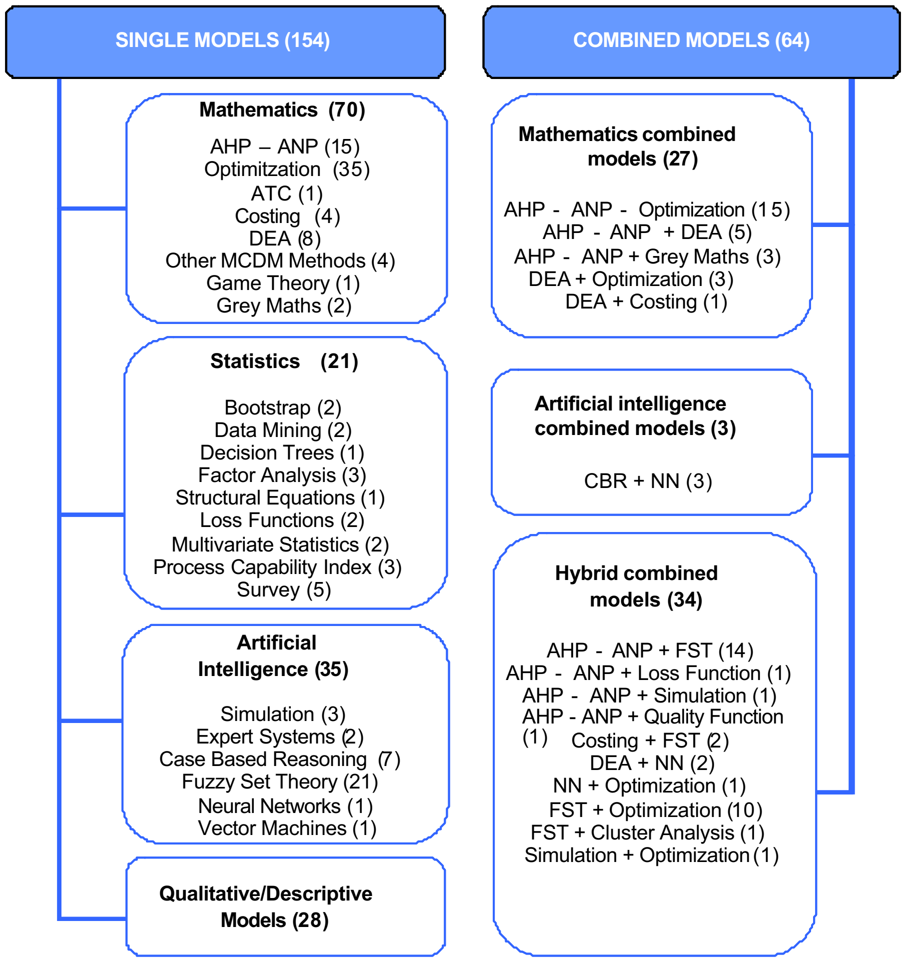

Fig. 1. Papers classification according to Ha and Krishnan (2008) framework.
AHP: Analytic Hierarchy Process, ANP: Analytic Network Process; ATC: Analytic Target Cascading; CBR: Case Based Reasoning; DEA: Data Envelopment Analysis; FST: Fuzzy Set Theory; MCDM: Multi-Criteria Decision Making and NN: Neural Networks.

Table 6
Ratio scale of comparative judgments (Saaty, 1980).

Value	Interpretation
1: equal importance	*i* and *j* are equally important
3: weak importance over one another	*i* is slightly more important than *j*
5: strong importance	*i* is much more important than *j*
7: very strong importance	*i* is by far much more important than *j*
9: absolute or extreme importance	*i* is definitely much more important than *j*
2, 4, 6, 8: intermediate values between 2 adjacent judgments.	

C. *Calculation of the attribute weights*. Starting from the data obtained through the comparative judgment, the objective of this phase is to calculate the vector whose components are the priorities of each element of the hierarchy, namely weights to be assigned to each element of the hierarchy for the calculation of the global score.
D. *Calculation of global score*. Using the attribute and characteristic weights and considering the related measures, global scores are calculated.

Basic versions of AHP and ANP are widely used in the literature to deal with the SSP. They face the SSP from a ranking perspective, just providing a final standing of different suppliers.

Generally, the hierarchical schema adopted in most of the papers is composed by four hierarchical levels (main goal; attributes; characteristics; and alternatives). To rank the suppliers, pairwise comparisons among suppliers themselves is used (Chan, 2003; Chan and Chan, 2004; Chin et al., 2006; Gencer and Gurpinar, 2007; Hou and Su, 2006, 2007; Levary, 2007, 2008; Schoenherr et al., 2008; Wu et al., 2009).

Onesime et al. (2004) and Pi and Low (2006) derive priorities for the hierarchical schema of AHP through pairwise comparisons among its elements, while derive supplier scores for each characteristics through the utilization of indicators based on a Quality Function approach.

As regards validation, out of the 51 papers utilizing AHP-based approaches that have been retrieved in our literature review, 17 papers just provide numerical examples, while 2 papers presents survey questionnaires to derive the hierarchical schema; the remaining number of papers (32) claim to include the illustration

Table 7
AHP-based supplier selection model with real life applications classification.

Industry	Papers	Generic components supplier selection	Raw materials supplier selection	Strategic partner selection
General electronics	12	Chen and Huang (2007), Gencer and Gurpinar (2007), Hou and Su (2007), Levary (2007), Che and Wang (2008), Hasan et al. (2008), Lee (2009), Lee et al. (2009), Levary (2008), Ting and Cho (2008), Yang et al. (2008)		Wu et al. (2009)
Home appliances	6	Kahraman et al. (2003), Sevkli et al. (2003), Zaim et al. (2003), Demirtas and Üstün (2007), Demirtas and Üstün (2008), Sevkli et al. (2008)		
Automotive/tyre manufacturer	3	Perçin (2006)	Noorul Haq and Kannan (2006a, 2006b)	
Semiconductor industry	2	Yua and Tsai (2008), Chan and Chan (2004)		
Food industry	2		Çebi and Bayraktar (2003), Bottani and Rizzi (2005)	
Telecommunicat.	1			Önüt et al. (2008)
Pipe manufact.	1	Özgen et al. (2008)		
Paper Manufact.	1		Noorul Haq and Kannan (2007)	
Logistics	1			Buyukozkan et al. (2008)
Healthcare	1			Benyoucef and Canbolat (2007)
Commercial tools	1			Schoenherr et al. (2008)
Apparel industry	1			Altinoz (2008)

of real case studies. Actually, data from real-world scenarios are employed for testing the methodologies. These 32 papers are classified in Table 7 on the basis of the industry in which the model is applied. Furthermore, papers are classified on the basis of the specific purchasing decision that has to be performed, identifying three main cases (selection of suppliers of generic components, selection of suppliers of raw materials, selection of suppliers for establishing a strategic partnership). The flexibility of the AHP-based approaches is testified by the wide range of industries involved in the case studies and by the different purchasing scenarios faced by the models.

However, looking at each of them in detail, none of the papers focuses on performing a cost/benefit analysis regarding the hidden "traps" related to the adoption of AHP for dealing with SSP that can prevent from the utilization of such methodologies in real world cases. This aspect highlights that also for AHP-based applications it exists a dichotomy between empirical evidence and theoretical approaches.

Furthermore, in the extant literature, several scholars have expressed some concerns about practical applications of AHP-based methods for modeling and solving real world problems.

Harker and Vargas (1990) and Perez et al. (2006) show that AHP suffers from the so-called "rank reversal" problem. Indeed, because priorities associated with alternatives depend on what alternatives are considered, hence, even adding or deleting *irrelevant* alternatives can lead to change in the final rank. Triantaphyllou and Mann (1995) suggest that the recommendations made the AHP should not be taken literally. In matter of fact, the closer the final priority values are with each other, the more careful the user should be. Both these shortcomings can have a significant impact on the practical usability of AHP-based models for tackling the SSP.

4. Objective of the research

The main goal of the paper is to identify the presence of a persistent dichotomy between theoretical approaches and empirical applications in the supplier evaluation process and contributing to understand the causes of this dichotomy.

Indeed, despite the wide spectrum of techniques and methods available for tackling the SSP, there is a lack of thorough empirical tests regarding the practical usability of such methods in real corporate environments.

The analysis will be carried out by implementing a model on the AHP which is, as shown above, the most popular method used (even in combination with other methods) to address the problem (Saaty, 1980, 1994). We focus on highlighting benefits and shortcomings in using AHP-based models, analyzing in a detailed manner each step in the application of the method.

5. The case study and the unit of analysis

The empirical application of the AHP methodology is carried out within the context of the supply system of the Italian railway industry. In particular, the unit of analysis under consideration in this study is the case of *suppliers* operating for a large *customer* firm of the railway industry on a *particular component* of the traction system (Fig. 2).

The *customer* is AnsaldoBreda (AB), the major player in Italian railway industry. AB, a state owned leader firm operating at an international level, outsources about 70% of parts and subsystems for the construction of railway locomotives and electric traction. Its supply system consists of about 500 hundred medium and small sized suppliers localized both in Italy and abroad (Esposito and Passaro, 2007). In particular, the supply system of AB encompasses suppliers belonging to different supply systems, characterized by different standards of quality, technology, cost and relationships with second tier suppliers (Fig. 3). AB has constantly revised its supplier evaluation and selection practices through the years. Indeed, in the 1980s, the company had no formal assessment for suppliers, just relying on expert judgments; during the 1990s, a quantitative index measuring defective pieces delivered by suppliers was introduced. In the early 2000s, the company has also introduced a measure for keeping track of delivery punctuality. Nowadays, AB is open towards the

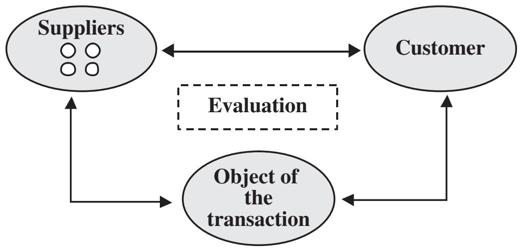

Fig. 2. The unit of analysis.

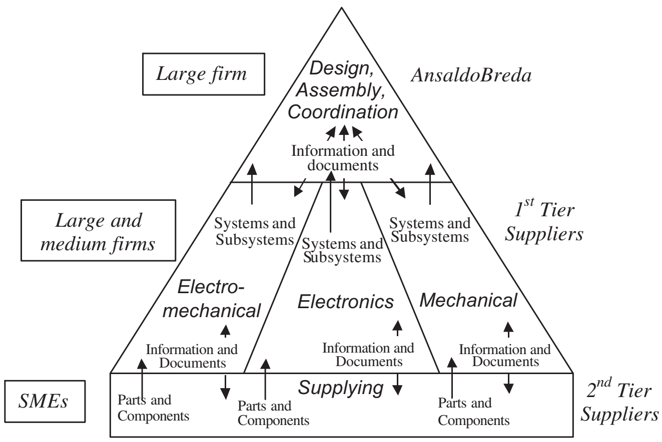

Fig. 3. AB production supply chain.

adoption of a more complex and formalized methodology for achieving a more precise and accurate ranking of the suppliers, thus being an excellent test-bed for the objectives of this research.

The *component* analyzed is the *bogie*, also defined *wheel truck*, which is the structure that supports the rail vehicle body, making it stable and ensuring comfort and safety. The bogie is characterized by a remarkable technological complexity.

In this work, we analyze *suppliers* delivering this specific component. There are currently four potential AB suppliers for the required component that have passed the pre-qualification stage in AB selection process. Namely, this means that these firms can provide AB with a product that complies with required technical and technological specifications. These firms are a typical example of first-tier suppliers, belonging to the Mechanical sub-system of the AB supply chain shown in Fig. 3.

However, given the complexity of the considered supply system, the process of supplier evaluation cannot disregard the specific item to be provided by the supplier, its technological and technical characteristics, and its standardization level. For instance, a supplier delivering complex systems typified by a high technological level cannot be evaluated with the same criteria of a supplier that provides capacity supplying. In other words, the critical problem to solve depends on what we really want to evaluate, namely defining the unit of analysis. Evaluating AB suppliers as in a pure dyadic relationship is not enough because the train is a complex system in which parts and components coming from different technological areas are assembled.

The adopted research strategy was based on the interaction between the research group and company managers. For this reason, a mini-focus group including members from four different departments of AB (Material Planning, Industrialization, Quality Management, and Purchasing) was set up. About 20 mini-focus group sessions took place in four months period during the year 2010 at the company site and were facilitated by members of the research group. In particular, focus groups sessions have been concerned with each of the stages of the method to be implemented (identification of the attributes and of their hierarchical model; identification of the characteristics; comparative judgments; global score calculation; and post-implementation discussion).

As for the suppliers, in order to implement the methodology, entrepreneurs or production managers of the four firms were interviewed during face-to-face meetings at supplier site using a questionnaire to collect the required data and information.

6. Implementation of the method

In the following, we describe the implementation of each step of the AHP-based model, highlighting benefits and shortcomings related to each specific step.

6.1. Structuring the problem into a hierarchy

The first step was the identification of the attributes for supplier evaluation. The starting point was the list of 30 attributes identified by Ha and Krishnan (2008) shown in Table 5. Among these 30 attributes, AB committee members were asked to choose the most relevant, without any restriction in the number to be selected. However, as they did not recognize all the attributes from the list as representative of their requirements, they were also given the freedom to propose other attributes. After a round of meetings, the committee agreed upon the four following attributes:

- *Process and Product Quality*, i.e., the efficiency and the effectiveness of the manufacturing processes and the quality of the final product;
- *Service Level*, i.e., delivery punctuality and the respecting of other contract conditions;
- *Management and Innovation*, i.e. the supplier's attitude towards strategic R&D investments, human resource management and capability of managing relationships with customers;
- *Financial Position,* i.e. the firm's capacity to generate profits and liquidity.

In practice, as expected, these choices reproduce the points of view of the different functional areas involved in the committee. Indeed, Material Planning executive pointed out the importance of Service Level aspects; Industrialization area representative was mainly interested in Management and Innovation characteristics; Quality Management vice-president highlighted product and process quality aspects, while the Purchasing director was mainly concerned with the financial position of the suppliers.

In order to define the complete hierarchy, each attribute had to be associated with a set of measurable characteristics. Indeed, defining attributes is not sufficient unless measurable characteristics are identified. In particular, three characteristics for each attribute were identified after several meetings with AB committee. This was translated into the hierarchical scheme shown in Fig. 4.

6.2. Comparative judgments

In order to identify weights for supplier evaluation, each member of the working committee was asked to compare each pair of attributes and characteristics (using the ratio scale illustrated in Table 6 and respecting the above-mentioned reciprocity condition). This aspect is crucial for the correct application of the AHP methodology. Indeed, the results of this step should be complying with consistency check (Saaty, 1980, 2001a). Consistency can be easily achieved in the case of a single decision

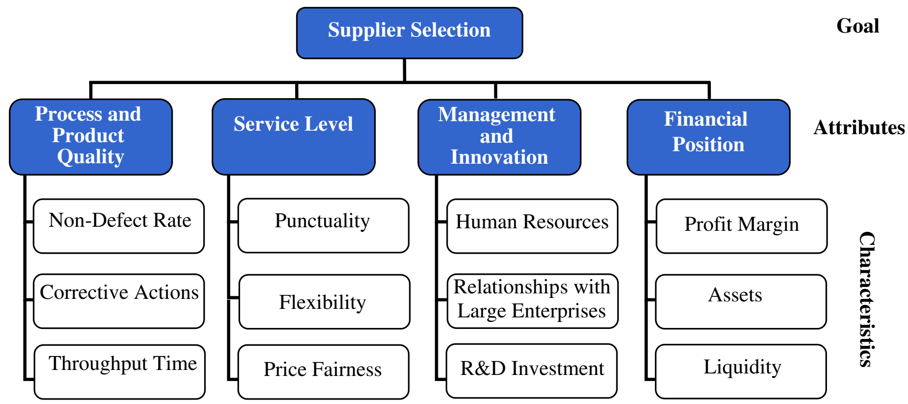

Fig. 4. Hierarchical structure of the problem.

Table 8
Aggregated pairwise comparison matrix of the four attributes.

	PPQ	SL	M&I	FP
Process and Product Quality (PQ)	1	1.68	3.22	3.00
Service Level (SL)	0.59	1	3.76	3.94
Management and Innovation (MI)	0.31	0.27	1	0.54
Financial Position (FP)	0.33	0.25	1.86	1

maker, thanks to repeated interviews protocols that can reduce the degree of inconsistency of pair-wise comparison matrices. However, in presence of multiple decision makers endowed with different preference systems, this process could be less straightforward. Actually, reaching a consensus among the whole AB committee on each single pair-wise comparison could require a significant effort (it has to be noticed that the amount of pair-wise comparisons strikingly increases in the case of ANP applications, being the main drawback of the network extension of the AHP).

For this reason each committee member was asked to provide his own preferences, by defining pair-wise comparison matrices of the four attributes and of the characteristics. Therefore, the aggregation of the matrices provided by each committee member was performed using the geometric average (Tables 8–12). All the matrices satisfy the consistency test (Saaty, 1980, 2001a). However, it is worth to be noticed that this step can jeopardize the efficiency of the overall procedure. In this case, for instance, despite each executive, in the formulation of his own pair-wise comparison matrices, used all the elements in the AHP ratio scale (ranging from 1/9–9), looking at the matrices resulting from the aggregation (Tables 8–12), it appears that the values of pair-wise comparison elements (and, consequently, the ones of the derived priorities) fall within a quite limited range. This means that the use of aggregation methodologies generally introduces compensation mechanisms that can result in averaged derived priorities that do not keep into account the diversity of opinion across AB committee.

6.3. Calculation of the attribute weights

After having collected the judgments regarding the relative importance of attributes and characteristics, it has been possible to extract the vector of priorities for the attributes and, within each attribute, its characteristics. In the AHP literature, several methods are available to obtain priority vectors starting from the pairwise comparison matrix. In this case study, the one based on the eigenvector corresponding to the maximum eigenvalue (Saaty, 1980) was utilized. In practice, starting from the components of the eigenvector corresponding to the maximum eigenvalue, to each of the attributes is assigned a priority (w_i) under

Table 9
Aggregated pairwise comparison matrix of the three characteristics of PPQ.

	DR	CA	TT
Non-Defect Rate (DR)	1	4.16	1.68
Corrective Actions (CA)	0.24	1	0.29
Throughput Time (TT)	0.59	3.41	1

Table 10
Aggregated pairwise comparison matrix of the three characteristics of SL.

	PT	FL	PF
Punctuality (PT)	1	4.60	1.19
Flexibility (FL)	0.22	1	0.32
Price Fairness (PF)	0.84	3.16	1

Table 11
Aggregated pairwise comparison matrix of the three characteristics of M&I.

	HR	RLE	I
Human Resources (HR)	1	1.97	2.21
Relationships with LE (RLE)	0.51	1	0.58
R&D Investments (I)	0.45	1.73	1

Table 12
Aggregated pairwise comparison matrix of the three characteristics of FP.

	PM	ASS	LQ
Profit Margin (PM)	1	0.61	0.39
Assets (ASS)	1.63	1	0.50
Liquidity (LQ)	2.59	2.00	1

normalization condition:

$$\sum_{i=1}^{n} w_i = 1$$

The same constraint is also extended to the characteristics of each attribute. The derived priorities are listed in the hierarchical schema depicted in Fig. 5.

6.4. Calculation of global score

Once attribute and characteristic weights were calculated, it was necessary to associate to each supplier a global score. In order to do that a specific indicator was identified for each

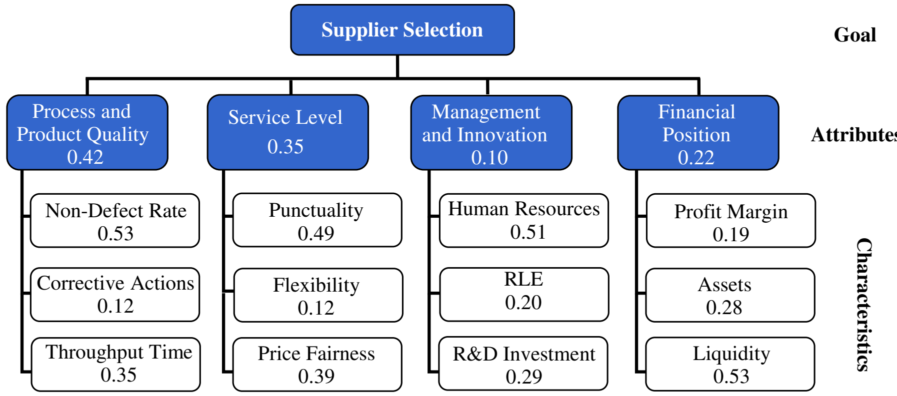

Fig. 5. Hierarchical structure of the problem with priority vectors.

Table 13
Supplier indicators performance.

Attributes	Characteristics	Indicators
PQ	Non-Defect rate	$I_{1,1}=1-$(Defective pieces/arrived pieces)
	Corrective actions	$I_{1,2}=1-$(Corrective actions/audits), if audits >0 $I_{1,2}=1$, if audits$=0$
	Throughput *T*	$I_{1,3}=$Real throughput time/standard throughput time
SL	Punctuality	$I_{2,1}=1-$(Late lines/ordered lines)
	Flexibility	$I_{2,2}=$(Total turnover–railway turnover)/total turnover
	Price fairness	$I_{2,3}=$Price/standard price
MI	Human resources	$I_{3,1}=$No. graduates/total employees
	RLE	$I_{3,2}=1-\lvert$(First 3 customers turnover/total turnover)$-0.75\rvert$
	R&D expend.	$I_{3,3}=$Investments expenditure/total turnover
FP	Profit margin	$I_{4,1}=$Net income/total turnover
	Equity to assets	$I_{4,2}=$Equity/asset
	Liquidity	$I_{4,3}=$Current asset/current liabilities

characteristic. Apart from employed financial indicators, belonging to the most common measures utilized in standard accounting practice, the development of the indicators required a significant effort, in order to ensure the comparability of the different measures and to allow for their aggregation into a single score. The synthesis of the indicators is illustrated in Table 13.

However, even defining appropriate indicators could be sufficient to measure the level of supplier performance, they could be not suitable to evaluate how the customer perceives the supplier performance on the base of its own set of preferences. For example, if an indicator is equal to 0.8 for a first supplier and 0.9 for a second supplier, it is clear that the performance of the second supplier is higher than the first, but if the customer on the base of its own set of preferences, perceives all values higher than 0.7 the same way, then from the customer point of view the first and the second supplier have the same score

Furthermore, it is not possible just employing the derived weights for applying a simple linear weighted sum model, aggregating the raw scores into a final rating for each supplier. Indeed, the weighted sum model can be effectively employed when all the indicators to be aggregated are expressed in the same unit of measure and when the scales used for each indicator are homogeneous (Saaty, 1980, 1994; Triantaphyllou and Mann, 1995).

All these aspects underline that, after having identified the set of twelve indicators, a further step is needed, in order to build value scales associated with customers' needs and perceptions for each indicator. The value scales were identified following three steps:

- Definition of labels representing range of values for each indicator;
- Definition of the pair-wise comparison matrices for the labels associated to each indicator;
- Calculation of the value scales.

In the first step, for each indicator, ranges of numerical values were associated to five ordered labels: Outstanding (A), Above average (B), Average (C), Below average (D), and Poor (E). This was done in order to represent the actual perception of differences between pairs of performance values better. In many cases, indeed, using labels defined by intervals seem preferable especially when the differences are not perceived in the same manner along the scale values. For instance a difference of 0.1 could be considered negligible under a given threshold value but significant over another threshold value. The introduction of interval labels could produce problems in terms of discontinuity induced by interval boundaries but this aspect can be partly overcome if the choice of the numerical encoding of the labels is appropriately performed through the aid of the decision maker and/or using fuzzy intervals. The benefits of using interval scales are addressed in depth in Bouyssou et al. (2000) and Saaty (2001b).

For this reason, by means of mini-focus groups, AB managers were asked, for each indicator, to identify performance ranges. The obtained result is shown in Table 14. It is possible to see how the same numerical values have a very different meaning for AB managers if referred to different indicators. For example, a 0.50 score corresponds to a "Poor" value on the *Punctuality* dimension, but it represents an "Outstanding" value on the *Flexibility* dimension. These issues can be verified also in the case of the Human Resources measure, for which a 0.20 value of the indicator represents an "Outstanding" performance.

In the second step, the pair-wise comparison matrix of the five labels (A, B, C, D, and E) was identified for each indicator. To this end, according to Table 6, the AB committee was asked, for each indicator, to what extent each one of the five performance levels is preferred to the others. In this way 12 matrices were built, each of them with an acceptable level of inconsistency. The maximum eigenvalue and associated eigenvector for each matrix were so identified (Table 15).

In the third step, through standard normalization operations, eigenvectors associated with each pair-wise comparison matrix were translated into derived scores representing the scale value of indicators shown in Table 16. The meaning of these vectors is the following: if, for example, $I_{1,1}=0.94$, the corresponding

Table 14
Scale of interval labels.

Indicators	Scale of interval labels				
	A	B	C	D	E
Non-Defect rate	$0.98 \le I_{1,1} \le 1$	$0.95 \le I_{1,1} < 0.98$	$0.90 \le I_{1,1} < 0.95$	$0.85 \le I_{1,1} < 0.90$	$I_{1,1} < 0.85$
Corrective actions	$0.95 \le I_{1,2} \le 1$	$0.90 \le I_{1,2} < 0.95$	$0.85 \le I_{1,2} < 0.90$	$0.80 \le I_{1,2} < 0.85$	$I_{1,2} < 0.80$
Throughput time	$I_{1,3} < 1.05$	$1.05 \le I_{1,3} < 1.10$	$1.10 \le I_{1,3} < 1.25$	$1.25 \le I_{1,3} < 1.40$	$1.40 \le I_{1,3}$
Punctuality	$0.98 \le I_{2,1} \le 1$	$0.95 \le I_{2,1} < 0.98$	$0.90 \le I_{2,1} < 0.95$	$0.85 \le I_{2,1} < 0.90$	$I_{2,1} < 0.85$
Flexibility	$0.50 \le I_{2,2} \le 1$	$0.40 \le I_{2,2} < 0.50$	$0.30 \le I_{2,2} < 0.40$	$0.20 \le I_{2,2} < 0.30$	$I_{2,2} < 0.20$
Price fairness	$I_{2,3} < 1.05$	$1.05 \le I_{2,3} < 1.10$	$1.10 \le I_{2,3} < 1.25$	$1.25 \le I_{2,3} < 1.40$	$1.40 \le I_{2,3}$
Human resources	$0.15 \le I_{3,1}$	$0.12 \le I_{3,1} < 0.15$	$0.09 \le I_{3,1} < 0.12$	$0.06 \le I_{3,1} < 0.09$	$I_{3,1} < 0.06$
RLE	$0.90 \le I_{3,2} \le 1$	$0.70 \le I_{3,2} < 0.9$	$0.6 \le I_{3,2} < 0.70$	$0.40 \le I_{3,2} < 0.60$	$I_{3,2} < 0.40$
R&D expend.	$0.30 \le I_{3,3}$	$0.20 \le I_{3,3} < 0.30$	$0.15 \le I_{3,3} < 0.20$	$0.10 \le I_{3,3} < 0.15$	$I_{3,3} < 0.10$
Profit margin	$0.20 \le I_{4,1}$	$0.15 \le I_{4,1} < 0.20$	$0.10 \le I_{4,1} < 0.15$	$0.05 \le I_{4,1} < 0.10$	$I_{4,1} < 0.05$
Equity to assets	$0.60 \le I_{4,2}$	$0.50 \le I_{4,2} < 0.60$	$0.40 \le I_{4,2} < 0.50$	$0.30 \le I_{4,2} < 0.40$	$I_{4,2} < 0.30$
Liquidity	$1.3 \le I_{4,3}$	$1.10 \le I_{4,3} < 1.30$	$1.0 \le I_{4,3} < 1.10$	$0.80 \le I_{4,3} < 1.0$	$I_{4,3} < 0.80$

qualitative level is C (see Table 14) and therefore the performance is equal to 0.382 (see Table 16).

Thanks to these preliminary steps, it was possible to obtain the performance of the four suppliers. In practice, once each indicator was calculated for each supplier and translated into a qualitative level (see Table 14), a vector of performance was finally determined (see Table 15). The results of these three steps are shown in Table 17.

Thanks to the vector of the priorities (Fig. 5) and the vector of supplier performance (Table 17) we can identify the global score for each supplier, a composite global score was calculated for each supplier by combining, through a weighted sum, the previously determined performances and weights. The obtained results, for each supplier ranked on the basis of the final global score, as illustrated in Figs. 6–9.

Table 15
Maximum eigenvalues and associated eigenvectors.

Indicators	Maximun eigenvalues	Eigenvectors components				
		1st	2nd	3rd	4th	5th
Non-Defect rate	5.07	0.787	0.493	0.301	0.183	0.116
Corrective actions	5.20	0.824	0.363	0.336	0.215	0.173
Throughput time	4.86	0.855	0.426	0.244	0.138	0.080
Punctuality	5.04	0.882	0.382	0.227	0.135	0.078
Flexibility	5.04	0.812	0.469	0.285	0.173	0.099
Price fairness	5.21	0.789	0.520	0.256	0.184	0.085
Human resources	5.06	0.912	0.376	0.128	0.081	0.054
RLE	4.86	0.855	0.426	0.244	0.138	0.080
R&D expenditure	5.14	0.920	0.340	0.154	0.098	0.065
Profit margin	5.06	0.891	0.328	0.267	0.142	0.084
Equity to assets	5.09	0.764	0.548	0.274	0.168	0.107
Liquidity	5.07	0.787	0.493	0.301	0.183	0.116

6.5. *Analysis of the obtained results*

A detailed illustration of the implementation of an AHP-based model in a real-world context has been reported, in order to highlight the actual points of strengths and the shortcomings of these approaches to solve a SSP in the corporate practice. We illustrate these aspects starting from the analysis of the results provided by the proposed model.

The final result of this process has been a ranking of the four potential AB suppliers, from the one with the highest (Beta, 0.72) to the one with the lowest score (Gamma, 0.58).

It is worth to notice that the relative score difference between the first and the last supplier in the ranking is quite limited ((0.72 − 0.58)/0.72 = 19.4%), and that the first three suppliers are standing very close, reporting a negligible relative difference ((0.72 − 0.68)/0.72 = 5.5%).

This seems to suggest a first shortcoming in the adoption of AHP-based methodologies: slight variations in the indicators score and/or managers' judgments can modify the final ranking. This aspect was also highlighted by AB managers, who recognized that such results would still require expert judgments to "*break the tie*". This result highlights one of the above-mentioned AHP shortcomings pointed out by Triantaphyllou and Mann (1995). However a detailed analysis of the evaluation tree lets us identify the different factors affecting the final score. For example, the high global score of Beta comes from the best performance on the attributes PQ (priority 0.42) and FP (priority 0.13). On the contrary, the attributes SL (priority 0.35) and MI (priority 0.10) play a negative role in the global score. Nevertheless, the evaluation tree also provides relevant indications to the actions to be adopted to increase the global score. For example, in the case of Beta, since the priority of SL is higher than that of MI, the model suggests that, to improve the global score, it is more effective to leverage the SL attribute. In this sense the approach is a useful decision support tool. Furthermore, if the evaluation system is known to the potential suppliers, it allows identifying appropriate strategies in order to improve their own performances. For instance, given the priorities, it is more effective to leverage the punctuality results than the flexibility ones.

These considerations underline that a formalized supplier evaluation method can play a role as a useful management tool for both customers and suppliers. In fact, the customer may use this approach for managing the entire supply system (for example, adopting specific actions to support suppliers), whereas suppliers may use the evaluation tree as a tool to identify their strengths and weaknesses and adopt corrective actions to improve their position within the supply system.

7. Discussion and implications

The real implementation of a AHP-based methodology to solve a SSP in a complex environment has fostered various comments and implications. Emerging issues can be discussed following de Boer and van der Wegen (2003) evaluation framework for decision models for supplier selection, whose criteria are listed in Table 18.

First of all, it emerges that a correct implementation of the methodology is a complex issue with many crucial aspects to be tackled. One of the main strengths of AHP-based methodologies lays in the *capability of aggregating information* (criterion C1 in Table 18), through the decomposition of the problem in a

Table 16
Values scales of the indicators.

	$I_{1,1}$	$I_{1,2}$	$I_{1,3}$	$I_{2,1}$	$I_{2,2}$	$I_{2,3}$	$I_{3,1}$	$I_{3,2}$	$I_{3,3}$	$I_{4,1}$	$I_{4,2}$	$I_{4,3}$
A	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
B	0.627	0.441	0.500	0.433	0.577	0.659	0.412	0.500	0.370	0.368	0.718	0.627
C	0.382	0.408	0.286	0.257	0.351	0.325	0.140	0.286	0.167	0.300	0.359	0.382
D	0.232	0.261	0.161	0.153	0.214	0.233	0.089	0.161	0.107	0.160	0.220	0.232
E	0.148	0.211	0.093	0.089	0.122	0.108	0.059	0.093	0.071	0.094	0.141	0.148

Table 17
Vectors of suppliers performances.

	PPQ			SL			M&I			FP		
Supplier	$I_{1,1}$	$I_{1,2}$	$I_{1,3}$	$I_{2,1}$	$I_{2,2}$	$I_{2,3}$	$I_{3,1}$	$I_{3,2}$	$I_{3,3}$	$I_{4,1}$	$I_{4,2}$	$I_{4,3}$
Alpha	1.00	1.00	0.09	1.00	0.12	1.00	0.09	1.00	1.00	0.09	0.14	0.63
Beta	1.00	1.00	1.00	0.15	0.12	1.00	0.41	0.50	0.17	0.09	0.72	1.00
Gamma	0.38	0.21	0.29	1.00	1.00	1.00	0.06	1.00	0.37	1.00	0.14	0.15
Delta	0.38	1.00	1.00	1.00	0.12	1.00	0.09	1.00	1.00	0.30	0.14	0.23

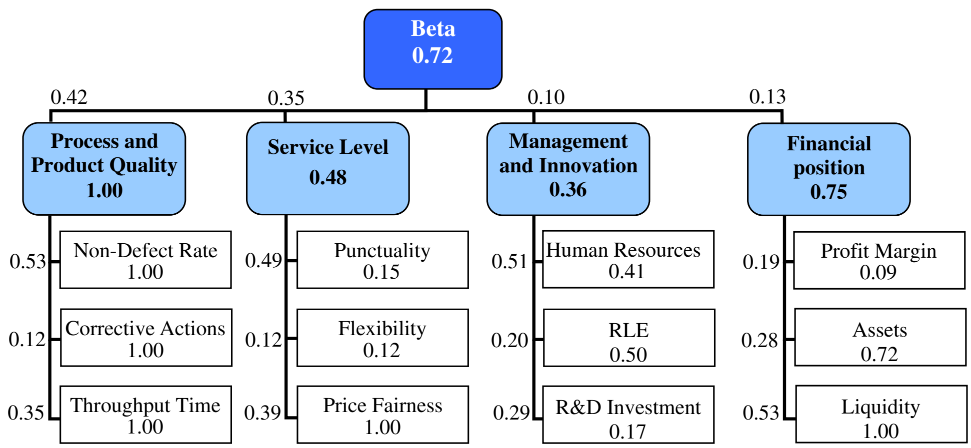

Fig. 6. Evaluation tree of supplier Beta.

hierarchical schema. Therefore, AHP-based models are useful in constructing *structured and formalized approaches* for supplier evaluation, as they allow taking into account multiple criteria, indicators and data for the calculation of a final supplier score. In this sense, AHP-based models make good use of available information (criterion C2 in Table 18), also allowing the incorporation of intangible and qualitative measures in the performance evaluation exercise (criterion C3 in Table 18).

With regards to the possibility of achieving a fair participation of individual members in case of a group decision (criterion C4 in Table 18), as the core of the AHP is represented by the comparative judgments which are the result of the interaction between interviewees and interviewers, not only the choice of the interviewed managers, but also the ability of the researchers in running the interview, are relevant. Moreover, the judgments significantly depend on the specific point of views of the involved interviewees. This influence also includes the identification of indicators and their value scales that strongly depend on involved management perceptions. Furthermore, it has been shown as the pair-wise comparison mechanism can be unpractical in the case of group discussion; the use of aggregation methodologies can significantly reduce the variance in the weights assigned to the involved criteria.

A crucial aspect regards the *flexibility of the model* (criterion C5 in Table 18). Indeed, it has been shown that the supplier selection system must be tailored to a specific component (the object of transaction) and customized according to the specific requirements. This means that it is not possible to identify a set of generic attributes that fit to the whole supply system of a specific customer. The need of customization also includes the list of attributes to be considered. Even if in literature a wide set of attributes have been proposed (Ha and Krishnan, 2008; Dickson, 1966; Weber et al., 1991), the application has shown that these attributes can be considered generic and/or abstract. However it should be pointed out that, thanks to the flexibility of the AHP-based approach, it is easily adaptable to the evaluation of different components by repeating the stages of the procedure. Finally, once the model has been implemented on the basis of the customer's strategic objectives, any change in the latter implies a revision of the path. Thus, any supplier selection methodology should be dynamic, in order to take this aspect into account. This means that, once the methodology is implemented, the result has to be considered as a starting point to be continuously monitored and improved.

As regards *the usefulness and the acceptability of the outcome* of the decision model (criteria C6 and C7 in Table 18), all the above mentioned considerations, including the fact that the final ranking could be not so effective due to negligible differences in the final scores, underline why, although the number of applications for supplier selection is growing, firms are not likely to use these tools because they are often too distant from the reality of the corporate world. In fact, most firms approaching the supplier selection problem simply adopt a qualitative methodology based

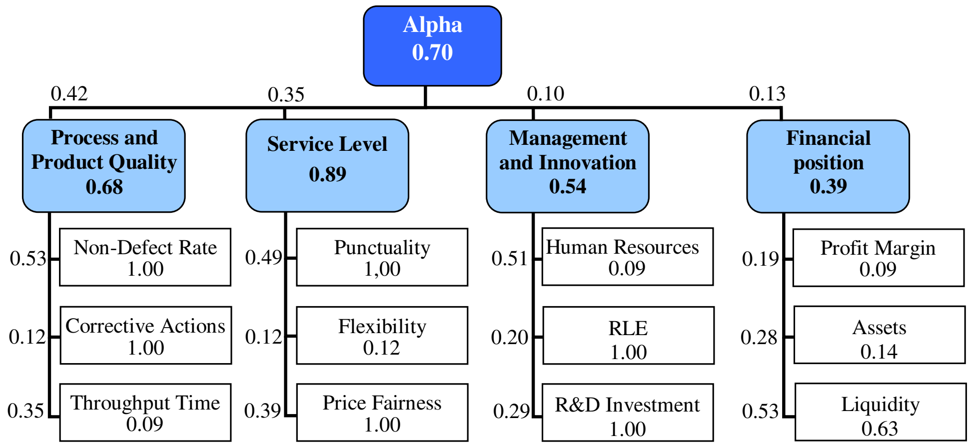

Fig. 7. Evaluation tree of supplier Alpha.

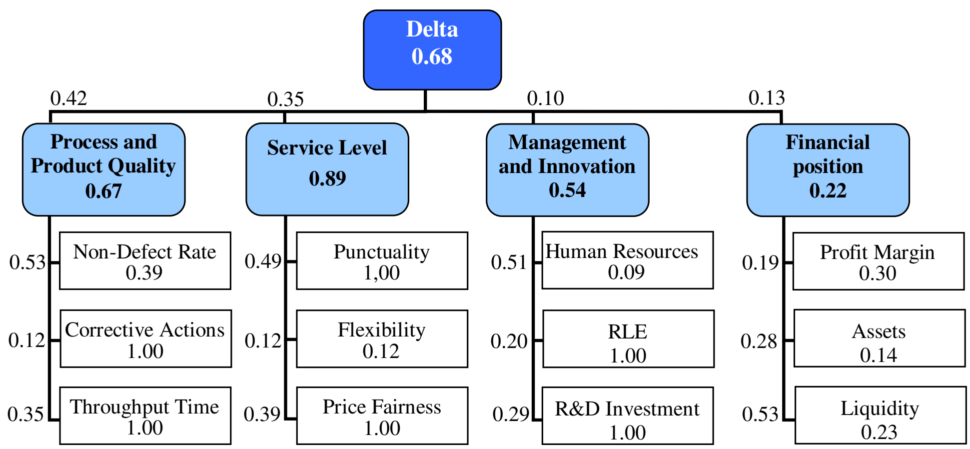

Fig. 8. Evaluation tree of supplier Delta.

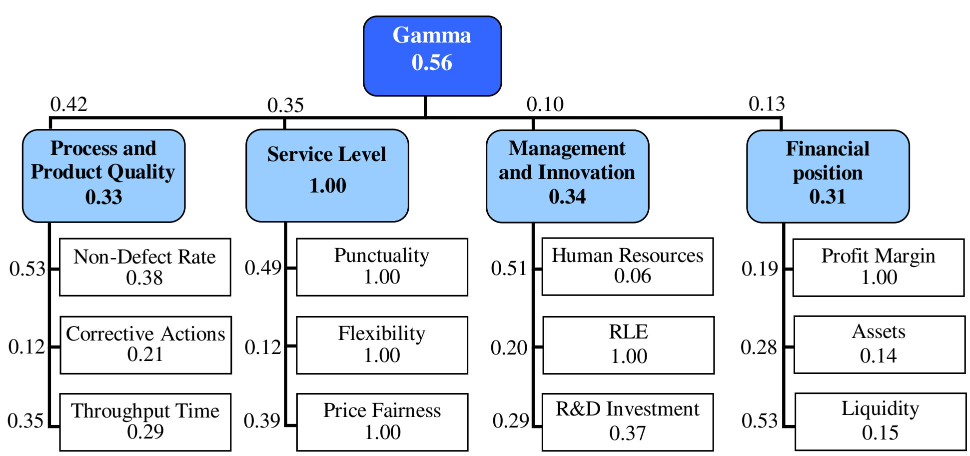

Fig. 9. Evaluation tree of supplier Gamma.

on judgment from some experts, as also stated by various authors (de Boer and van der Wegen, 2003; Esposito and Passaro, 2007).

However, while employing qualitative and not formalized methodologies can present some advantages in terms of *costs and higher flexibility* (criterion C8 in Table 18) and in terms of *easiness of implementation and user friendliness* (criterion C9 in Table 18), formalized approaches also provide significant benefits that were also highlighted by AB managers in a post-implementation focus group.

A first benefit regards the development of *learning processes*. Indeed, thanks to the *clear structure and functioning* of the AHP-based methodology (criterion C10 in Table 18), setting up such a methodology allows both customer and suppliers to improve the knowledge of how the supply system really works (critical characteristics and attributes, their priorities, the hierarchical structure of the evaluation, etc.), identifying its strengths and weaknesses. Therefore, the utilization of such methodology is able to provide the decision maker *with new insights* for his

Table 18
de Boer and van der Wegen (2003) supplier selection models evaluation framework.

Dimensions	Symbol	Criteria
Complexity fit	C1	Does the model aggregate information in a proper way?
	C2	Does the model sufficiently utilize available information?
	C3	Is it (to a satisfactory extent) possible to incorporate opinions and beliefs?
	C4	Is it (to a satisfactory extent) possible to achieve a fair participation of individual members in case of a group decision
	C5	Is the model sufficiently flexible for changes in the decision situation?
Cost vs. Benefit	C6	Is the outcome of the decision model useful?
	C7	Is the outcome of the decision model acceptable?
	C8	Are the required investments justifiable?
	C9	Is the model sufficiently user-friendly?
	C10	Is the way the decision model works sufficiently clear?
	C11	Does the decision model increase the insight in the decision situation?
	C12	Does the decision model contribute to the communication about and the justification of the decision?
	C13	Does the decision model contribute to your decision making skills?

purchasing decisions (criterion C11 in Table 18) and to improve *decision making skills* (criterion C13 in Table 18).

A further benefit is the involvement of various actors, this way transforming the supplier evaluation issue from an operational to a strategic supply system management tool. This process produces an additional effect due to the increase of *motivation*, as the presence of some clear attributes upon which the selection is based improves the *communication and justification* of purchasing decisions (criterion C12 in Table 18) and pushes both the suppliers and the customers to achieve better performance; this can have a sort of *cascade-effect* on the whole supply system, as in their effort to improve their performance for fulfilling buyer's selection parameters, first tier suppliers could adopt and implement similar methodologies towards their vendors. In this way, the benefits of the adoption of formal methodologies can spread across the whole supply system. However, this could also lead to a *side-effect*: firms could simply focus on the aspects considered relevant for the selection, completely disregarding the rest.

Considering the consequences on the relationships within the supply chain, two main managerial implications emerge from the work.

As regards *customer firms*, the proposed methodology facilitates the management of the whole supply chain, beyond the dyadic supplier–customer relationship, by allowing a continuous realigning of the suppliers' aims to those of the customers and orienting their policies towards their own suppliers. To this end, appropriate programs for supplier development or early supplier involvement could be adopted.

As regards *suppliers*, they are interested in participating in the construction of the evaluation methodology in order to comprehend how they are evaluated and improve their position within the supply system by adopting appropriate corrective actions and practices. To this end, they have to consider both *external and internal aspects* of the customer–supplier relationship. The former are mainly represented by *customer requirements* while the latter are represented by *constraints and capabilities affecting the supplier's decision* to adopt specific measures and practices. The internal aspects of the issue are influenced by the specificity of the customer–supplier relationship. In fact, if the supplier has to satisfy the requirements of more customers with similar importance, the requirements of a specific customer will probably have a lesser importance. In this case, the key capability could be represented by the adoption of a *flexible approach* to satisfy the requirements of more customers. On the contrary, if the supplier has to respond to the requirements of a specific prevailing customer, he/she is forced to adopt a *hierarchical approach* and will invest resources to improve those attributes and characteristics needed to satisfy only the prevailing customer's requirements.

8. Conclusions

As it emerges from a thorough analysis of the current literature, the SSP is one of the most popular issues within the general topic of supply chain management. Quite often, models dealing with the SSP are just tested on numerical examples and/or computational experiments, with little attention to the problems, which arise in their practical implementation, with a little empirical evidence of the practical usefulness of such formalized tools in the practice. In order to contribute to understand the determinants of this dichotomy between theoretical approach and empirical application, an AHP-based model for supplier selection has been developed and applied to a real and complex case study.

The literature survey has shown that among the numerous and different types of methodologies and techniques to cope with SSP, models based on Analytic Hierarchy Process (Saaty, 1980) and its extensions are the most widespread tool in the literature. Moreover, the survey has also highlighted that AHP based models can be used in combination with many other approaches.

As regards the case study, the detailed implementation of the proposed methodology has been focused on the unit of analysis constituted by *suppliers* operating for AnsaldoBreda, the main Italian railway manufacturer, on a particular *component* of the traction system. The case study has allowed the identification of strengths and weaknesses of using formalized models to tackle the SSP, also highlighting potential barriers preventing firms to adopt such methods and various implications for customers and suppliers.

Further researches will be devoted to a further and deeper understanding of the dichotomy between theoretical approach and empirical application in the SSP, by employing other formalized methodologies (for instance, based on Fuzzy Logic) and testing the benefits deriving from their implementation in a corporate context.

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